NENA Requirements for 3D Location Data for E9-1-1 and NG9-1-1

Abstract: This document sets forth guidelines and requirements for operationalizing three-dimensional location in NG9-1-1 and E9-1-1. It is the intent that the requirements and guidelines in this document will be adopted in whole or in part in future NENA and IETF standards. Additionally, this document is intended to provide interim guidelines and requirements in advance of standardization.

NENA Requirements for 3D GIS for E9-1-1 and NG9-1-1

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1 Executive Overview

Introducing three-dimensional (3D) location and mapping to 9-1-1 operations represents a massive sea change in how caller location is conveyed and how callers are located. It is the largest shift in location for 9-1-1 since wireless Phase II was introduced in the late 1990s. Though many of the underlying technical capabilities already exist to operationalize 3D location for 9-1-1, they are not currently being leveraged for routine operations and there is a gap in understanding, implementation and standardization. This document begins addressing these gaps and also describes future work needed to complete standardization of 3D location and mapping for 9-1-1.

The concept of 3D location in 9-1-1 has long been accounted for by Standards Development Organizations (SDOs) including the National Emergency Number Association (NENA), the Internet Engineering Task Force (IETF), the 3rd Generation Partnership Project (3GPP), and the Alliance for Telecommunications Industry Solutions (ATIS). Geodetic location standards support shapes and points in three dimensions; for example, the Global Positioning System (GPS) has always used a 3D reference frame. The concept of mapping (as opposed to location) in NENA and IETF standards, including the NENA Standard for NG9-1-1 GIS Data Model, NENA-STA-006 [2], and Location to Service Translation (LoST) (RFC 5222 [3]), have typically only considered data provisioning in two dimensions.

This document is organized in several sections. The beginning sections of the document provide background on 3D location and mapping, including background on the applicable regulatory history (especially in the United States) and technical information about how the applicable technology works (see Section 2 *Introduction and Background*). Later sections provide recommendations and requirements for implementing 3D location operationally and for constructing 3D maps (see Section 3 *Methods and Roadmap to Operationalizing Z-Axis Information*). The later sections of the document provide recommendations for future work, particularly for standards development (see Section 4 *Further Recommendations* and Section 5 *IANA Actions*).

New regulatory developments from the United States (US) Federal Communications Commission (FCC) add urgency to the need for additional guidelines for handling 3D location. Beginning April 2021, wireless carriers were required to provide 3D location for 9-1-1 calls in phases as documented in the FCC's Wireless E911 Location Accuracy Requirements, Fifth Report and Order and Fifth Further Notice of Proposed Rulemaking in PS Docket No. 07-114 [4] (known as "z-axis" proceedings). Per a series of consent decrees reached in June 2021, major US wireless carriers Verizon Wireless [5], T-Mobile USA, Inc., [6] and AT&T Services, Inc. [7]agreed to provide this location information nationwide.

The intent of this Requirements Document (REQ) is to support longer-term standardization through NENA and IETF. Development of these guidelines is urgent, as NENA standards for Geographic Information Systems (GIS) are used to locate 9-1-1 callers by finding the address, marker or landmark most likely to be associated with a caller's location. Also in scope are requirements for resolving routing queries in 3D (for example, a freeway overpass may have a different serving Public Safety Answering Point (PSAP) than the surface underneath it).

This document has five objectives:

1. To provide a technical and regulatory background for 3D 9-1-1 locations
2. To establish uniform language in reference to z-axis within the 9-1-1 community for terms "altitude," "height," and "elevation" (as they are currently used interchangeably across specifications)
3. To provide practical guidance for operationalizing 3D location, such as how the Automatic Location Identification (ALI) should be configured and provisioning of 3D GIS datasets (including Digital Elevation Models [DEM] and 3D structures)
4. To provide requirements for future standards development for 3D location, such as how uncertainty should be conveyed for certain civic address elements
5. To provide baseline requirements for implementations and enhancements

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Reason for Issue/Reissue

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Document Number	Approval Date	Reason For Issue/Reissue
NENA-REQ-003.1-2022	06/10/2022	Initial Document

2 Introduction and Background

2.1 Intended Audience

This document is intended for a broad audience and includes decision makers, 9-1-1 personnel, product vendors, and the academic/standards development community. Each stakeholder group may find different parts of this document useful. For example, much of Section 2 *Introduction and Background* will be of general interest to the 9-1-1 community and may be used in telecommunicator training materials. Much of Section 3 *Methods and Roadmap to Operationalizing Z-Axis Information* will be of interest to technologists such as developers implementing solutions or the technical staff within the 9-1-1 community or those involved with 9-1-1 regulatory activity. Finally, Section 4 *Further Recommendations* is targeted to the academic and standards development community, as it provides specific requirements for future standards work. A non-exhaustive list of potential stakeholders targeted by this document includes:

- PSAPs/Emergency Communication Centers
- Decision-Makers/Managers
- Elected Officials
- Originating Service Providers (OSPs)
    - Commercial Mobile Radio Services (CMRS); i.e., cellular carriers[1]
    - Satellite Communications Providers
    - Voice over Internet Protocol (VoIP) Providers
- 9-1-1/E9-1-1/NG9-1-1 Service Providers
- 9-1-1 Authorities
- Regulatory Bodies (especially the US FCC)
- Solution Providers
- Mobile Originating Service Providers
- Device/Equipment Providers
- GIS Data Providers
- GIS Professionals
- Standard Development Organizations

[1] "Commercial Mobile Radio Services" (CMRS) is a US FCC designation for any carrier or licensee whose wireless network is connected to the public switched telephone network; for practical purposes, this is the same as a "cellular network."

2.2 Location and 3D Mapping

This document describes four types of locations that are largely consistent with the technical standards landscape, industry conventions, and United States regulatory requirements:

- Civic Location
- Dispatchable Location
- Geodetic Location
- Stated Location

2.2.1 Civic Location

A Civic Location is a location format that conveys a civic address. A civic address is a set of elements that conforms to an addressing scheme; such as a street address or a place name. In 9-1-1 operations, for a civic address to be useful, the civic address must contain necessary details that can be used to route an emergency call or to support the dispatch of field responders. From a technical perspective, a civic address may be conveyed by the originating device and/or by the originating service provider (OSP) to the 9-1-1 system. The means for provisioning or determining the civic location by the device OSP is not within the scope of this document, but for background information, some example methods include provisioning a static address or estimating an address from geodetic or other information. For example, VoIP clients traditionally have a provisioned static (fixed) Civic Location registered for them. Certain wireless products or services (e.g., femtocells, Wi-Fi Calling or Wireless Home Phones (WHP) may also provide a fixed civic location registered for them.

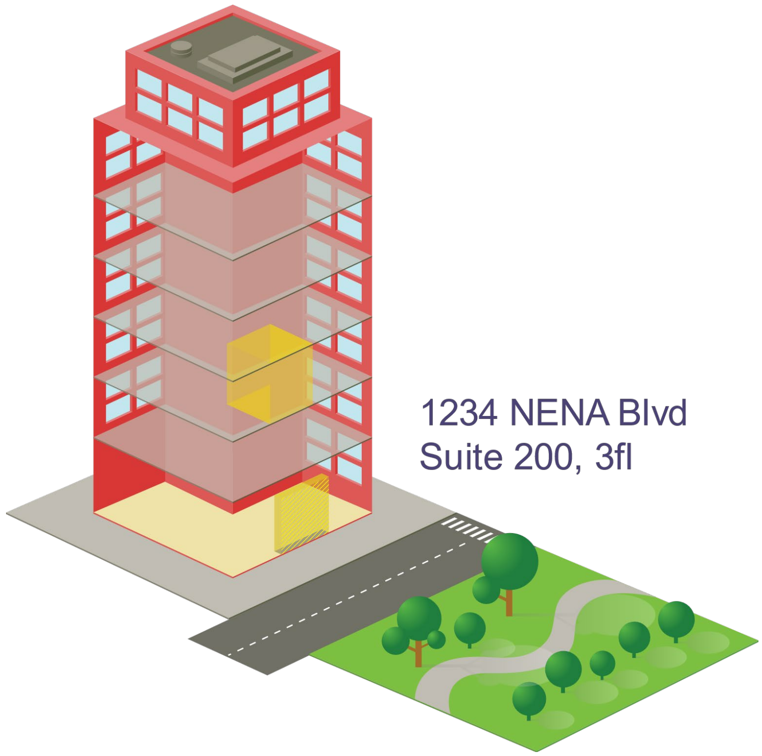

Figure 1: Simplified Illustration of a Civic Location

2.2.2 Dispatchable Location

In United States regulation, a Dispatchable Location (DL) is defined in the FCC's Wireless E911 Location Accuracy Requirements, Sixth Report and Order and Order on Reconsideration in PS Docket No. 07-114 [9], as the "street address of a caller plus additional information, such as floor level, to identify the 9-1-1 caller's location". This was the initial concept of location in 9-1-1; when all calls originated from fixed landline phones, it was certain that the civic location delivered by the OSP was the location provisioned for the specific telephone number when an individual placed an emergency call. When DL is associated with a wireless call, it is usually a Civic Address based on the estimated geodetic location of the wireless device (in some circumstances it may be a configured address associated with a Wi-Fi access point (AP), or may be based on signals visible to the device such as a Bluetooth Low Energy (LE) beacon). Notably, a DL may not be directly associated with the geodetic location of the caller, but the civic address(es) and subaddress elements are generally intended to be the correct location(s) for dispatch.

Note that a DL may be a registered (provisioned) civic address that has been validated against authoritative[2] address records, such as the 9-1-1 Master Street Address Guide (MSAG) or Location Validation Function (LVF). Note that a validated address is an address that conforms to the 9-1-1 authority's records, that is unique and exists; however, a validated address may not be the correct location of the caller. Some examples of an incorrect but valid address being conveyed are described later in this document.

Methods for estimating a device's physical location and associating that location with an address (e.g., determining a DL) have been standardized as noted in Location Accuracy Improvements for Emergency Calls, ATIS-0700028 [10]. There are a variety of methods to identify a DL, including reverse-geocoding, use of Wi-Fi APs and Bluetooth beacons with registered addresses, use of civic addresses associated with the caller and others. This document addresses guidelines and requirements for associating a civic address with a physical location. It will also address guidelines and requirements for expressing uncertainty associated with a DL. Finally, it will include conveyance requirements for entities outside of the 9-1-1 system when conveying information to the 9-1-1 system.

Although wireless DL civic addresses are not currently delivered with the same indicators of accuracy (i.e., confidence and uncertainty) as provided with wireless 9-1-1 location calculations, ATIS-0700028 [10] and NENA Standard Data Formats For E9-1-1 Data Exchange & GIS Mapping, NENA-STA-015 [11], provide one of four "quality level ratings" in the legacy Class of Service field to indicate approximate accuracy:

- WDL2 (Wireless DL Level 2) – The caller's location is estimated to be at the given DL and on the given floor. This may be considered analogous to a geodetic location uncertainty of 50 meters horizontally and less than 3 meters vertically. [3]
- WDL1 (Wireless DL Level 1) – The caller's location is estimated to be at the given DL, but the actual location may not be on the given floor (or no floor is provided). This may be considered analogous to a geodetic location uncertainty of 50 meters horizontally and more than 3 meters vertically.
- WCVC (Wireless Civic Location) – The caller's location is estimated to be near but probably not at the given DL. This may be considered analogous to a geodetic

[2] The term "authoritative" is used within standards documents to mean "provided by the established or recognized authority." As illustration, civic addresses are often expressed in a variety of equivalent forms, for example, "North River Boulevard," "N. River Blvd," "River Blvd N." 9-1-1 authorities provide a standard (canonical) authoritative representation of valid addresses in the Master Street Address Guide (MSAG) for legacy use and in the authoritative Location Validation Function (LVF) for NG use. In the case of LVFs, one is designated as authoritative while others, containing the same data, are replicas.

[3] The 50 meter horizontal and 3 meter vertical location accuracy requirements are codified in United States regulation; see section 2.6.

location uncertainty of greater than 50 meters horizontally but within the outdoor range of a typical Wi-Fi router (100 meters).

- VMBL (VoIP Mobile) – The caller's provisioned civic address information may be conveyed when it is believed to be within 50 meters of the caller's actual location, but similar to the WDL2, WDL1, and WCVC legacy classes of service, PSAP Customer Premise Equipment (CPE) and mapping systems are expected to primarily use geodetic location.

See Section 5 *IANA Actions* for recommendations to standardize how use of these methods is communicated in NG9-1-1. See Section 3.2.4 *Requirements for Integrating Z-Axis Information into ALI* for a description of how Class of Service is displayed to a telecommunicator.

There is wide variation among both carriers and 9-1-1 Authorities with regard to which legacy classes of service may be used in given situations. For example, the State of Texas generally uses WRLS associated with a Phase I cell site,[4] while the State of California generally used W911 associated with a Phase I cell site.[5] These variations can exist with the uses of the above four legacy Classes of Service. For example, one carrier may use VMBL for certain services, while another may use WDL1 or WCVC for what appear to be very similar, although perhaps not identical, services. Addressing these historical and current differences and inconsistencies regarding the uses of legacy classes of service are beyond the scope of this document. Differences and inconsistencies will be reduced over time as all participants move towards a fully deployed NENA i3 ecosystem.

[4] "WRLS" is a legacy CoS value that was intended to communicate that a wireless cell sector is configured only to deliver Phase I information.

[5] As asserted by workgroup members representing these stakeholder entities. These are implementation-specific values that are not expected to be widely seen.

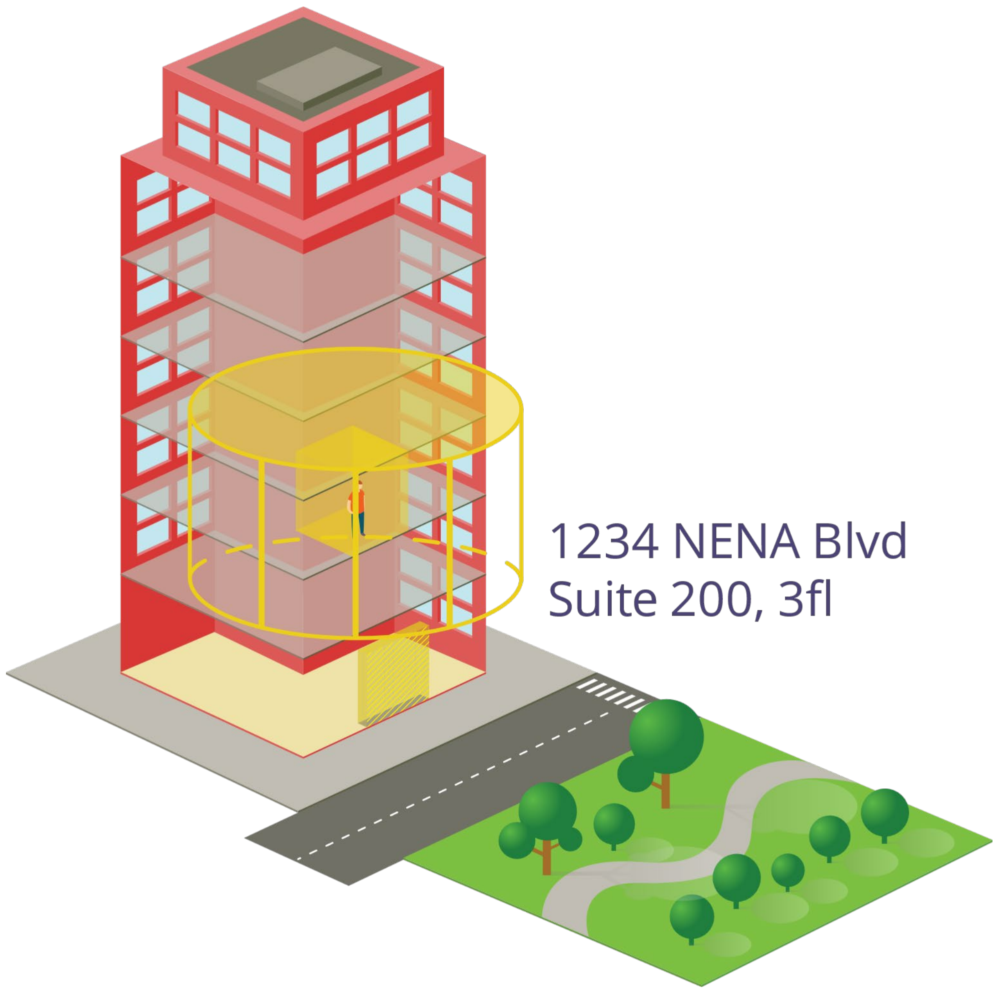

Figure 2: A Dispatchable Location Estimated Based on the Physical Location of a Caller in Three Dimensions

2.2.3 Geodetic Location

A geodetic location is a representation of a location in two or three-dimensional space (2D or 3D) against a spatial frame of reference.[6] In 9-1-1, geodetic location has historically been expressed in 2D (latitude and longitude). With current technology, geodetic location will be expressed in 3D (latitude, longitude, and altitude).

[6] A reference frame, or geodetic datum, is "an abstract coordinate system with a reference surface (such as sea level) that serves to provide known locations to begin surveys and create maps." National Geodetic Survey, "Datums and Reference Frames," National Oceanic and Atmospheric Administration (NOAA), last modified Jul 1, 2020, https://geodesy.noaa.gov/datums/index.shtml.

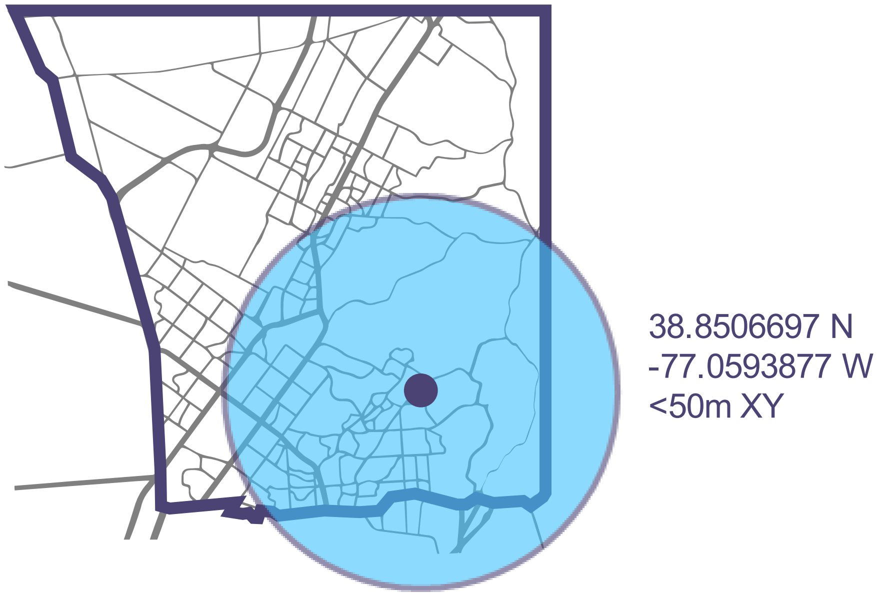

Figure 3: A Two-Dimensional Representation of a Geodetic Location

Geodetic location is fundamental to location in 9-1-1 because it provides a means for representing a position estimate. Devices, often with the cooperation of network elements, can estimate their position. This position estimate is expressed using a standard geodetic reference, as coordinates within the reference. For emergency services to correctly identify the appropriate responding agency and for responders to locate the caller, a high-quality location estimated in 3D space is essential. Geodetic location expressed as standardized coordinates allows 9-1-1 networks and elements inside and outside those networks to exchange and process location information without conversion. Converting from a geodetic to a civic location (reverse geocoding) introduces additional error and greater uncertainty. The capacity to exchange 3D geodetic location between elements in and across 9-1-1 networks is fundamental to interoperability.

Thanks to advances in technology and regulatory developments, wireless calls in the United States convey location in 3D (X, Y, and Z): longitude, latitude, and altitude.

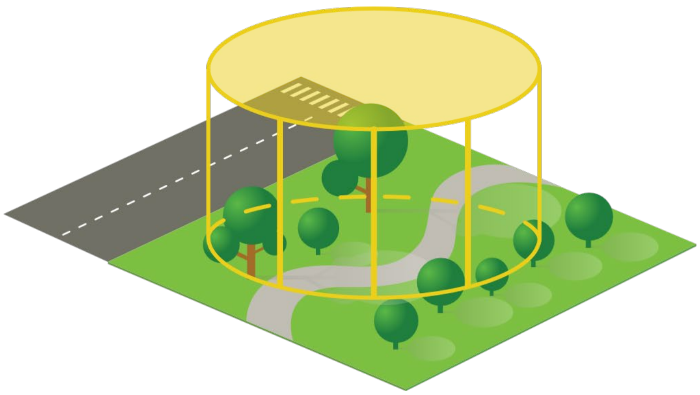

Figure 4: A Geodetic Location Expressed in 3D with Negative Altitude

Note in the figure above that the Altitude expressed ("Z") is, in fact, a negative number. This is a valid output; the individual may, for example, be underground. In some cases, the correct World Geodetic System 1984 (WGS84)[7] Altitude at ground level is a negative number (this may happen in low desert regions or near the ocean). Additionally, it is also possible that a positive WGS84 altitude is actually underground at a specific location. Accordingly, telecommunicator training SHOULD include a basic understanding that z-axis altitude values, when read on their own, do not necessarily communicate an individual calling device's Height (See Section 2.3.4 *Height*). Additionally, telecommunicator end-user software SHOULD utilize at least one of the methods included in this document (See Section 3 *Methods and Roadmap to Operationalizing Z-Axis Information*) in order to make the 3D geodetic location useful to the telecommunicator.

2.2.4 Stated Location

A Stated Location is a location that is conveyed during call processing, usually verbally. An example of a Stated Location includes a civic address conveyed verbally when prompted by a telecommunicator. A Stated Location might or might not be different from the Civic or Dispatchable Location conveyed by the OSP. Other examples of Stated Location are the caller's location relative to a given landmark or a vanity address such as the name of a music festival. From an operational perspective, a Stated Location is the response to the prompt: "9-1-1, what is the location of your emergency?" Operationally, Stated Location is part of the routine processing of nearly every 9-1-1 call. Within the technical scope of this document, it is used to confirm that the conveyed Civic or Dispatchable Location is accurate or to determine the correct civic address corresponding to a conveyed Geodetic Location (e.g., for dispatch).

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[7] The WGS84 datum is widely considered the standard frame of reference for conveying geodetic location (coordinates) between systems.

2.2.5 3D Mapping

This document provides requirements and guidelines for how to operationalize 3D location, whether a Dispatchable Location or a Geodetic Location, for E9-1-1 and NG9-1-1 systems. Mapping software is relied on to provide useful information to the telecommunicator and accurately convey the uncertainty associated with a conveyed location. OSPs are required to convey location information, including Altitude, to the 9-1-1 system. Downstream elements and actors (such as in the 9-1-1 system or telecommunicators at the PSAP) will need to identify a location that is actionable for 9-1-1 operations and field responders, such as a Civic Location with a Height or floor number.

2.3 Vertical Measurement Terms: "Altitude," "Elevation," and "Height"

The terms "3D height," "Height," "Elevation," "Altitude," "Z-coordinate," or "Height Above Ellipsoid" are often used interchangeably when referring to a measured distance in the vertical context. This document defines the terms "Height," "Elevation," and "Altitude" for use in NENA documents.[8]

Table 1: Vertical Measurement Terms for 9-1-1

Term	Description
Altitude	The measurement of the device's orthogonal distance from the WGS84 ellipsoid. Often referred to as "Height Above Ellipsoid" (HAE). This is equivalent to the term "Z Coordinate" in previous editions of the NENA Master Glossary.
Elevation	The orthogonal distance of the Earth's surface from the WGS84 ellipsoid at a provided location; also, the Altitude of the ground level.
Height	The distance between Elevation and Altitude for a given location; often referred to as "Height Above Ground Level" (AGL).

2.3.1 The WGS84 Ellipsoid

WGS84, or World Geodetic System 1984, is the standard reference ellipsoid in technical standards, including NENA i3 Standard for Next-Generation 9-1-1, NENA-STA-010 [11], NENA NG9-1-1 GIS Data Model, NENA-STA-006 [2], IETF RFC 4119 [11], 3GPP TS 23.032 [12], and others. Modern conventions in mobile operating systems also communicate

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[8] In the field of geodesy, the scope of handling measurements and terminology is much more sophisticated than this document can promulgate requirements for 9-1-1. See *OGC Abstract Specification Topic 2: Referencing by coordinates*, https://docs.opengeospatial.org/as/18-005r4/18-005r4.html.

coordinates in terms of reference against the WGS84 reference ellipsoid.[9] Additionally, the United States Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS) constellations[10] use the WGS84 reference ellipsoid for coordinates in two and three dimensions.[11]

Z-axis information (Altitude) is conveyed to the 9-1-1 system by estimating Height Above Ellipsoid (HAE) in meters referenced against the WGS84 ellipsoid. This means that requirements to convey Altitude measurements for 9-1-1 calls do not introduce a new method of conveying location. The change is only that there is use of all three coordinates for the same positioning system that has been in use since GPS coordinates were first introduced for emergency calls.

The WGS84 reference ellipsoid does not meaningfully represent either the mean sea level or the ground level at a given location; either the sea level or ground level could be above or below the reference ellipsoid at any given time. The figure below shows the simplified illustration of the relationship between the actual surface of the earth, the reference ellipsoid, and the mean sea level.

[9] See, e.g., Apple, Inc., "Apple Developer Documentation," accessed September 19, 2021, https://developer.apple.com/documentation/corelocation/; Google LLC, "Location: Android Developers," last updated September 8, 2021, https://developer.android.com/reference/androiDLocation/Location, respectively ("Location Services Developer Documentation"). This citation is illustrative only and does not constitute endorsement of any product or service.

[10] A Global Navigation Satellite System (GNSS) is a constellation of satellites that broadcast timing signals. By receiving multiple signals and comparing the transmitted times with the time of reception, a device can compute a position estimate (a location "fix"). Devices that support multiple GNSS constellations can more quickly obtain a location fix and reduce the area of uncertainty of the location estimate.

[11] The workgroup notes that there are new satellite positioning systems being deployed over time that may use other reference frames. They are out of scope for the purposes of this document.

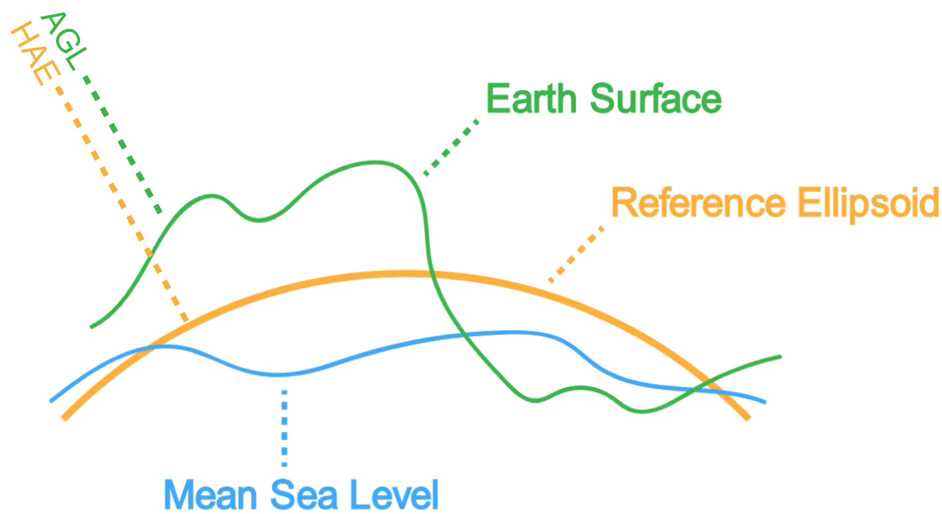

Figure 5: Relationship Between the Earth's Surface, a Reference Ellipsoid, Mean Sea Level, AGL, and HAE

The same base altitude that location services or a GNSS receiver will determine will have multiple outputs that vary depending on the frame of reference that altitude is compared to. For this document, the two output types in-scope are HAE and Above Ground Level (AGL). HAE is the altitude above the WGS84 reference ellipsoid which is a mathematical model approximating the shape of the earth. This is described with the defined term Altitude. This is the baseline, or "technical," z-axis measurement that, along with the X and Y axes, constitutes a mathematically-defined location usable by systems and software. After HAE is provided by a device, a downstream element is needed to convert HAE to human-intelligible information, such as AGL, in order to be actionable for a telecommunicator.

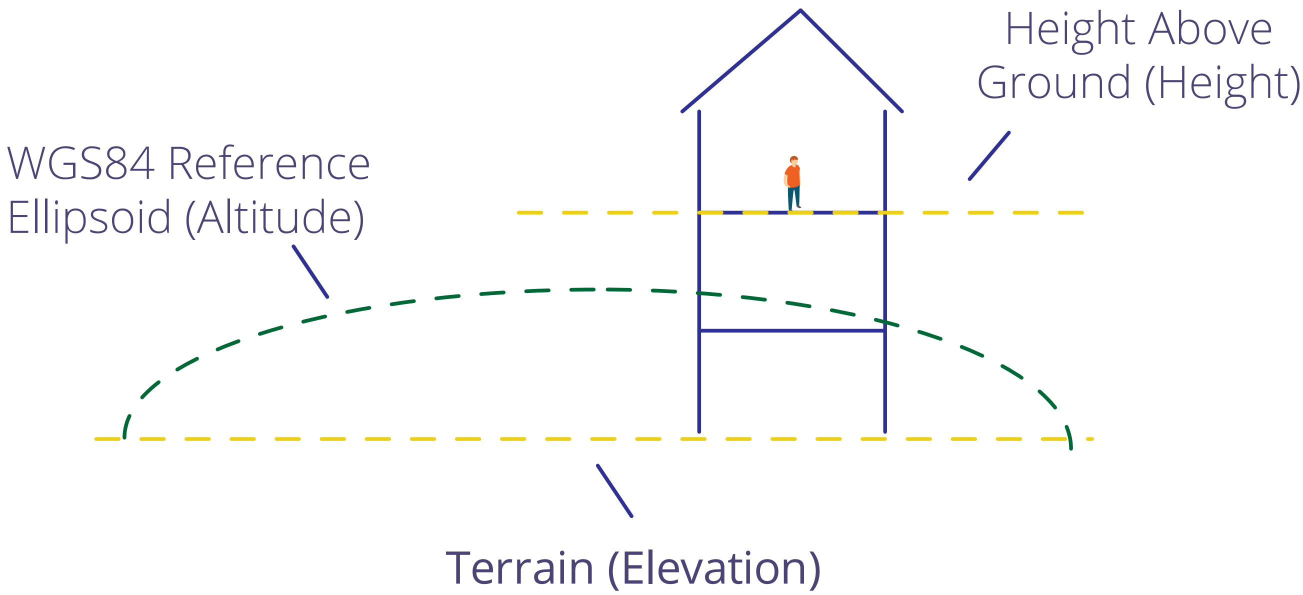

Figure 6: Terrain, Ellipsoid, and AGL

WGS84 coordinates are not normally useful operationally on their own; 2D coordinates have always needed a 2D map to be useful, and 3D coordinates need a 3D map to be useful. The figure below shows a hypothetical two-dimensional location without a map, as opposed to the same hypothetical two-dimensional location placed against a map.

Figure 7: 2D Geodetic Location (left) and 2D Geodetic Location with a Map (right)

The guidelines and requirements set forth in this document provide for the means to implement a "map" for the z-axis, or Altitude, of a given location in E9-1-1 and NG9-1-1 environments.

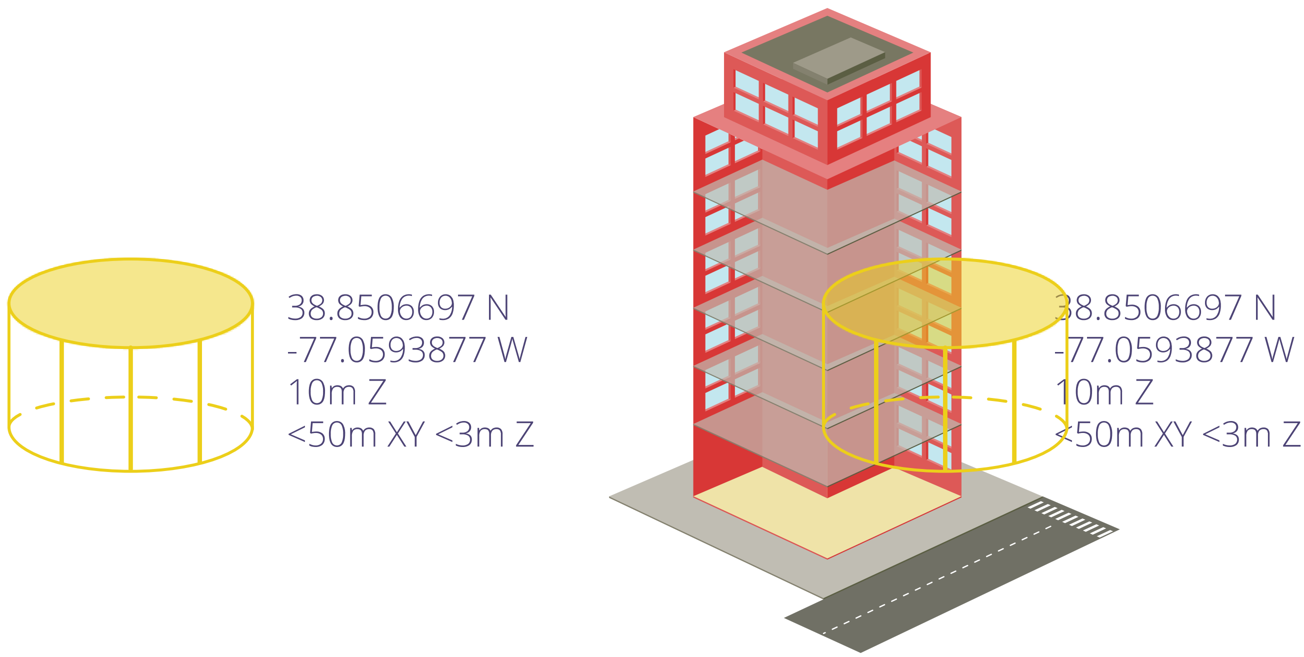

Figure 8: 3D Geodetic Location (left) and 3D Geodetic Location with a 3D Map (Right)

2.3.2 Altitude

In other fields or documents, the term "altitude" may describe an object's vertical distance above mean sea level (e.g., an airplane pilot may say "we are cruising at an altitude of 30,000 feet"). Mean sea level is not a mathematically constant value, and a consistent mathematical baseline must be used for vertical positioning. This document defines Altitude to mean the measurement of the device's orthogonal distance from the WGS84 ellipsoid. This is equivalent to the term "Z Coordinate" in the NENA Master Glossary of 9-1-1 Terminology, NENA-ADM-000 [1] as of this writing and is consistent with the concept of location in IETF RFC 5491 [14]. It is the same value as HAE. Altitude is the geodetic measurement that service providers will deliver to the 9-1-1 system.

2.3.3 Elevation

Traditionally, the term "elevation" refers to the vertical distance of the Earth's surface above mean sea level ("Mount Everest's recognized elevation is 29,029 feet…"). This document defines Elevation as the orthogonal distance of the Earth's surface from the WGS84 ellipsoid at a given location. This, for example, would be the set of measurements contained in a GIS digital elevation model used by the 9-1-1 system. Because the surface of water bodies (including mean sea level, freshwater lakes and rivers, etc.) varies with season, lunar cycle, and other conditions, the Elevation data used for them will be consistent with normal average measurements in GIS systems.

2.3.4 Height

This document defines Height as the difference between a measured altitude and the elevation at the same latitude and longitude:

Height (above ground level) = Altitude (above ellipsoid) – Elevation (of ground)

As long as both altitude and elevation are measured from the same reference frame (the WGS84 ellipsoid), Height measures the distance above ground level (AGL). In cases where the measuring device is below the surface of the Earth (basements, tunnels, sewers, etc.), the height value will be a negative number. Negative value height is commonly referred to as "depth."

2.4 Location Data Exchange Formats

This section provides an overview of data exchange formats used for 9-1-1 and NG9-1-1, including legacy formats (ALI), NG9-1-1 location format (Presence Information Data Format [PIDF]), and an overview of relevant standards.

NENA Standard Data Formats for E9-1-1 Data Exchange & GIS Mapping [11] standardizes legacy data exchange formats that are used to pass location data to the PSAP. The following table shows the currently active format versions and the fields used:

Table 2: ALI Data Exchange Formats in STA-015.10-2018 [11]

ALI Exchange Version	Longitude (X-axis)	Latitude (Y-axis)	Altitude (Z-axis)	Confidence/ Uncertainty
Version 2.1	9 characters, positions 320-328	9 characters, positions 329-337	5 characters, positions 338-342	not specified
Version 3.1	LON label, 11 characters +000.000000/ -000.000000, left padded with zeroes or spaces	LAT label, 10 characters +00.000000/ -00.000000, left padded with zeroes or spaces	ELV label, 6 characters +00000/-00000, left padded with zeroes or spaces	not specified
Version 3.1 (wireless)	LON label, 11 characters +000.000000/ -000.000000, left padded with zeroes or spaces	LAT label, 10 characters +00.000000/ -00.000000, left padded with zeroes or spaces	ELV label, 5 characters +####/-####, right padded with zeroes after decimal (if needed)	Horizontal uncertainty in meters: COF label, 7 characters, left padded with zeroes or spaces Horizontal confidence: COP label, 3 characters, left padded with zeroes or spaces (percentage 0-100) Z-axis uncertainty and confidence not specified
Version 4.3 (XML)	LongitudeType label; 9 digits, 6 fractionDigits +180.000000, -180.000000; min -180, max +180	LatitudeType label; 8 digits; 6 fractionDigits; +00.000000 -00.000000; min -90, max +90	ElevationType label; 5 digits, integer (measured in meters)	Horizontal uncertainty: ConfidenceMetersType; integer; min 1, max 1800000 for X/Y Horizontal confidence: ConfidencePercentType; integer; min 0, max 100 Z-axis uncertainty and confidence not specified

The Version 2.1 format is the minimum requirement to receive 2D or 3D coordinate data, although it does not include confidence and uncertainty, and, for most US-based 9-1-1 systems, was a necessary upgrade for receiving E9-1-1 Phase II location data from wireless carriers. Version 2.1 has largely been superseded by the Version 3.1 formats for most 9-1-1 systems, although some Version 2.1 (or earlier) systems are still in use. At this time few 9-1-1 systems have been upgraded to the Version 4 formats, since upgrades to 9-1-1 systems are expected to be conformant with NG9-1-1 standards and PSAPs will receive a Presence Information Data Format Location Object (PIDF-LO) instead. However, Version 4 may be in use by some service providers.

It is important to note that, with the exception of the Version 3.1 Wireless format, the NENA standards require z-axis values to be reported as an integer, meaning that a precision of less than one meter cannot be passed. Also, the Version 3.1 Wireless format limits sub-meter precision to altitudes under 100 meters (e.g., "+99.9"), thus making it unavailable at most of the world's surface. Compare this to the horizontal coordinate values, where the six-digit decimal place accuracy represents a potential precision within roughly 1 centimeter.

NENA ALI legacy data exchange formats do not have fields for z-axis uncertainty and confidence. With legacy data formats, providers may convey z-axis uncertainty in a non-standard field (subject to local agreements for delivery of ALI information).

2.4.1 E2 Interface

As noted in the NENA Standard for the Implementation of the Wireless Emergency Service Protocol E2, NENA-STA-018 [15], the E2 interface is used to convey location information from a mobile network to an Emergency Services Message Entity (ESME), as an ALI system. It connects the wireless Mobile Positioning Center/Gateway Mobile Location Center (MPC/GMLC) and the ESME for NENA i2 service. The data structures passed over the E2 interface are defined in NENA-STA-018 [15] as an extension of ANSI/J-STD-036-C-2. Section 9.3.10.2 of NENA-STA-018 [15] defines the geographic position data elements and provides its capabilities and limitations.

Latitude and longitude (L) are transmitted as 24 binary bits, then converted to a signed decimal integer N (-8,388,608 to +8,388,608) and converted to degrees using the following:

$$\mathrm{L} = \frac{\mathrm{N}}{2^{23}} * \mathrm{K}$$

Where K is 90° for latitude and 180° for longitude. The resolution is +/- 0.000011 degrees for latitude and +/- 0.000021 deg for longitude, which is roughly 10 by 20 centimeters.

Altitude is transmitted as 16 binary bits and converted to a signed decimal integer. The range in altitude is from -32,767 to +32,767 meters (+/- 108,288 feet). The resolution is +/- 1 meter.

Confidence is transmitted as 7 binary bits and converted to an unsigned decimal integer. A value of 0 indicates "no information," while values equal to or greater than 100 should not be used. When altitude is included, the confidence value is assumed to apply to both horizontal and vertical uncertainty.

Uncertainty is transmitted not as a value but as a code. The horizontal and vertical uncertainty codes are each transmitted as 7 binary bits and converted to unsigned decimal integers $\mathrm{C_{Horiz}}$ and $\mathrm{C_{Vert}}$. These uncertainty codes are converted to horizontal and vertical uncertainties $\mathrm{U_{Horiz}}$ and $\mathrm{U_{Vert}}$ as follows:

$$\mathrm{U_{Horiz}} = 10(1.1^{\mathrm{C_{Horiz}}} - 1)$$

$$\mathrm{U_{Vert}} = 45(1.025^{\mathrm{C_{Vert}}} - 1)$$

$\mathrm{U_{Horiz}}$ and $\mathrm{U_{Vert}}$ are then rounded to the nearest integer to get the horizontal and vertical uncertainties in meters.

The conversion from uncertainty codes to uncertainty values is exponential, meaning the uncertainty value difference between two small uncertainty codes is small, and the uncertainty value difference between two large uncertainty codes is much larger. For example, the difference between uncertainty code 0 and 1 is only one horizontal meter, while the difference between uncertainty code 50 and 51 is 117 horizontal meters. The maximum horizontal uncertainty is roughly the distance from New York City to Omaha, Nebraska with uncertainty code 127 and a horizontal distance of 1,806,627 meters.

The table below shows the converted values for some uncertainty codes:

Table 3: E2 Interface Uncertainty Encoding

Horizontal Uncertainty Code	Horizontal Uncertainty (meters)	Vertical Uncertainty Code	Vertical Uncertainty (meters)
0	0	0	0
1	1	1	1
2	2	2	2
3	3	3	3
4	5	4	5
5	6	5	6
6	8	6	7
7	9	7	8
8	11	8	10
9	14	9	11
10	16	10	13
[. . .]	[. . .]	[. . .]	[. . .]
49	1,057	49	106
50	1,164	50	110
51	1,281	51	114
52	1,410	52	118
53	1,552	53	122
54	1,709	54	126
[. . .]	[. . .]	[. . .]	[. . .]
98	113,879	98	461
99	125,268	99	474
100	137,796	100	487
101	151,577	101	500
102	166,735	102	514
103	183,410	103	527
[. . .]	[. . .]	[. . .]	[. . .]
125	1,493,079	125	941
126	1,642,388	126	965
127	1,806,627	127	990

2.4.2 PIDF-LO

The IETF created a set of standards concerning the exchange of location; Next Generation 9-1-1 relies on these specifications. The data object that contains location data is called a Presence Information Data Format Location Object (PIDF-LO).

The main specifications related directly to the exchange of PIDF-LO location data are RFC 4119 [11], RFC 5139 [16], and RFC 5491 [14]. RFC 7459 [17] updates RFC 5491 [14] and pertains specifically to the exchange of confidence and uncertainty.

To properly characterize a 3D location with its confidence and uncertainty values for use in 9-1-1 systems, a PIDF-LO Ellipsoid element as defined in RFC 5491 [14] SHALL be used (note that PIDF-LO uses the WGS84 coordinate system). In NG9-1-1 systems this SHALL be represented as a prism with a circular or elliptical base, with its surfaces representing the limits of the uncertainty zone. The ellipsoid is constructed around a central point specified in three dimensions (longitude, latitude, and altitude), and three axes perpendicular to one another are extended outwards from this point. The semi-major and semi-minor axes lie in the X-Y plane, and the vertical axis is orthogonal to that plane. An orientation angle, measured in degrees clockwise from north, represents the direction of the semi-major axis from the center point. This requirement does not necessarily apply to the user interface, as PIDF-LO deals strictly with how location information is conveyed, and does not apply to how this information is presented to a user.

The base of the uncertainty cylinder is a circle or ellipse representing the 2D horizontal uncertainty. The radius of the circle is taken from the Ellipsoid element’s semi-major axis, and the semi-minor axis and orientation data are typically ignored. In future applications, an elliptical base may be used at the discretion of the 9-1-1 implementer.

The following example, adapted from RFC 5491 [14] and 7459 [17], shows a PIDF-LO Ellipsoid element representing the location of a measuring device with a longitude of -77.059388 degrees, a latitude of 38.850670 degrees, and an altitude of 132.6 meters. The horizontal uncertainty is given as an ellipse with a semi-major axis of 17.6 meters and a semi-minor axis of 12.3 meters, and the ellipse is rotated such that the semi-major axis is pointing 36 degrees east of north. The vertical axis represents the vertical uncertainty of 2.4 meters, and all uncertainty values are reported at a confidence of 90%:

```
<presence xmlns="urn:ietf:params:xml:ns:pidf"
          xmlns:gp="urn:ietf:params:xml:ns:pidf:geopriv10"
          xmlns:gml="http://www.opengis.net/gml"
          xmlns:gs="http://www.opengis.net/pidflo/1.0"
          xmlns:con="urn:ietf:params:xml:ns:geopriv:conf"
          entity="pres:somone@gpsreceiver.example.com">
  <tuple id="ellipsoid">
    <status>
      <gp:geopriv>
        <gp:location-info>
          <gs:Ellipsoid srsName="urn:ogc:def:crs:EPSG::4979">
            <gml:pos>
              -77.059388 38.850670 132.6
            </gml:pos>
            <gs:semiMajorAxis uom="urn:ogc:def:uom:EPSG::9001">
              17.6
            </gs:semiMajorAxis>
            <gs:semiMinorAxis uom="urn:ogc:def:uom:EPSG::9001">
              12.3
            </gs:semiMinorAxis>
            <gs:verticalAxis uom="urn:ogc:def:uom:EPSG::9001">
              2.4
            </gs:verticalAxis>
            <gs:orientation uom="urn:ogc:def:uom:EPSG::9102">
              36
            </gs:orientation>
          </gs:Ellipsoid>
          <con:confidence pdf="normal">
            90
          </con:confidence>
        </gp:location-info>
        <gp:usage-rules/>
        <gp:method>Hybrid_A-GPS</gp:method>
      </gp:geopriv>
    </status>
    <timestamp>2020-10-26T20:57:29Z</timestamp>
  </tuple>
</presence>
```


When PSAP systems render this example PIDF-LO element on a map, they may display a cylinder with its central point at a longitude of -77.059388 degrees, a latitude of 38.850670 degrees, and an altitude of 132.6 meters. The horizontal uncertainty will be rendered as a circle with a radius of 17.6 meters, and the total height of the cylinder will be 4.8 meters, or twice the vertical uncertainty.

Unlike in the NENA data exchange formats and the E2 interface, in a PIDF-LO shape the longitude, latitude, altitude, uncertainty axes, and orientation angle can be provided at any resolution. The longitude and latitude SHOULD be provided at a resolution of +/- 0.000001 (six significant figures, or roughly within ten centimeters).

RFC 7459 [17] states that the confidence parameter is an optional value in a PIDF-LO element. If no confidence parameter is included, RFC 7459 [17] states that the confidence value is assumed to be 95%. For use in 9-1-1 systems, all PIDF-LO elements SHALL include the confidence parameter to avoid ambiguity, and uncertainty values SHALL be converted to the required confidence level as early in the data flow as practical.[12]

2.5 Authoritative vs. Supplemental Location

E9-1-1 and NG9-1-1 systems receive authoritative location from the OSP, as is required under extant conventions and regulations in the United States, Canada, Europe and elsewhere. The location information is conveyed using standard protocols (meaning, the mechanism that the 9-1-1 authority expects the location to be provided through). For E9-1-1, this is usually ALI data via E2, while for NG9-1-1 it is a PIDF-LO conveyed with the call setup signaling. In addition to this required and standardized location, 9-1-1 systems MAY also receive supplemental location out-of-band, such as through a third-party LIS (usually over the internet). Supplemental Location MAY even come from the same source as authoritative location, such as location services on a mobile device; a third-party LIS may provide the exact same source location data at the same time through both authoritative and supplemental mechanisms. The figure below shows a hypothetical supplemental location service where mobile location services provide the caller's location through the cellular carrier's MPC and into the ALI system, with the same location conveyed over the internet through a third-party LIS.

[12] This document is a NENA Requirements (REQ) document and not a NENA Standards (STA) document. By convention, NENA STA documents normally do not impose requirements on OSPs, but instead specify interfaces to 9-1-1 systems. Here the normative requirements imposed upon OSPs by this document state the requirements of the 9-1-1 community.

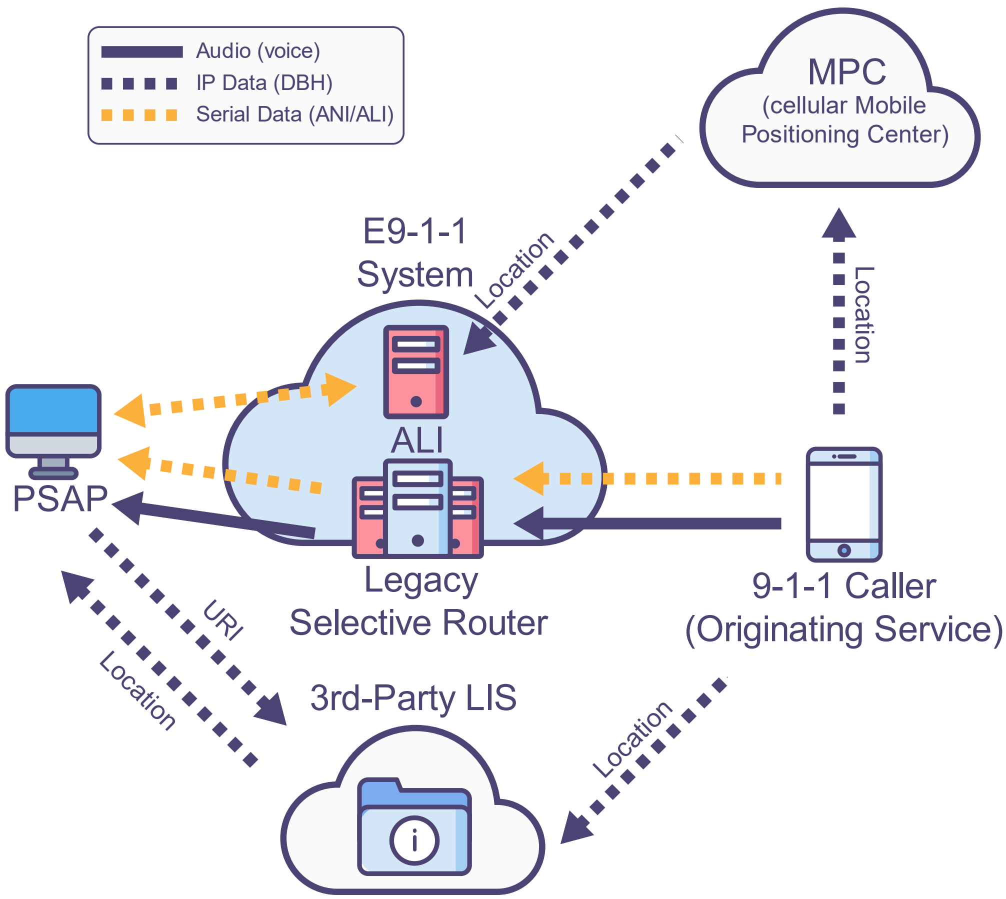

Figure 9: Hypothetical Supplemental Location Service

The above illustration is for legacy E9-1-1 calls. In NG9-1-1 calls, the originating device may provide location information as a PIDF-LO when it originates the call; the OSP may include this as its authoritative location (e.g., after a plausibility test) or in addition to its authoritative location.

A detailed description of supplemental locations and any requirements for providers of Supplemental Location are out of scope for this document. Generally, there are no regulations or standards that apply to Supplemental Location; the fact that the location exists outside of standards and regulatory coverage is what makes the location "supplemental." For more information see Recommended Best Practices for Supplemental 9-1-1 Location Data [18].[13]

[13]Note that this work has been adopted as a formal NENA information document that is unpublished as of this writing. See "Join NENA's Supplemental Location Data WG," accessed September 19, 2021, https://www.nena.org/page/JoinSuppLocnDataWG.

2.6 Regulatory Background

This section provides an overview of relevant legal and regulatory requirements for 3D location in 9-1-1 in the United States, Canada, and Europe. This document is primarily intended for a North American audience, specifically in the United States; however, the technical background and methods described in this document are relevant and can be applied internationally.

2.6.1 United States

The US Federal Communications Commission (FCC) has required wireless carriers to deliver horizontal location information for mobile phone 9-1-1 calls since 1994 under the E9-1-1 First Report and Order [19]. In 2014, the Commission turned its attention to indoor call location accuracy with the Third Further Notice of Proposed Rulemaking [20]. In 2015, the FCC published its Fourth Report and Order [21], establishing rules and deadlines for these calls. In these rules, the FCC deferred adoption of a specific z-axis metric, citing a widely agreed-upon need for further testing. After testing using an independently-administered test bed, the FCC adopted a z-axis location accuracy metric of ±3 meters in the vertical plane for 80% of calls made from z-axis capable devices, as demonstrated in the test bed.[14] The FCC also sought comment on additional issues, including the feasibility of further narrowing both the horizontal and vertical accuracy metrics, requiring delivery of floor level estimates, and expanding deployment requirements outside the Cellular Market Areas (CMA)-based metrics adopted earlier. In February 2020, the National Emergency Address Database (NEAD) project was terminated,[15] hence the FCC's DL requirements need to be met by other location determination technologies. Note that while regulations define the minimum area subject to oversight and enforcement by government, OSPs may use technologies that are available anywhere within the United States or globally, such as mobile location services.

The FCC's Sixth Report and Order ("Sixth R&O") [9] adopted many of the proposals from the Fifth Report and Order and Fifth Further Notice of Proposed Rule Making (NPRM) [4]. The Sixth R&O [9] allows carriers to comply with 2021 and 2023 z-axis requirements by deploying z-axis technology that covers at least 80% of the buildings greater than 3 stories in a given CMA (instead of the population-based metrics originally adopted). It also adds a nationwide z-axis requirement: carriers must deploy z-axis technology nationwide by April 3, 2025. The Sixth R&O [9] aligns wireless location accuracy requirements with those rules

[14] FCC, Fifth Report and Order [4], ¶¶ 2, 25, 56; 9-1-1 Service, CFR § 9.10(i)(2)(ii)(C), (i)(2)(ii)(D)

[15] See Letter from Thomas C. Power, Secretary, and Thomas K. Sawanobori, Vice President, NEAD, LLC, to Marlene H. Dortch, Secretary, FCC, PS Docket No. 07-114, at 1 (filed Feb. 14, 2020).

governing Multi-Line Telephone Systems (MLTS) and VoIP by requiring delivery of dispatchable location by January 6, 2022 where technically feasible.[16]

Per a series of consent decrees reached June 2021, major US wireless carriers Verizon Wireless [5], T-Mobile USA, Inc., [6] and AT&T Services, Inc. [7] have agreed to provide vertical location information nationwide as of June 10, 2021.

Note that while this document cites FCC dockets, any FCC orders ultimately enter US law by being codified in US Code.[17]

2.6.2 Canada

While the Canadian Radio-television and Telecommunications Commission (CRTC) currently has no specific guidelines in place for conveying caller altitude/z-axis within a 9-1-1 context, it has taken and will be taking more steps to have 9-1-1 caller altitude included with 9-1-1 calls.

In *Telecom Decision CRTC 2020-373 - CISC Emergency Services Working Group (ESWG) – Consensus report ESRE0086 regarding dispatchable location from originating networks* [22], Telecommunications Services Providers (TSPs) were directed, among other things to:

- deliver the most accurate dispatchable location available to the PSAP call handling functional element when so requested, either automatically or manually, specifically the geodetic location, the validated civic location, or both, and comprising:
    - initial location data, and
    - system-derived location and/or additional data such as supplemental address information

[16] Implementing Kari's Law and Section 506 of RAY BAUM'S Act; Inquiry Concerning 911 Access, Routing, and Location in Enterprise Communications Systems; Amending the Definition of Interconnected VoIP Service in Section 9.3 of the Commission's Rules, PS Docket Nos. 18-261 and 17-239, GN Docket No. 11-117, Report and Order, 34 FCC Rcd 6607 (2019) (Report and Order), corrected by Implementing Kari's Law and Section 506 of RAY BAUM'S Act; Inquiry Concerning 911 Access, Routing, and Location in Enterprise Communications Systems; Amending the Definition of Interconnected VoIP Service in Section 9.3 of the Commission's Rules, PS Docket Nos. 18-261 and 17-239, GN Docket No. 11-117, Erratum, DA 19-1217 (PSHSB Dec. 2, 2019) (Erratum). For non-fixed MLTS and VoIP situation, geodetic coordinates, including z-axis, may be provided as an alternative or as additional supplemental information. Cf., 47 CFR §§ 9.16(b)(3)(ii) and 9.3 (alternative location information may be coordinate-based, and it must be sufficient to identify the caller's civic address and approximate in-building location, including floor level, in large buildings).

[17] See generally, United States Code of Federal Regulations, Title 47, Ch. I, SubCh. A, Part 9. https://www.ecfr.gov/cgi-bin/text-idx?SID=114628af1a962c1f58dcda5a23bc2048&mc=true&tpl=/ecfrbrowse/Title47/47cfr9_main_02.tpl

In Canada, Dispatchable Location is defined as: A location determined by a PSAP telecommunicator, typically aided by Computer Aided Dispatch (CAD) software that utilizes a map. This location is derived from the best available location data delivered with the call and any additional data determined once the call has reached the PSAP. Location is typically represented in the PSAP in either or both Geodetic and Civic formats.

A validated civic location includes detailed address information such as apartment number (in the case of a residential multi-dwelling unit, for example) or floor number in the case of a commercial building.

Further, the Commission is currently considering another report from the ESWG, Consensus report ESRE0092 regarding Handset-based Location Implementation in Canada. In this report, the ESWG recommends, among other things, that the Commission request the ESWG to continue to monitor and report, as applicable, on the following question:

- When will we be able to implement the z-axis (vertical) coordinate in Canada? Google and Apple are actively working on the vertical coordinate, and testing is already possible with Google. ESWG will propose future trial work (1-2 years) to help determine the parameters required to use z-axis in Canada. As well, PSAPs will need to work with their vendors to determine what CAD and mapping changes (if any) are required to support delivery and display of z-axis data. ESWG will continue to monitor developments around the world and file a future report when the technology is ready for deployment in Canada.

The ESWG is composed of Telecommunication Service Providers, PSAPs, and 9-1-1 Industry specialists. The Working Group addresses issues that relate to the provisioning of 9-1-1 services. This includes the technical and operational implementation of 9-1-1 services as assigned by the CRTC or as requested by stakeholders.

2.6.3 Europe

Article 109(6) of the Directive 2018/1972/EC establishing the European Electronic Communications Code [23] requires the Member States of the European Union to make sure that caller location is sent to the appropriate PSAP and that this location information is based on both the network and the handset’s capabilities:

> *Member States shall ensure that caller location information is made available to the most appropriate PSAP without delay after the emergency communication is set up. This shall include network-based location information and, where available, handset-derived caller location information. Member States shall ensure that the establishment and the transmission of the caller location information are free of charge for the end-user and the PSAP with regard to all emergency communications to the single European emergency number ‘112’. Member States may extend that obligation to*

> *cover emergency communications to national emergency numbers. Competent regulatory authorities, if necessary after consulting BEREC[18], shall lay down criteria for the accuracy and reliability of the caller location information provided.*

This is completed by the Commission Delegated Regulation (EU) 2019/320 [24], which requires all smartphones sold in the EU Single Market starting from March 17 2022 to be able to send handset-derived location information to emergency services when an emergency communication is placed.

As of October, 2021 there is no specific requirement on vertical location information for European states.

2.7 Confidence and Uncertainty

Location conveyed for wireless emergency calls MUST include the Confidence and Uncertainty (C/U) values associated with that location. For a mobile device, a location is normally *estimated*; the location in three-dimensional space is calculated with the accuracy and precision technologically available.

In contrast, in a legacy fixed wireline 9-1-1 or other fixed service environment, uncertainty is assumed to be essentially zero. An address is provisioned for a telephone number (e.g., based on a wiremap database of the endpoint of the wire). Absent any errors in provisioning or customer records, the address for the caller conveyed to the PSAP is assumed to be correct; in PSAP operations *confidence* is incorrectly assumed to be 100%, and *uncertainty* is incorrectly assumed to be 0. The address is normally validated against the MSAG or LVF.

A call originated from a mobile device such as a cell phone is the most common type of emergency call, and this will increasingly become the case in an expanding wireless world. Most industry estimates place the number of calls originating from wireless devices in 2020

[18] BEREC is the Body of European Regulators for Electronic Communications. See https://berec.europa.eu

to be above 80%[19] with available data from the FCC's Annual 9-1-1 Fee Reports [25] showing at least 70%.[20]

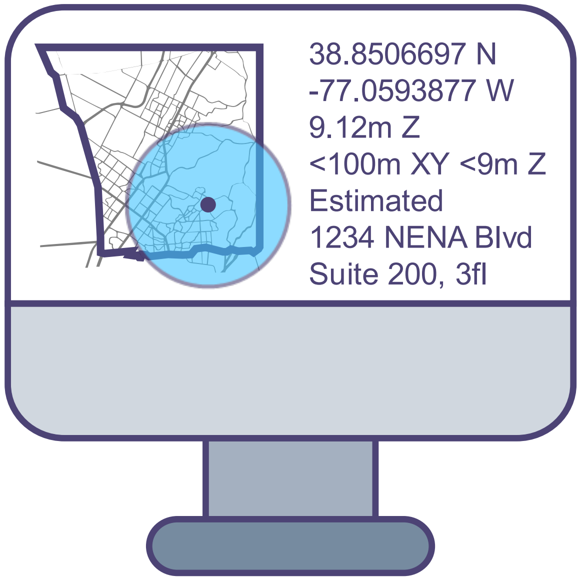

Figure 10: Simplified Illustration of Software Showing a 9-1-1 Caller's Geodetic and Dispatchable Location with C/U

2.7.1 Uncertainty

All measured or calculated location estimates include varying degrees of precision, accuracy, and uncertainty. For calculated location estimates, uncertainty is defined as the mathematically derived error range around a reported location (e.g., a set of coordinates or a civic address) within which a caller's device is located with a probability of a specified confidence. The position-determination technology used to calculate a location estimate for the device determines that the device is located within an area of a certain size, with a specified confidence. Because uncertainty is expressed as an area, it is commonly referred to as an *area of uncertainty*. Note that, depending on the position-determination technologies used, in general the device may in reality be anywhere within the area of uncertainty; it is not more likely to be in the center than near an edge. In the United

[19] National Emergency Number Association, "NENA 9-1-1 Statistics," accessed September 19, 2021, https://www.nena.org/page/911Statistics.

[20] The FCC reports in its 2019 Annual 9-1-1 Fee Report that 149,605,690 of 213,840,824 total reported 9-1-1 calls in 2018 were from wireless devices, which is about 70%; however, the FCC notes the actual proportion of wireless calls is much higher, as they were not able to collect data from all states and territories and not all respondents separated wireless calls in their reports. For example, 91% of Colorado's reported 9-1-1 calls in 2018 originated from wireless devices, compared to about 80% in California and Minnesota.

States, the FCC requires, in phases, that 80% of all wireless 9-1-1 calls are accurate within 50 meters horizontally and within 3 meters vertically of the provided location coordinates, or that dispatchable location is delivered for 80% of calls.[21] For a geodetic location, uncertainty is required to be expressed in meters.[22]

For 2D horizontal location calculations, uncertainty is calculated as an error ellipse representing an iso-contour of the normal Gaussian distribution of calculated points at a given confidence level. The coordinates delivered for the device's location are the center of the uncertainty ellipse. A horizontal location calculation algorithm will provide the center of the ellipse, the ellipse's semi-major and semi-minor radii, and the angle of the ellipse's semi-major axis with respect to the x-axis. This calculation is done "behind the scenes," and implementations typically simplify the ellipse to a circle, and only a radius and center are used. The user usually sees only the end result, a circle and a center point, displayed on their screens.

2.7.2 Confidence

Confidence is the mathematically derived probability that the device's location is within the area expressed as the location's uncertainty. For example, a 90% confidence means there is a 90% probability that a 2D geodetic location is located within the circle that represents the location's uncertainty. In the United States, the FCC requires 90% confidence when conveying uncertainty for wireless 9-1-1 calls.[23]

Confidence and uncertainty are dependent variables. The shape of the 2D geodetic uncertainty ellipse is dependent on the distribution of the measurements used to calculate the location, and the confidence value scales the ellipse accordingly. As detailed in Section 5.4.2 of RFC 7459 [17], the scale factor is proportional (larger confidence values give larger uncertainty ellipses) but not linear (doubling the confidence value does not double the size of the uncertainty ellipse)[24]. Considering the extreme cases, since we know it is mathematically impossible to calculate the "exact" location of anything, an uncertainty radius of 0.0 meters implies 0% confidence. Likewise, since we cannot be absolutely

[21] See 47 CFR 9.10 (i)(2), accessed September 19, 2021, https://www.law.cornell.edu/cfr/text/47/9.10; note that this document simplifies the FCC's requirements, and this document does not constitute legal advice for regulatory compliance or enforcement purposes.

[22] See 47 CFR 9.10 (j)(1)(ii).

[23] See 47 CFR 9.10 (j)(1)(i).

[24] Because horizontal and vertical measurements are calculated independently, use n=2 (two degrees of freedom) for horizontal scaling and n=1 for vertical scaling.

certain of exactly where anything is, to have 100% confidence implies there is an infinitely large uncertainty radius.

2.7.3 Comparing Confidence/Uncertainty Measurements

When measuring a position in space, there is always some level of inaccuracy. Measuring techniques have different levels of precision, mathematical calculations introduce roundoff errors, and inaccurate reference point locations can add errors to the measurements. What we think of as an "exact measurement" is really a locus of possible locations around a mathematically exact point. If a measurement is a dot on a map, the uncertainty can be thought of as the radius of a circle drawn around that dot, with that dot at its center; the caller's actual location is somewhere within that circle, with a probability of being correct within the reported level of confidence (e.g., 90%, or 9 out of 10 times). It is important to observe that the caller is normally not located at the dot that represents their "location"; they are located somewhere within the area of uncertainty around that dot. When a device such as a smartphone calculates its position, typically it will calculate a cluster of possible discrete locations depending on the reference data it is using. The distribution is assumed to be a standard normal bell-curve distribution around a center point. The size of the uncertainty circle depends on the percentage of those possible locations included inside the circle. If the calculation is for 90% confidence, then an uncertainty circle is drawn that contains 90% of the possible calculated locations, and the uncertainty is the radius of that circle. If the calculation is instead for 50% confidence, then only half of the calculated locations are inside the circle. RFC 7459 [17] provides a detailed description of probability distribution used for location confidence and uncertainty in 9-1-1.

Because the confidence level is a value selected based on how the location will be used and/or by implementation-specific rules or preferences, rather than by the nature of the underlying location technology, the same location calculation can be scaled to produce an infinite number of C/U pairs. GPS chips in smartphones and other devices are generally set by the chipset manufacturer at 67% or 68% confidence, roughly one standard deviation in a normal distribution. Other systems use 95% confidence, roughly two standard deviations. Per FCC regulations, service providers in the United States are required to report uncertainty to the 9-1-1 system at 90% confidence.[25] *Figure 11: The Same Horizontal Accuracy Expressed as Different C/U Pairs* shows the same location calculation presented as different C/U pairs.

Note that by choosing smaller confidence values to report uncertainty for the same calculated location, a reported location may create the perception of better accuracy. However, it is only an adjustment to how the same measurement is presented. It is very

[25] See 47 CFR 9.10 (j)(1)(i).

important to understand this distinction when operationalizing confidence and uncertainty. As described above, location for 9-1-1 is standardized at 90% in the United States.

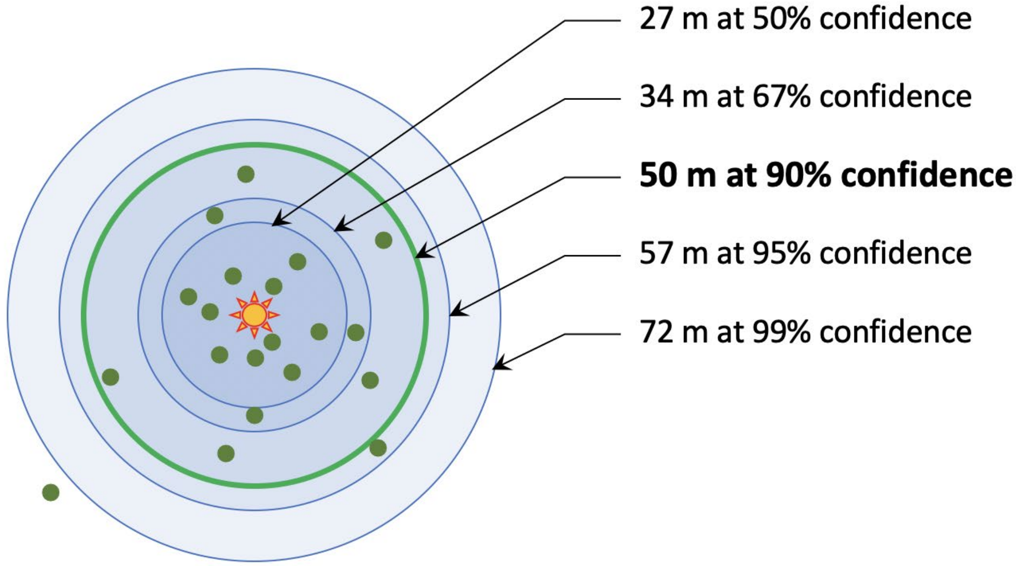

Figure 11: The Same Horizontal Accuracy Expressed as Different C/U Pairs

The accuracy of two separate measurements cannot be compared without knowing both the confidence and uncertainty of each measurement. In the figure above, a location with an uncertainty of 34 meters may seem more accurate than one with an uncertainty of 50 meters. However, when expressed with an uncertainty of 34 meters it is at only 67% confidence and is as accurate as when expressed with an uncertainty of 50 meters at 90% confidence. The expression with 90% confidence may be a larger, or less precise, area, but it is much more likely to be correct (9/10 times) versus when expressed with 67% confidence (correct only 2/3 times).

Location data delivered to the 9-1-1 systems in the United States from sources other than covered service providers is not subject to regulation, so they may be delivered at whatever confidence level the data source chooses. Supplemental data providers can technically provide uncertainty measurements at any confidence level. To provide a consistent and reliable reference, in the United States non-regulated location data sources SHOULD convey calculated C/U pairs at 90% confidence. Uncertainty can be scaled by adjusting the confidence used for a given location measurement. For more information on how this is done mathematically, please see – *Converting Uncertainties to Different Confidence Levels (Informative)*.

2.7.4 "Confidently"-Wrong Dispatchable Location

The primary risk when DL is conveyed without C/U is the scenario where the address conveyed is not the actual address where a person is located. Confidence/Uncertainty is a well-established concept with geodetic coordinates in general. When geodetic location is conveyed in 9-1-1, regulatory requirements[26] and established conventions[27] support conveying C/U. When a dispatchable location is calculated outside of the 9-1-1 system and communicated to it without C/U information associated with the location, the telecommunicator is not provided the context to understand the accuracy of this location.

The figure below demonstrates this problem in two dimensions. This shows a hypothetical system that estimates the location of a portable device based on the registered location of a variety of nearby beacons, such as Wi-Fi access points. In this very basic system, the dispatchable location service conveys the location of the wireless beacon with the best signal. It correctly identifies the address associated with the caller as the caller is in 1234 NENA Blvd, Apt 4.

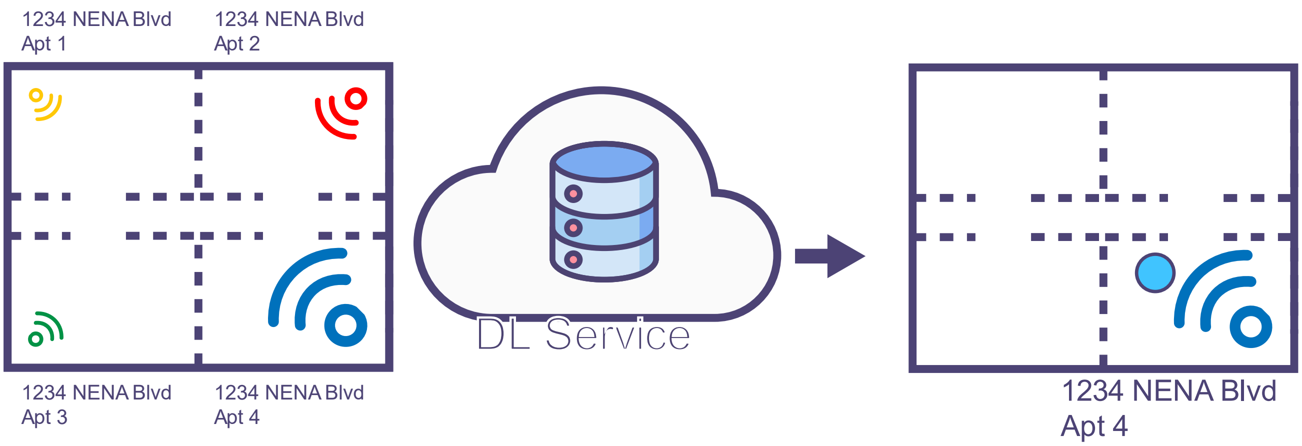

Figure 12: Dispatchable Location Service Identifying the Correct Civic Address

Wireless signals can behave in unpredictable ways, and regardless of the method used to try to estimate one's distance from a given registered address, it may determine that a location is closer to a wireless beacon that has the wrong address to associate with the caller. An example of this is shown in the figure below, where the caller is actually in 1234 NENA Blvd, Apt 1, even though the wireless environment leads the system to estimate that that the caller is most likely in Apt 4.

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[26] See 47 CFR 9.10 (j)(1)(i).

[27] See "Location Services Developer Documentation."

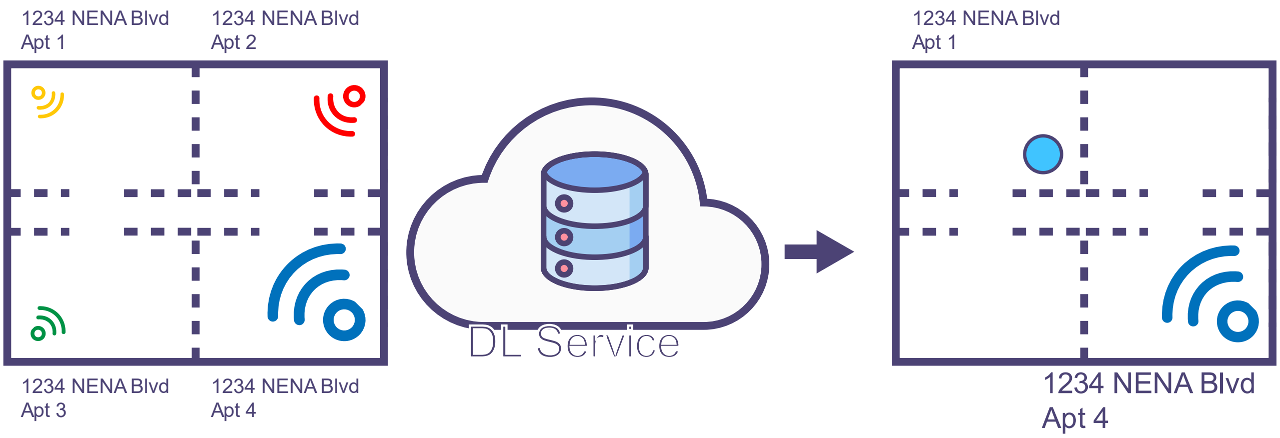

Figure 13: Dispatchable Location Service Identifying the Incorrect Civic Address

This problem is amplified in three dimensions. The figure below depicts an inaccurate initial location fix, which for whatever reason, places the caller in the *wrong building*. Should the DL service convey C/U information, it would not be problematic that this behavior would be observed occasionally; 9-1-1 operations are accustomed to location information that has very high uncertainty. However, the DL service needs to be able to convey uncertainty lest it convey "confidently wrong" location.

Figure 14: Depiction of DL Determining Caller is in the Incorrect Building

Location determination is never certain; the fact that DL is not exactly correct 100% of the time is not inherently a problem. However, when DL is generated and conveyed, the associated C/U needs to be calculated and conveyed to the 9-1-1 system in a way that is eventually actionable by telecommunicators.

2.7.5 Requirements for Conveying Uncertainty for a Civic Location

Existing conventions for civic location conveyance have only a very crude concept of uncertainty. Existing location standards were developed at a time when civic location was provisioned while geodetic location was calculated. As a result, these standards have an assumption that civic location information is inherently certain while geodetic location is inherently uncertain. For example, RFC 7459 [17] states: "[For a civic location], uncertainty is effectively described by the presence or absence of elements. To the recipient of location information, elements that are not present are uncertain . . . Uncertainty in civic addresses can be increased by removing elements. This does not increase confidence unless additional information is used." This was based on an operational model where civic location was accurate but an owner of location data wished to convey a location with uncertainty, for privacy or security. For example, a complete and accurate civic address might be conveyed without the building number or street name, leaving the city name and post code as the area of uncertainty.

When a mobile device places an emergency call, it is normally assumed that the device provides coordinates in three dimensions as described in this document (X/Y/Z). When a civic location is estimated based on the location of a device or other factors in the environment, this is called a Dispatchable Location. With the prevalence of mobile devices and calls from indoor locations, and the fact that these calls may carry a Dispatchable Location, it is critically important that C/U information can be included with a civic location.

This is a critical issue with emergency calls, because 9-1-1 requires that there be C/U information with every 9-1-1 call, given the context that mobile phones are portable and may place an emergency call from anywhere.

Section 3.4 *Implementing Dispatchable Location Methods* in this document describes requirements for conveying uncertainty associated with floor levels. There remains a need to do standards work to establish conventions for conveying uncertainty associated with a civic address when a civic address is delivered as a Dispatchable Location. In the meantime, if available, any Dispatchable Location SHOULD also be supplemented by a geodetic location, especially when a geodetic location was used to determine or confirm the proximity of the Dispatchable Location. This SHOULD be conveyed as multiple tuples within a single PIDF document [35].

Section 4.2 *IETF Standards Action Recommended* has considerations for future standards work in uncertainty associated with civic addresses.

As explored in other sections of this document, existing standards for legacy data exchange formats (nominally at NENA and ATIS), including ALI and E2, would need to be updated if they were to be able to accommodate all 3D location needs. Section 4.1.8 *Handling Z-Axis Confidence and Uncertainty for Legacy Data Exchange Formats* has considerations for future standards work to update these formats, including ALI. However, they may not be a priority for standards action.

2.7.6 Requirements for Conveying Uncertainty in Three Dimensions

Traditionally, when representing uncertainty in three dimensions, prevailing standards literature has assumed that this uncertainty is depicted with an ellipsoid. However, this assumption does not accurately convey uncertainty in three dimensions. Within a range of uncertainty, the actual location is equally likely to be anywhere within the area conveyed; for a location with only X and Y values, that is portrayed with a circle. For vertical uncertainty, the individual is equally likely to be located anywhere with the conveyed vertical range. When combining these two concepts, the resultant search area is a cylinder, not an ellipsoid. Accordingly, there is a need to convey and represent cylindrical search areas, ideally one that is backwards-compatible.

A cylindrical shape is generally not available in the standards literature for NG9-1-1; for example, PIDF-LO does not define a cylinder as a supported shape. The shapes supported by PIDF-LO and described in RFC 5491 [14] are:

- Point (2d and 3d)
- Polygon (2d)
- Circle (2d)
- Ellipse (2d)
- Arc band (2d)
- Sphere (3d)
- Ellipsoid (3d)
- Prism (3d)

Other shapes have been considered but offer no suitable solution. For example, a prism, when conveyed via PIDF-LO, cannot have a circular base. Section 5.2.8 in RFC 5491 [14] states a prism "extrudes a polygon by providing a height element. It consists of a base made up of coplanar points defined in 3 dimensions all at the same altitude," so it cannot construct a cylinder.

Mobile device-based location services, such as Device-Based Hybrid (DBH) or web geolocation Application Programming Interfaces (APIs) are becoming the most common way to provide a caller's location. They generally do not convey a discrete shape; instead, they convey information sufficient to construct a shape. This is a caller's estimated location and uncertainty around a point, as described above.[28]

[28] See "Location Services Developer Documentation."

2.7.6.1 Temporary Requirements for Operationalizing Uncertainty Information

A cylinder best captures horizontal and vertical uncertainty associated with an estimated call location. As discussed above, there is a long-term requirement to include a cylindrical shape in NG9-1-1 standards, but this is not currently supported. This section introduces *temporary* requirements intended to allow current implementations of E9-1-1 and NG9-1-1 standards to operationalize the location information and shapes that they receive now. These requirements are only recommended as a temporary measure for backwards-compatibility until the appropriate standards work can be completed to properly handle vertical and horizontal uncertainty, and until such standards can be implemented. See Section 4.2 *IETF Standards Action Recommended*.

Geodetic location in 9-1-1 is conveyed as a point with an area of uncertainty (X, Y and Z coordinates with horizontal and vertical uncertainty). This information is more useful when treated as a cylinder, such as in human interfaces or when formatting geospatial queries. This cylinder is constructed with a radius equaling horizontal X/Y uncertainty and overall height equaling twice vertical uncertainty (because the location's coordinates are at the cylinder's centroid and not its base).

In the figures below, consider the ellipsoid depicted in *Figure 15: Ellipsoid Construction*. It is constructed with values M and m (M and m are equal to the horizontal uncertainty; they are equal values because currently only shapes with a single radius are implemented, providing for a circular base) and v (equal to the vertical uncertainty), with its centroid at position c. The exact same information is to be used to construct the cylinder as shown in *Figure 16: Cylinder Construction*.

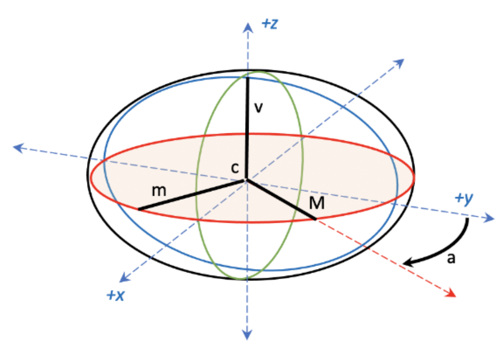

Figure 15: Ellipsoid Construction

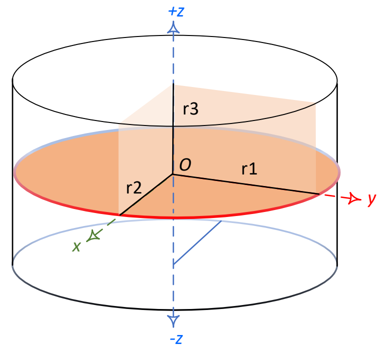

Figure 16: Cylinder Construction[29]

2.7.7 Mapping Location Types Across Standards

Different standards bodies have different concepts for location information and shapes used to describe locations. ATIS addresses some of these issues in its technical report, "Interworking of 2D and 3D Shapes Across Industry Standards," ATIS-0500045.[36] Readers of the current document should read this work for a fuller discussion of the topic. Integrators should conform to the guidelines and requirements in the ATIS report. The table below shows a non-authoritative excerpt drawn from the document showing mappings between IETF, 3GPP, and E2 for conveying caller location with uncertainty in three dimensions.[30] Integrators should adopt these mappings and the other guidelines in the ATIS report. Note that the requirements in Section 2.7.6 Requirements for Conveying Uncertainty in Three Dimensions are compatible with these mappings (e.g., an IETF PIDF-LO ellipsoid that is treated as a cylinder).

[29] Taken from [36].

[30] See [36] at Table 7-5. Retrieved 10/26/2020.

Table 4: Non-authoritative comparison between different standards based representations for 3D shapes

3GPP TS 23.032 [12]	IETF PIDF-LO/OGC	E2/ESP	Presentation (Shape Analogy)
Ellipsoid point with altitude	Point	Ellipsoid Point w/Uncertainty, (where Uncertainty = 0)	Point in 3-space
	Ellipsoid	Ellipsoid Point w/Uncertainty	Cylinder (Circle or Ellipse shaped cross section)
Ellipsoid point with altitude and uncertainty ellipsoid	Ellipsoid	Ellipsoid Point w/Horizontal Uncertainty and Vertical Uncertainty	Australian rules football, compressed/expanded on vertical axis
High Accuracy Ellipsoid point with altitude and uncertainty ellipsoid	Ellipsoid	Ellipsoid Point w/Horizontal Uncertainty and Vertical Uncertainty	Australian rules football, compressed/expanded on vertical axis
High Accuracy Ellipsoid point with altitude and uncertainty ellipsoid (all uncertainties are equal)	Sphere	Ellipsoid Point w/Horizontal Uncertainty and Vertical Uncertainty	Ball
	Prism		Vertically projected volume with polygon base

2.7.8 Approach to Standardization of GIS in NG9-1-1 Standards

The schema[31] of GIS datasets used in NG9-1-1, primarily those datasets used for call routing by the Emergency Call Routing Function (ECRF) and location validation by the LVF, are standardized. The NG9-1-1 GIS Data Model [2] documents these schemas, which facilitate interoperability between systems that produce and consume GIS data. It is also important to ensure that systems that need to compare civic locations to GIS data, or obtain civic locations from GIS data, can do so in a standardized way.

Civic locations in NG9-1-1, represented in PIDF-LO, conform to the NENA Next Generation 9-1-1 (NG9-1-1) United States Civic Location Data Exchange Format (CLDXF) Standard, NENA-STA-004 [26]. PIDF-LO is defined by the IETF as an international standard that tries to accommodate variances in addressing styles and methods that exist between different counties and localities. For example, PIDF-LO uses "A1," "A2," etc. as generic subdivisions rather than country-specific terms such as "state" or "canton." To further accommodate local differences, the IETF provides for country-specific documents to describe an extended profile of PIDF-LO, to capture and convey civic addresses in the country's specific style using PIDF-LO elements. In the United States, CLXDF [26] fulfills that requirement, by offering a PIDF-LO profile that may be used to represent United States civic locations and NENA CLDXF-CANADA provides a profile for addresses in Canada.[32]

The NG9-1-1 GIS Data Model [2] also ensures that GIS dataset schemas used to represent addressing data are conformant with address elements defined in CLDXF [26] and fulfill needs documented in the NENA i3 Standard for Next-Generation 9-1-1 [11]. By doing this, GIS datasets conformant with the NG9-1-1 GIS Data Model [2] can provide an interoperable basis for systems that analyze the relationship between civic locations and GIS data that represent them.

2.8 Defining "Z-Axis Capability"

The applicable regulations include a term "z-axis capable." The FCC generally defines this as a device that can support calculation of a z-axis value without a hardware upgrade.[33]

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[31] "Schema" in this context may be a traditional database schema, example files, definitions in a markup language, or some equivalent, and may not meet the strict technical definition of "schema."

[32] See "Join NENA's CLDXF-CANADA Work Group," accessed September 19, 2021, https://www.nena.org/page/join_CLDXF_CANADA. Document not published as of this writing.

[33] See FCC, Sixth R&O at 34: *In the Fifth Report and Order, we stated that the 3-meter metric should apply to all "z-axis capable" handsets, which we defined as handsets that "can measure and report vertical location without a hardware upgrade." [. . .] We further used this definition as the basis for our deployment requirements, stating that "any device technically capable of measuring and reporting vertical location information without a change in hardware must be enabled to do so."*

The following subsections provide background and guidance on determining z-axis capability for devices.

2.8.1 Guidance on "Z-Axis Capability"

CMRS providers may provide z-axis capability through their network infrastructure and subscriber devices by means of over-the-top applications as well as operating system or firmware upgrades. CMRS providers deploying z-axis technology must affirmatively push the z-axis technology to all existing z-axis capable device models on the provider's network that can receive it, and CMRS providers must continue to support the z-axis technology on these devices thereafter. A CMRS provider using the handset-based deployment option must make the technology available to existing z-axis capable devices nationwide; a CMRS provider using a CMA-based deployment option must make the technology available to all z-axis capable devices in the CMA. For all new z-axis capable devices marketed to consumers, the z-axis technology must be pre-installed.[34]

Every PSAP and 9-1-1 authority in the United States has z-axis location information available in their jurisdiction [5] [5] [6], if it is implemented by the 9-1-1 system or the PSAP. Those at the PSAP or 9-1-1 authority who do z-axis testing for their jurisdiction should work with wireless carriers, 9-1-1 service providers, and/or location providers (such as ALI services) to determine:

- which devices on the carrier's network are considered "z-axis capable" (if available),
- whether the devices intended to be used for testing are "z-axis capable," and
- whether z-axis information is correctly delivered to each component throughout the CMRS and 9-1-1 system.

2.8.2 "Non-Z-Axis Capable" Devices or Situations

There are a number of circumstances in which z-axis information may not be available, including but not limited to:

- where the caller's latitude and longitude location information is not available
- smartphones not certified by the carrier for its mobile network
- non-smartphone devices (e.g., feature phones or data-only devices)
- devices not running a current version of an operating system
- "rooted" or "jailbroken" devices running a modified or custom operating system

[34] See FCC, Sixth R&O at 42.

kernel[35]
- legacy devices or software no longer supported by the manufacturer or software provider
- devices purchased or imported from a country other than the one in which a call is placed

Initially, 9-1-1 systems may not be able to consume or pass z-axis information. Also, not all phones may be "z-axis capable." In the long term, there will always be a subset of devices that cannot deliver z-axis information.

3 Methods and Roadmap to Operationalizing Z-Axis Information

The following sections provide practical advice for operationalizing z-axis information for 9-1-1, including basic, short-term methods such as configuring ALI to include altitude information and some longer-term scenarios such as constructing detailed models of buildings for new construction using information from Architecture and Engineering firms. The methods are listed in increasing complexity and cost; for example, Section 3.1 *Preparing for Z-Axis Information at the PSAP* provides guidelines to prepare staff for z-axis information, such as some basic training guidelines, while Section 3.5.2 *Basic 3D Building Representation – Extruded Structure Polygons* provides guidelines for procedurally generating building shapes using artificial intelligence. Agencies SHOULD strive to achieve the most advanced methods practical.

Note that for the methods described below, in many cases, there already exist commercial datasets that may meet some to all local needs. On the other hand, a jurisdiction may choose to build some or all of the data locally; particularly with respect to digital elevation models.

3.1 Preparing for Z-Axis Information at the PSAP

By April 2021, carriers were required to begin providing z-axis information with 9-1-1 calls. FCC regulations in the Sixth R&O [9] require "delivery to the PSAP"; in reality, this means "delivered to the 9-1-1 system" for technical reasons. In legacy E9-1-1, wireless carriers convey location information to ALI systems for legacy E9-1-1 calls rather than directly to the PSAP. In NG9-1-1, wireless carriers convey location information by reference within the call setup signaling. The location is accessible to NGCS elements and PSAPs. This means

[35] A "rooted" or "jailbroken" device is one whose security and copy protection have been circumvented to remove software restrictions, often to use a custom operating system and unlicensed software. See, e.g., Wikipedia, "Jailbreaking of Apple devices," last modified September 18, 2021, https://en.wikipedia.org/wiki/Jailbreaking_of_Apple_devices.

that PSAPs must configure their local systems to use the z-axis information provided to the 9-1-1 system.

Note that the guidelines below primarily apply to a legacy PSAP and many functions at a legacy PSAP are not standardized. In NG9-1-1, the equivalent functions of the PSAP CPE and CAD are Call Handling, Incident Handling and Dispatch, and location is handled differently than in the legacy 9-1-1 environment.

Legacy PSAPs should begin by working with their 9-1-1 authority and carrier to ensure z-axis information will be delivered to their PSAP, and to be familiar with how the data will be formatted. PSAPs should also determine whether updates to ALI will be populated in their CPE or CAD, and should work with their providers to make sure the right configuration changes and updates are made. Note that even if a CPE or CAD product supports z-axis information from ALI, the local deployment may be several software versions behind and not support it. Even as of this writing, some PSAPs do not receive caller latitude and longitude with wireless calls because they are running old software; these PSAPs will not have access to z-axis either.

Transitional NG9-1-1 systems may not handle ALI data within the 9-1-1 system; they may convert the location information to a properly-formatted PIDF-LO within the NG9-1-1 system from the inbound E2 interface. Transitional NG9-1-1 systems need to perform careful testing, as they may be converting E2 to PIDF-LO and then back to ALI to support a legacy PSAP. For PSAPs operating in a transitional NG9-1-1 environment, the PSAP must coordinate with the Next Generation 9-1-1 Core Services (NGCS) operator and wireless carriers to ensure location data is properly formatted and delivered.

3.1.1 Preparation Guide for the PSAP:

Recommended steps known as of the preparation of this document are generally described briefly below.

3.1.1.1 Step 1

Assess the potential applicability for the deployment of wireless vertical location in their area with each of their respective nationwide wireless carriers. This inquiry should be made to the applicable wireless carriers both as to z-axis and as to dispatchable location. This is similar to the coordination and cooperation associated with the initial deployment of wireless Phase 2 horizontal location. Note that all major wireless carriers in the United States do provide z-axis information with emergency calls.

3.1.1.2 Step 2

Assess current status of their ALI format as far as whether the z-coordinate field (formerly called the ELV [elevation] field) and the z-uncertainty field, and as far as whether their CPE has enabled DL Classes of Service of WDL2, WDL1, and WCVC, which are respectively codes P, Q, and O. As a 9-1-1 area transitions from legacy or transitional ALI to PIDF-LO, legacy Classes of Service and current ALI formats may transition to more enhanced data format presentations for telecommunicators, where they have not already done so. Modifications of an ALI format will require coordination and testing in CPE, mapping, and CAD. There may be states where essentially an entire state uses a single ALI format (e.g., within the state of California), and there may be states that have several different ALI formats currently (e.g., within the State of Texas).

The z-coordinate field and the z-uncertainty fields should be added to the ALI format to be displayed to a telecommunicator. Where the ALI formats have been modified at the PSAP, the activation of new fields should be confirmed with the 9-1-1 system service provider and applicable OSPs. When DL is provided, in the absence of the WDL2, WDL1, and WCVC Classes of Service being added to CPE, the telecommunicator's display may show default values such as "Wireless 911 Caller" or "No record found" in place of what would have been the Phase 1 cell sector information.

NG9-1-1 PSAPs and NGCS do not use ALI, and a PIDF-LO already supports z-axis information. The NG9-1-1 system and the NG9-1-1 PSAP should already support 3D location in part, provided the GIS information is able to make use of the vertical axis.

3.1.1.3 Step 3

Begin the process to operationalize and use z-coordinate field and z-uncertainty field information at PSAPs. There is no reasonable expectation that telecommunicators will interpret or use raw Altitude (height above ellipsoid) information by itself without the use of a 3D mapping system or other mechanism that converts Altitude to something that is actionable. A vertical z-coordinate by itself is no more useful to telecommunicators than having horizontal x and y coordinates without a map. Additional guidance on various approaches to operationalize this information is contained later in this document.

3.2 Automatic Location Identification (ALI) for Z-Axis

3.2.1 Delivery of Uncompensated Barometric Pressure

The FCC Fourth Report and Order [21] mandated that wireless carriers provide uncompensated barometric pressure (UBP)—if supported by the device—as a precursor to an actual z-axis measurement. Despite the z-axis delivery requirements in the 5th and 6th Report and Order, this requirement has not been modified.

Because current data formats do not include dedicated fields or labels for barometric data, current practice is to deliver the information using a portion of the LOC field in the NENA Version 3.1 data format. Per ATIS-0700028, Section 8.4 [10], UBP is delivered as an unsigned (always positive) six-digit integer and is measured in hectopascals (hPa). As reference, average sea level pressure is about 1013 hPa. The data appears in the LOC supplemental data field as "UBP NNNNNN" as noted in ATIS-0700028 [10].

One concern about delivering and using UBP is that the data is "uncompensated": it does not "compensate" for variations in air pressure. For example, local weather conditions affect barometric pressure, meaning that UBM measurements at the same altitude may be quite different on different days and different hours. In another example, within a building, changes may be caused by forced-air heating and air conditioning systems. These changes can make indoor UBP measurements seem to be at a lower altitude than an outdoor measurement at the same level. UBP also does not take into account the problem of "drift," or calibration errors that occur as the measuring device ages.

UBP alone SHALL NOT be used to determine a device's altitude. If barometric pressure readings are compensated for local variations in air pressure such as by using weather sensor networks, they can be used to determine a device's altitude with a high degree of accuracy. While compensated barometric pressure readings may be useful for determining caller altitude, a detailed description of their function and any further requirements are outside of the scope of this document.

There is not a dedicated field for UBP in NG9-1-1 location. In the interim, this document recommends placing UBP information, when conveyed as part of an NG9-1-1 call, in the "LOC" field of a Civic Address in a PIDF-LO. The "LOC" field is described in RFC 4776 [27]. A future revision or extension to PIDF should introduce a dedicated field for UBP.

3.2.2 Maintaining Integrity of Location Information

When converting location information between different formats (for example, converting a geodetic location to a civic location, converting between different datums, or converting Height/Altitude information to a floor level), there is usually some loss of precision and/or accuracy. Converting location information between formats should always be avoided, unless it is necessary, and when conversions are done, the original location information should be retained and conveyed to downstream entities.

When conveyed into the 9-1-1 system, 3D geodetic location information shall be conveyed with respect to the WGS84 datum, including the z-axis measurement. This requirement also applies to elements within the 9-1-1 system that communicate with each other through standardized interfaces. Geodetic location information may also include additional height or altitude measurements, including an estimated floor level, AGL measurement or other method. All other measurements shall be conveyed in the international SI measurement system (e.g., meters for z-axis altitude and uncertainty, hPa for barometric pressure).

Note that when HAE is converted into an estimated floor level, the level of precision is reduced from meters to the height of a story (approximately three meters, but can vary greatly from building to building). This same limitation applies to an estimated floor level provided without an HAE measurement.

3.2.3 Converting HAE to Actionable Information

HAE information must be converted into actionable information to be useful. For example, converting HAE to caller Height or to estimated subaddress information (DL) can provide actionable information to the telecommunicator. Some recommended workflows are below.

3.2.3.1 Calculating Height of a 9-1-1 Calling Device

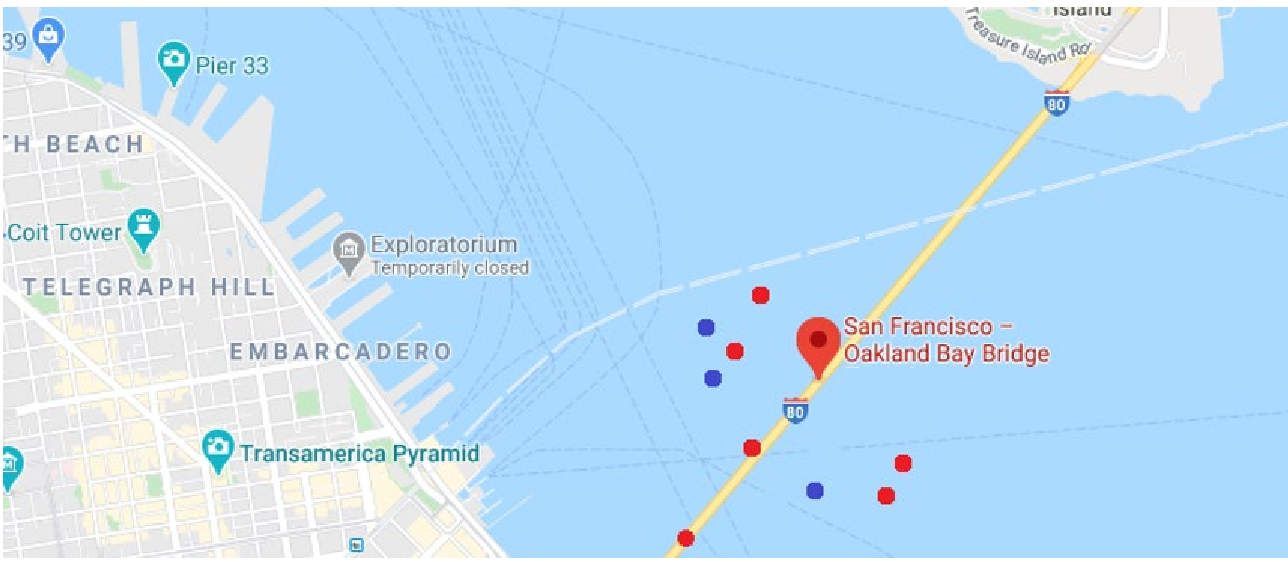
Location information is sent from CMRS providers as latitude, longitude, and altitude with C/U; one C/U value for x/y and one C/U value for z. Z-axis information delivered from the handset via the CMRS provides Altitude (HAE), not Height (above ground level).

PSAPs that utilize accurate GIS data sets in 3D can use software that calculates the Height of the 9-1-1 calling device. The calling device's Height equals the Altitude of the device minus the Elevation of the ground.

Height (above ground level) = Altitude (above ellipsoid) – Elevation (of ground)

Telecommunicators may need to know the Height of a calling device to locate the caller inside a building. Height is useful information in both urban and rural areas indoors to locate calling devices in multistory buildings, but also outdoors to distinguish, for example, whether an emergency call is placed from a bridge or underneath it on the surface of the water. It is also useful in wilderness areas, as it may be helpful to be able to use Altitude information to determine whether a caller is more likely at the top or bottom of a cliff, when horizontal uncertainty may place the caller on either side of it.

When only latitude/longitude are delivered with 9-1-1 calls, it is not possible to determine if, for example, a call could be placed from the surface of a bridge or from the water underneath it, as shown in the example below. The figure below shows mock 9-1-1 calls placed in the area of the San Francisco-Oakland Bay Bridge. Each dot represents a call plotted on the map by x/y coordinates. The red dots represent calls placed from the bridge and the blue dots represent calls placed from the surface of the water (typically from a boat). Note that some calls' horizontal uncertainty places the call in the middle of the water, but the vertical measurement can inform the telecommunicator that the call was placed from the bridge. In some cases, this may help resolve jurisdictional issues with dispatch, as different agencies may be responsible for responding to calls on the bridge as opposed to on the surface of the water. This distinction can only be made when the 9-1-1 caller's Height can be determined with a reasonable degree of certainty.



Map data © Google 2022

Figure 17: Caller Height Measurement and Relationship with Bridges[36]

For Height measurement units, user interfaces may provide options for conversion from meters into feet. Local operations may prefer to use Imperial units (feet) instead of SI units (meters).[37]

There are many approaches to handling routing of queries in 3D for emergency services, including standardizing updates at the protocol level to better handle three dimensions (see [3]) or from novel use of Policy Routing (see [11] at 3.3: Policy [Policies]) as an interim

[36] Example image is from Google Maps.

[37] 1 foot is 0.3048 meters.

solution. A full exploration of this topic is out of scope for this section. For initial future requirements, see section 4.2.2 *3D LoST*.

3.2.3.2 Using Height of 9-1-1 caller (with address estimation):

ALI can convey vertical location information for emergency calls, including subaddress elements that convey a caller's vertical location, such as a floor level. Long-term, NG9-1-1 systems will use CLDXF-compatible address and subaddress elements [26]. In a legacy or transitional NG9-1-1 environment, ALI is character-constrained and will typically use abbreviations (e.g., "FLR" instead of "FLOOR"; see rows 8 and 9 in *Figure 18: Example ALI Format with Labels*). See the following sections for a full discussion of ALI in the context of this document. Below are some examples of subaddress elements that may be conveyed over ALI:

Stadium: Section 4, LVL 3
Parking at a Campus: East Lot, BSMT
Shopping Mall or Strip: FL 2, STE 250
Park: City Park, FIELD 2
Marina: DOCK 4, SLIP 32
Office Building: FL 5, RM 202

Per ATIS-0700028 [10], the priority of mapping of CLDXF elements [26] to the LOC element in the E2 Location Description parameter is as follows:

BLD|FLR|UNIT|ROOM|SEAT|MP|LOC|LMK (or LMKP) |PLC|UBP.

3.2.4 Requirements for Integrating Z-Axis Information into ALI

Implementations of ALI formats are roughly conformant with standards but are not uniform across the USA or elsewhere. NENA ALI formats, described in NENA Standard Data Formats for E9-1-1 Data Exchange & GIS Mapping [11], no longer regularly receive substantive updates because ALI is considered legacy technology. As described in Section 2.7.7 *Mapping Location Types Across Standards,* conforming with US regulatory requirements is not compatible with strictly conforming to NENA ALI formats, because not all of the required information can be captured in one of the formats.

Where requirements in this document conflict with NENA ALI data formats, this document should control.

Existing implementations vary widely. For example, "X" and "Y" may be "LAT" and "LON" in two different implementations. In order to utilize z-axis information, implementers need to work with their ALI service and software providers (such as CAD) to identify where and how z-axis information including confidence and uncertainty is displayed. Operational personnel must understand the meaning of each term in each software application because labels and conventions may not be consistent.

To display geodetic z-axis information, ALI data SHOULD be formatted with the following characteristics (examples provided below):

- Z-axis information SHOULD be located in ALI data in the line immediately following the line(s) containing X and Y information.
- X, Y, and Z location information SHOULD be conveyed over three contiguous lines.
- X and Y information MAY be on the same line, with horizontal confidence and uncertainty, or they MAY be on two separate lines, staggered with confidence and uncertainty, but all four values SHOULD be on two lines immediately preceding z-axis information.
- For backwards compatibility reasons, integrators SHOULD NOT change existing labels for X/Y confidence and uncertainty so as not to cause problems with other elements in existing implementations, even though labels MAY not conform with the same meanings in this document (e.g., if horizontal uncertainty is labeled "UNC" without specifying that it is for horizontal uncertainty). Telecommunicators SHOULD be trained to recognize the difference between horizontal and vertical uncertainty information on their displays.
- Z-axis information SHOULD be on the same line as z-uncertainty, and z-uncertainty MUST be clearly labeled as being the uncertainty associated with the z-axis measurement.
- In the United States, regulations require z-axis confidence to be 90 percent[38]. When the PSAP receives location via ALI, Z-confidence information may not be displayed at the PSAP because of limitations with ALI.
- Telecommunicators should understand that the z-axis confidence level for wireless 9-1-1 calls is required to be 90%[39]

Location data calculated on a mobile handset may not match regulatory requirements for confidence when conveyed via over-the-top methods. For example, prevailing location services platforms do not use 90% confidence, so third-party applications that provide location through an out-of-band delivery mechanism may not use the confidence level of 90%.[40] It is expected that when placing an emergency call, devices will deliver location at

[38] Get cite (FCC Part 9, 4th R&O)

[39] As established previously in this document, per FCC rules.

[40] See, e.g., Apple, Inc., *Enhanced Emergency Data: Fast, secure location for emergency calls*, https://cdn.ymaws.com/www.nena.org/resource/resmgr/docs/Apple_Enhanced_Emergency_Dat.pdf, August

90% confidence. In all cases, confidence presented to a telecommunicator SHOULD be 90%. Where it is not 90%, the confidence level MUST be presented to the telecommunicator.

3.2.4.1 Examples

The following examples are provided illustratively and are NOT normative. They provide examples that implement recommendations for ALI formats in this document currently in use by participating members of the document authorship (see following pages).

2018, where Apple HELO delivers confidence at 95%. This citation is provided illustratively and does not constitute or is not meant to imply endorsement.

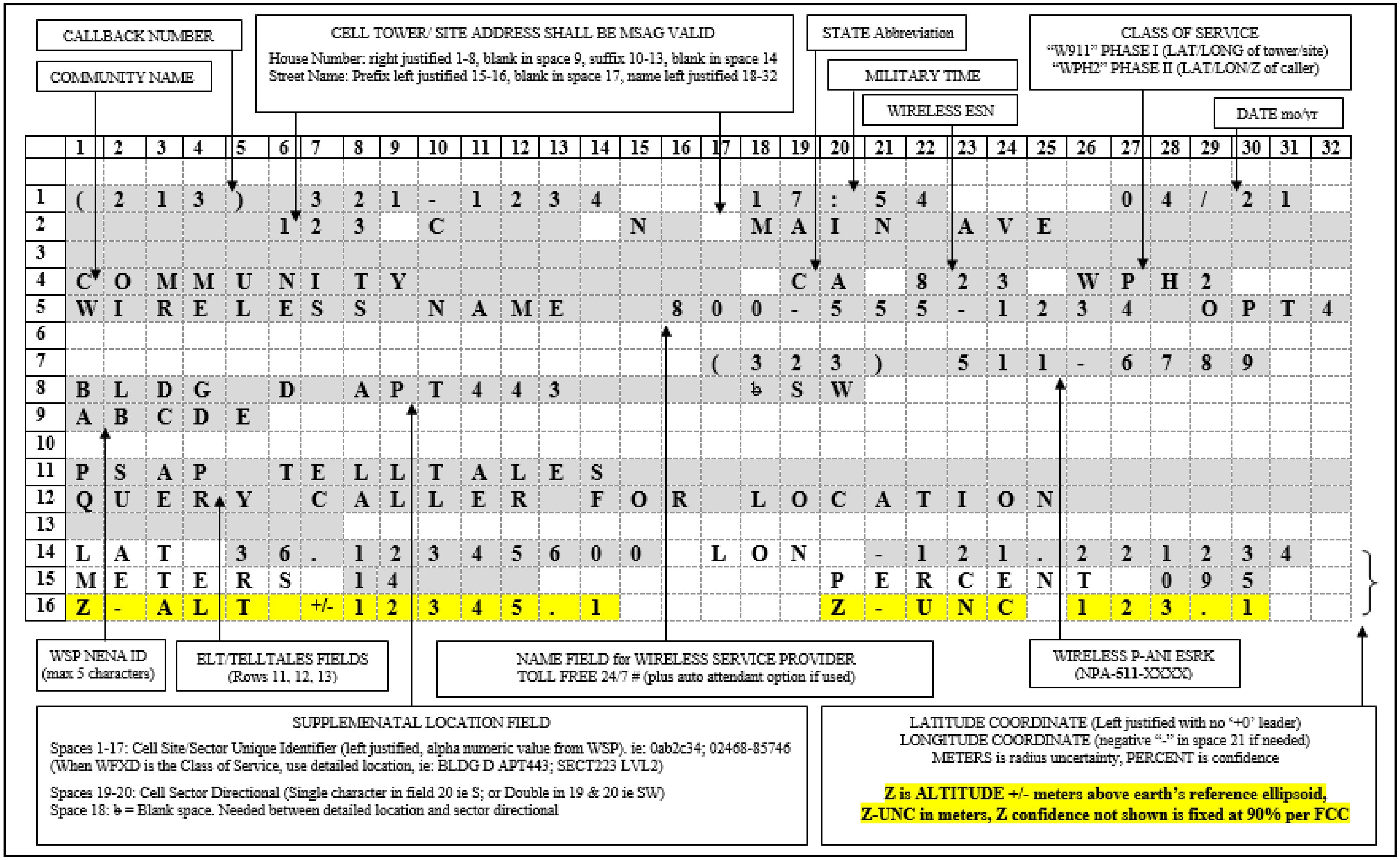


Figure 18: Example ALI Format with Labels

```
         1         2         3         4
1234567890123456789012345678901234567890
========================================
RR-ppp      ESN=eee         nnn?
(AAA) XXX-TTTT mmmmm dddddddddd?
HHHHHHHH UUUU ii?
sssssssssssssssssssssssssssssss?
sssssssssss (aaa) xxx-tttt cccc?
YYYYYYYYYYYYYYYYYYYYYYYYYYYY SS?
LLLLLLLLLLLLLLLLLLL?
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN?
ALT#=                TELCO=IIIII?
X=jjjjjjjjjjj CNF=CCC?
Y=qqqqqqqqqqq UNC=UUUUUUU?
Z=zzzzzz      Z-UNC=zzzzzz?
PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP?
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF?
EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE?
========================================
1234567890123456789012345678901234567890
         1         2         3         4


                               Offset/
Row Col       Field Name       Precision  Length  Field Characters
--- ---  --------------------  ---------  ------  ----------------
 01  01  Responding ALI            0         2       1 - 2
 01  03  Punctuation ('-')                   1
 01  04  PSAP ID                   0         3       1 - 3
 01  13  Punctuation ('E')                   1
 01  14  Punctuation ('S')                   1
 01  15  Punctuation ('N')                   1
 01  16  Punctuation ('=')                   1
 01  17  ESN RJZF                  3         3       4 - 6
 01  29  Position Number           0         3       1 - 3
 01  32  Punctuation (\015)                  1
 02  01  Punctuation ('(')                   1
 02  02  Area Code (NPA)           0         3       1 - 3
 02  05  Punctuation (')')                   1
 02  07  Office Code (NNX)         0         3       1 - 3
 02  10  Punctuation ('-')                   1
 02  11  TN                        0         4       1 - 4
 02  16  Time                      0         5       1 - 5
 02  22  Date                      0        10       1 - 10
 02  32  Punctuation (\015)                  1
 03  01  RJ House Number           0         8       1 - 8
 03  10  House # Suffix            0         4       1 - 4
 03  15  Prefix Directional        0         2       1 - 2
 03  17  Punctuation (\015)                  1
 04  01  Street Name               0        31       1 - 31
 04  32  Punctuation (\015)                  1
 05  01  Street Name              31        11       32 - 42
 05  13  Punctuation ('(')                   1
 05  14  Pilot NPA                 0         3       1 - 3
 05  17  Punctuation (')')                   1
 05  19  Pilot NNX                 0         3       1 - 3
 05  22  Punctuation ('-')                   1
```

05	23	Pilot Number-Last4	0	4	1 - 4
05	28	Class of Serv.Desc	0	4	1 - 4
05	32	Punctuation (\015)		1	
06	01	City Name	0	28	1 - 28
06	30	State Abbr.	0	2	1 - 2
06	32	Punctuation (\015)		1	
07	01	Location Informatn	0	20	1 - 20
07	21	Punctuation (\015)		1	
08	01	Customer Name	0	31	1 - 31
08	32	Punctuation (\015)		1	
09	01	Punctuation ('A')		1	
09	02	Punctuation ('L')		1	
09	03	Punctuation ('T')		1	
09	04	Punctuation ('#')		1	
09	05	Punctuation ('=')		1	
09	21	Punctuation ('T')		1	
09	22	Punctuation ('E')		1	
09	23	Punctuation ('L')		1	
09	24	Punctuation ('C')		1	
09	25	Punctuation ('O')		1	
09	26	Punctuation ('=')		1	
09	27	Company Id	0	5	1 - 5
09	32	Punctuation (\015)		1	
10	01	Punctuation ('X')		1	
10	02	Punctuation ('=')		1	
10	03	Map X coordinate	0	11	1 - 11
10	15	Punctuation ('C')		1	
10	16	Punctuation ('N')		1	
10	17	Punctuation ('F')		1	
10	18	Punctuation ('=')		1	
10	19	X,Y Confidence	3	3	4 - 6
10	22	Punctuation (\015)		1	
11	01	Punctuation ('Y')		1	
11	02	Punctuation ('=')		1	
11	03	Map Y coordinate	0	11	1 - 11
11	15	Punctuation ('U')		1	
11	16	Punctuation ('N')		1	
11	17	Punctuation ('C')		1	
11	18	Punctuation ('=')		1	
11	19	X,Y Uncertainty	0	7	1 - 7
11	26	Punctuation (\015)		1	
12	01	Punctuation ('Z')		1	
12	02	Punctuation ('=')		1	
12	03	Map Z Unedited	0	6	1 - 6
12	15	Punctuation ('Z')		1	
12	16	Punctuation ('-')		1	
12	17	Punctuation ('U')		1	
12	18	Punctuation ('N')		1	
12	19	Punctuation ('C')		1	
12	20	Punctuation ('=')		1	
12	21	Z Uncertainty	0	6	1 - 6
12	27	Punctuation (\015)		1	
13	01	Police	0	31	1 - 31
13	32	Punctuation (\015)		1	
14	01	Fire	0	31	1 - 31

14	32	Punctuation (\015)		1	
15	01	EMS	0	31	1 - 31
15	32	Punctuation (\015)		1	

Figure 19: Sample ALI Format

3.3 Digital Elevation Modeling

A Digital Elevation Model (DEM) is a type of raster GIS layer that represents continuous elevation values over a topographic surface by a regular array of z-values. For example, a DEM can portray elevation information for the surface of the earth as a shaded 2D image. Developing or acquiring accurate elevation data is a prerequisite to any and all of the methods described in this document. HAE information is not normally actionable or useful on its own; it must usually at least be converted to Height (above ground level). To do so requires provisioning of an accurate elevation model at a resolution suitable for its intended use. This section provides some background, requirements and guidance for provisioning of elevation models used for 9-1-1. It starts by discussing general elevation modeling concepts and how modern DEMs are created from Light Detection and Ranging (LiDAR), then discusses differences between traditional bare-Earth Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) that model more than the bare-earth and include elements like buildings or vegetation that occur on the surface, and concludes with data sources for elevation models and caveats.

Note that an NG9-1-1 deployment MUST have a GIS component, as many functions in NG9-1-1 require underlying GIS data, including location validation and location-based routing. Accordingly, provisioning of elevation data for 9-1-1, whether purchased as a service or managed internally, SHOULD be managed holistically along with the GIS data otherwise required for NG9-1-1.

This section includes several depictions of the same area with different modeling methods. The figure below shows aerial photography of that area in the native 6 inch pixel resolution.

Figure 20: Aerial Photography of part of Jefferson City, MO[41] as native 6 inch pixels[42]

3.3.1 Resolution of Elevation Models

Elevation models, like imagery and other raster datasets, express resolution as the size of each pixel in the array, such as 6 inch or 1 meter. Each pixel in a 1 meter dataset measures 1 meter by 1 meter and represents the elevation of that square meter. Smaller pixels are preferred to larger pixels as they more accurately represent and measure smaller objects. 1 meter pixels do not represent objects less than 1 square meter in size well and 10 meter pixels do not represent objects less than 10 square meters in size well.

[41] Retrieved December 18, 2020 from https://moimagery.missouri.edu/arcgis/rest/services/JeffersonCity ("Jefferson City Area").

[42] Note that Jefferson City Area data is published in US Imperial Units, so citations referencing this data set are cited in inches and feet. USGS data is published in International System of Units (metric system), so citations referencing this data set are cited in meters. NG9-1-1 implementations are required to use the metric system. For reference, 1 meter equals about 39.37 inches.

3.3.2 NENA Digital Elevation Model Level-of-Detail

Elevation models represent the height of the ground or other features above a reference frame and are an integral part of determining the location of a caller on the z-axis. Elevation data is typically arranged within Level-of-Detail (LOD), so the returned values or visualization can vary depending on the LOD called. This document specifies four levels of detail for 9-1-1 DEMs:

Table 5: NENA Digital Elevation Model Level of Detail

Level of Detail	Use	Recommended Pixel Resolution (Smaller pixels = higher resolution)	Example Dataset
One	Elevation services can identify the ground-level Elevation at a specific X/Y coordinate; it is also a necessary prerequisite to reconciling the difference between Altitude, Elevation, and Height	10 meter pixels or smaller when available Larger pixels (e.g., 15 meter or 30 meter) SHOULD NOT be used unless no smaller resolution data is technically feasible	USGS (United States Geological Survey) Reference Terrain Data such as National Map [28] Elevation Data and 3-Dimension Elevation Program (3DEP) products [29] (section 7.2.5.1) Digital Terrain Models (DTMs) (section 7.2.4.1)
Two	Elevation services identify if a caller is potentially below or above ground	10 meter pixels or smaller when available	USGS Reference Terrain Data such as National Map [28] Elevation Data and 3-Dimension Elevation Program (3DEP) products [29] (section 7.2.5.1) Digital Terrain Models (DTMs) (section 7.2.4.1)

Level of Detail	Use	Recommended Pixel Resolution (Smaller pixels = higher resolution)	Example Dataset
Three	Elevation services are used to set elevation of building and floor 3D Objects	3 meter pixels or smaller, built from data such as USGS QL3 or better[43]	Regionally or Locally sourced elevation models Enterprise GIS (derivable from QL2 LiDAR) (section 7.2.5.2) Digital Surface Models (DSMs) (section 7.2.4.2) Digital Terrain Models (DTMs) (section 7.2.2.1) in areas of primarily single-story structures with little forest cover
Four	Elevation services provide the foundation to drape 2D imagery and data onto 3D Objects	1 meter pixels or smaller, built from data such as USGS QL2 or better	Regionally or Locally sourced elevation models Enterprise GIS (derivable from QL2 LiDAR) (section 7.2.5.2) Digital Surface Models (DSMs) (section 7.2.4.2)

Regardless of LOD, the most recent, most accurate, and smallest pixel resolution elevation model should be used. See the following sections for detail. Note that existing DEMs created to support orthophotography products tend to be thinned out and should not be used for these public safety LODs.

3.3.3 **Comparing Different Resolutions**

The following figures depict the Jefferson City DSM at approximately levels One through Four as classified in the table above. Note that at level One, distinct objects are nearly impossible to make out. While this resolution may be minimally useful for determining

[43] See USGS LiDAR Base Specification [30].

approximate Height, the resolution is too low to be useful for identifying which story an individual may occupy within a building or even which building they are located in.

At Level Two, objects begin to become more distinct, and it is difficult, but possible, to begin to make out individual structures such as trees and buildings. At Level Three, or 1-3 meters per pixel, objects begin to take form. At Level Four or better, distinct structures are very easy to make out and the information is precise enough to start constructing building volumes from. See the figures below.

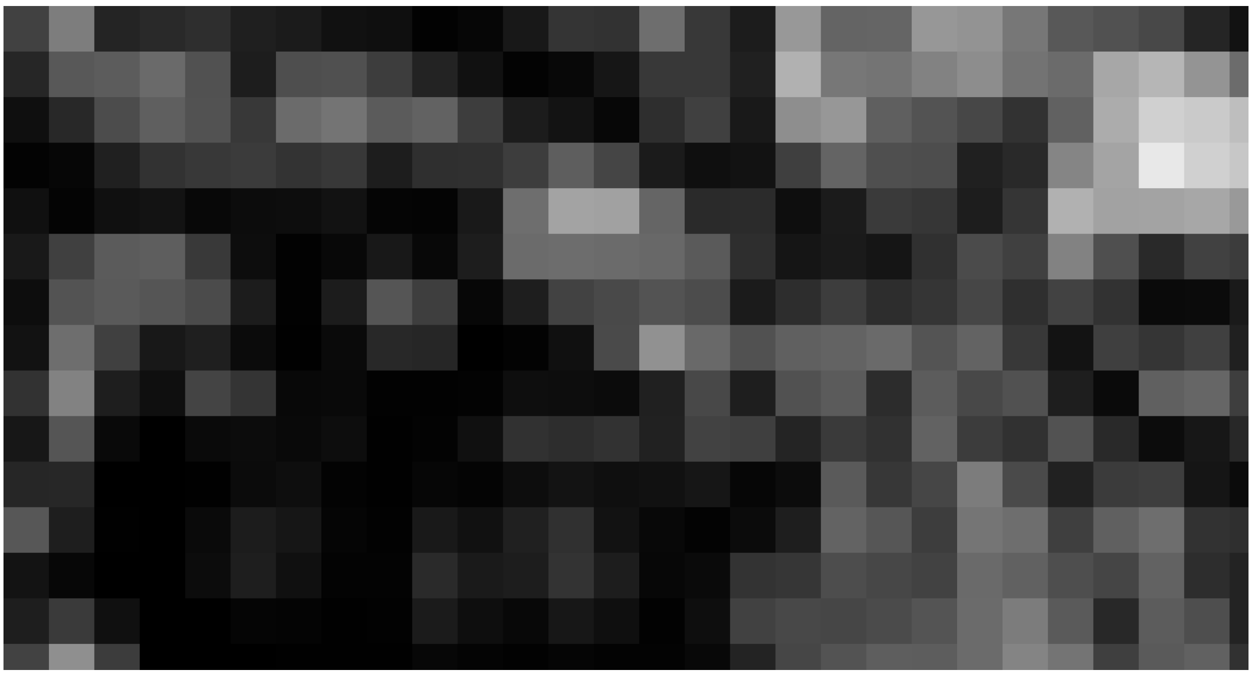


Figure 21: Level One DSM for Jefferson City Area

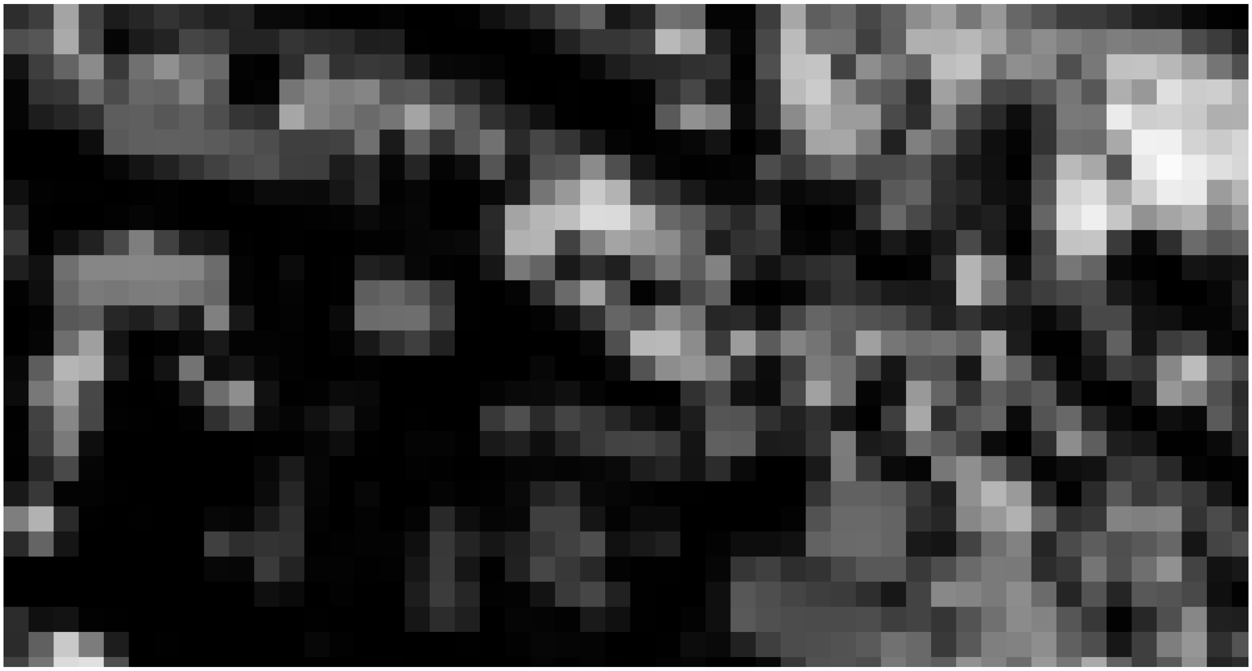


Figure 22: Level Two DSM for Jefferson City Area

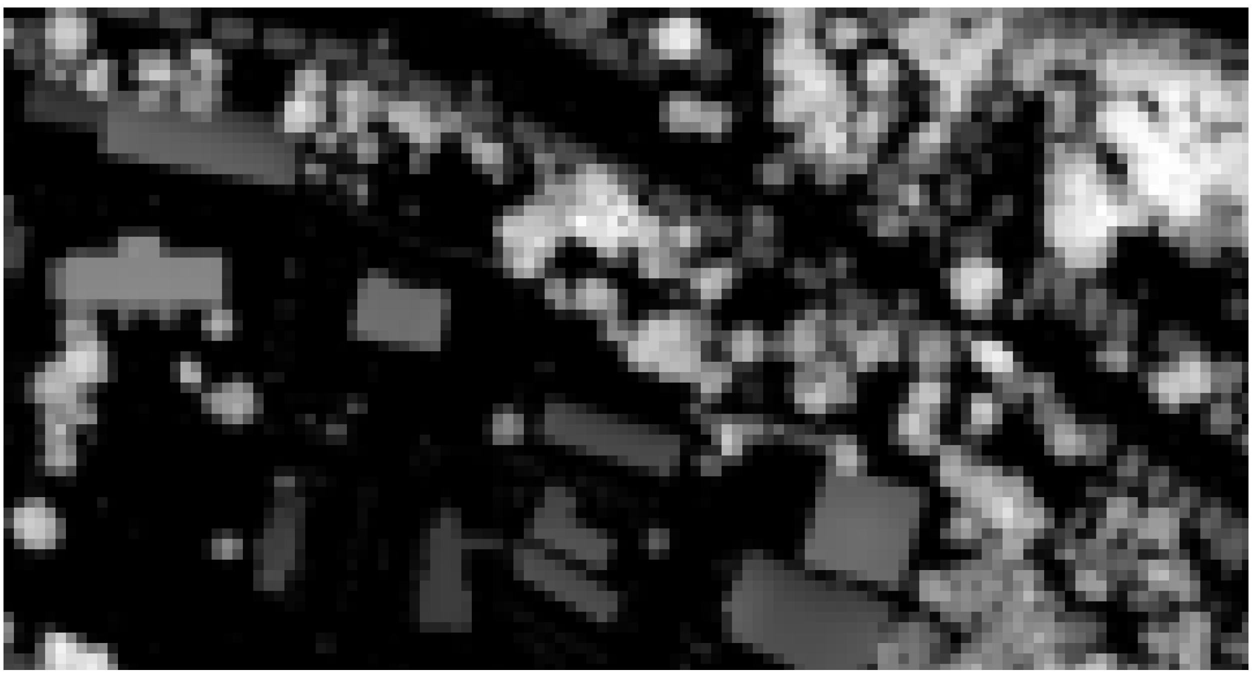


Figure 23: Level Three DSM for Jefferson City Area

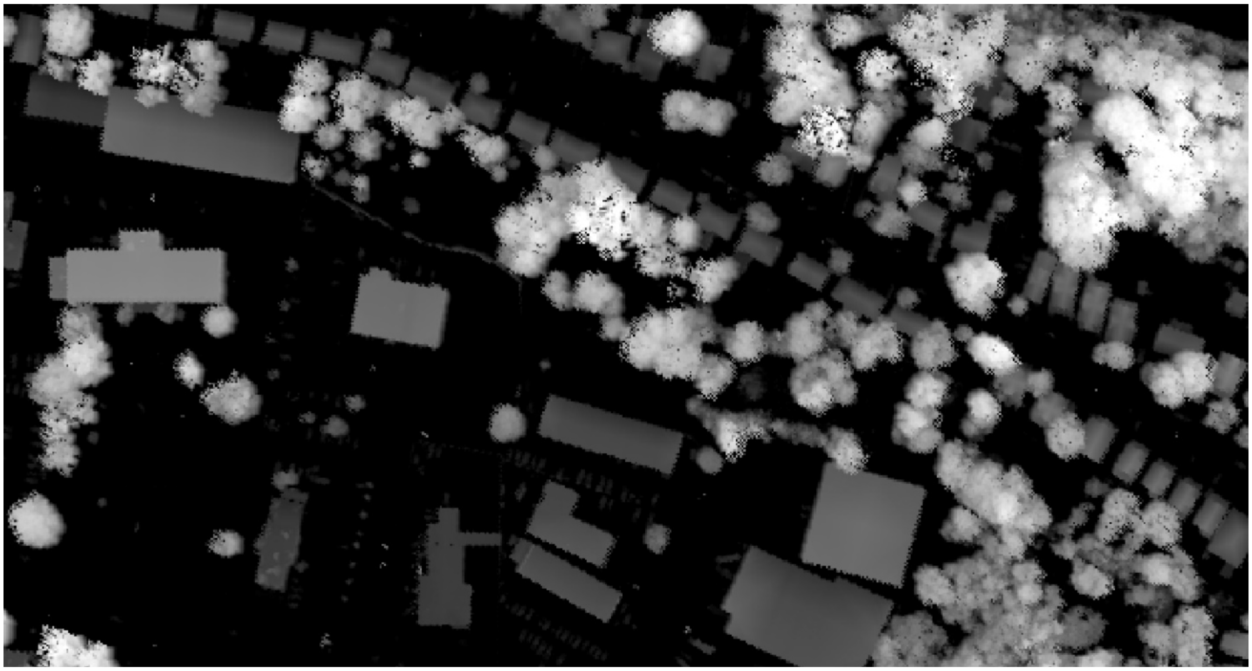


Figure 24: Level Four DSM for Jefferson City Area

3.3.4 Constructing Digital Elevation Models with LiDAR

DEMs are derivable from several sources, but they are usually derived from LiDAR point clouds. LiDAR is a method where lasers are used to measure distances from a laser emitter, which can then map three-dimensional surfaces. Raw LiDAR points contain elevation information of the return, regardless of what surface the LiDAR sensor detected (regardless of whether the detected surface is the ground, a building, vegetation, or even a bird). This is shown in the example below:

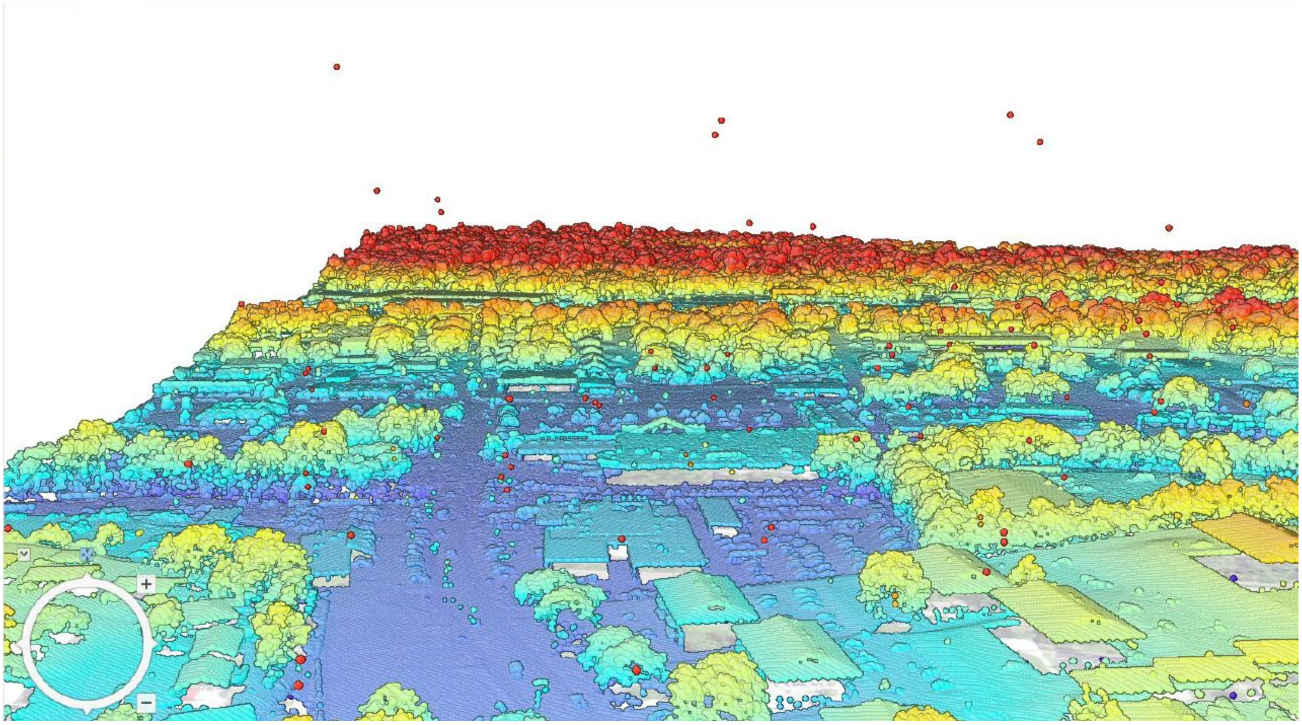


Figure 25: Raw LiDAR for Jefferson City Area (Oblique view)[44]

Post-processing of raw LiDAR data into classes is defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) LASer (LAS) Format Specification [31]. This specification provides codes for each point for classifying the type of feature detected.

Not all implementations classify LiDAR data the same way. Some projects focus on "bare earth" and leave most points with the "unclassified" code. Other projects will use additional codes to categorize points as buildings, vegetation, road surfaces, water, and others. Classification is important as it determines what types of DEMs can be derived most reliably. The following table shows standard point classifications:

Table 6: ASPRS Standard Point Classes (Point Data Record Formats 6-10)

Classification Value	Meaning
0	Created, never classified
1	Unclassified
2	Ground

[44] See Jefferson City Area.

Classification Value	Meaning
3	Low vegetation
4	Medium vegetation
5	High vegetation
6	Building
7	Low point (noise)
8	Reserved
9	Water
10	Rail
11	Road Surface
12	Reserved
13	Wire – Guard (Shield)
14	Wire – Conductor
15	Transmission Tower
16	Wire-Structure Connector
17	Bridge Deck
18	High Noise
19	Overhead Structure
20	Ignored Ground
21	Snow
22	Temporal Exclusion
23-63	Reserved
64-255	User Definable

LiDAR points can be collected at varying densities. As noted in the USGS LiDAR Base Specification [30], the USGS Quality Level 2 (QL2) data collection standard requires no more than 0.7 meters horizontal difference between collected LiDAR points. QL2 data supports 1-meter pixel elevation model products.

The two most common types of DEMs are Digital Terrain Models (DTMs) and Digital Surface Models (DSMs).

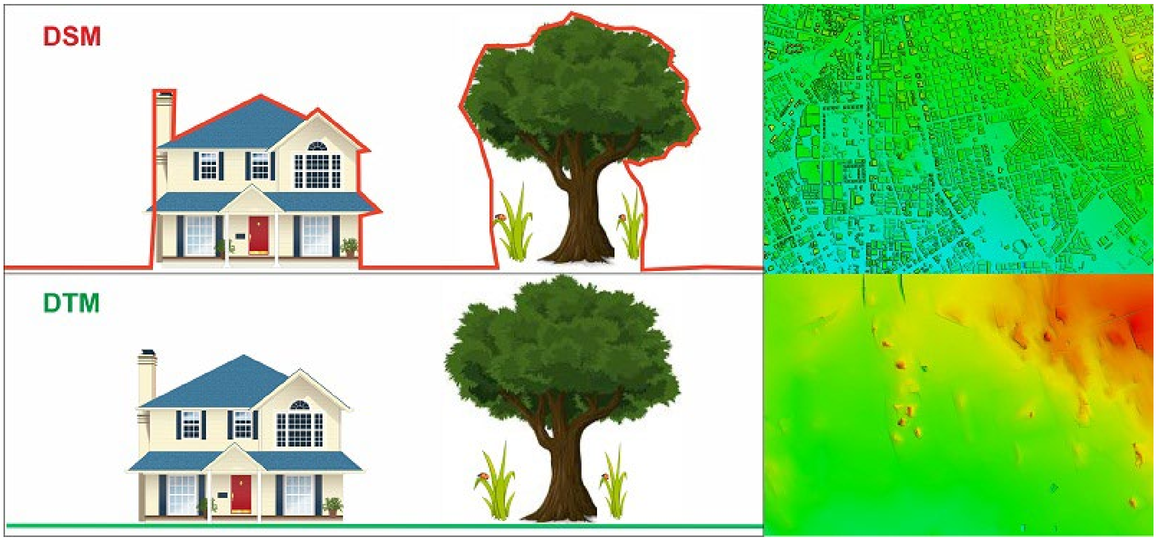


Figure 26: DSM and DTM[45]

3.3.4.1 Digital Terrain Model (DTM)

Digital Terrain Models (DTMs) are raster elevation data that model bare-earth surface. Values in these datasets usually represent ground level and exclude vegetation or buildings. DTMs are useful for 9-1-1 operations as they are widely available and can be used to convert the reported Altitude of the caller to an estimated Height. DTMs provide information for single-story buildings and ground-level information for multi-story buildings. As such, DTMs meet the needs of the Levels-of-Detail One and Two in *Table 5: NENA Digital Elevation Model Level of Detail*.

Hillshade is a method for depicting elevation models by applying a light direction to the elevation model. Terrain differences create shadows, making changes in elevation look like they would in the real world. *Figure 30: DTM for Jefferson City Area with Hillshade modeled in 30 inch pixels* depicts how light position in a hillshade model simulates the angle of sunlight.

[45] Taken from https://www.satpalda.com/blogs/3d-landscape-dsmdtm-service, retrieved December 18, 2020.

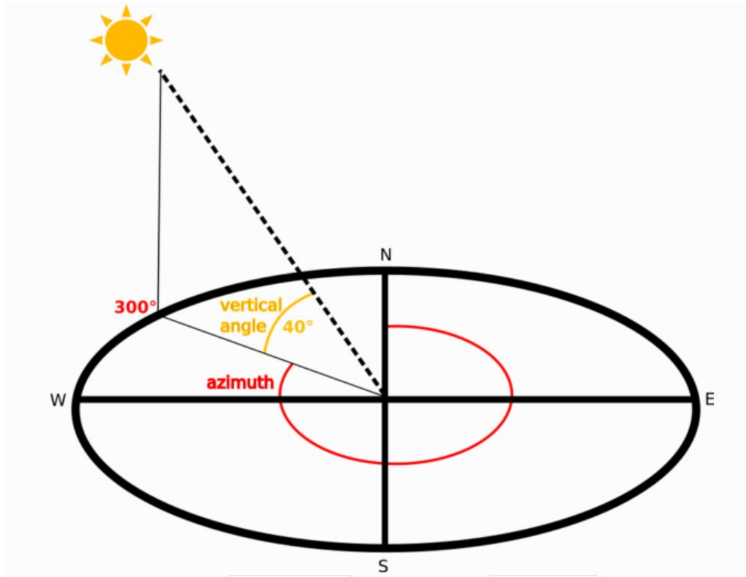


Figure 27: Hillshade[46]

The four figures below depict DTM for the Jefferson City Area. Figures which depict raw DTM data or depict data at too low of a resolution are not human intelligible. For this reason, DTM is often depicted with hillshade at an intelligible resolution. Note that the first two figures below, showing raw data without hillshade, are not intelligible. The second two apply hillshade, but only the third figure is at a sufficient resolution to be intelligible.

[46] Taken from https://docs.qgis.org/3.4/en/docs/training_manual/rasters/terrain_analysis.html, retrieved December 18, 2020.

Figure 28: DTM for Jefferson City Area modeled in 30 inch pixels

Figure 29: DTM for Jefferson City Area from the legacy USGS National Elevation Dataset modeled in 10 meter pixels

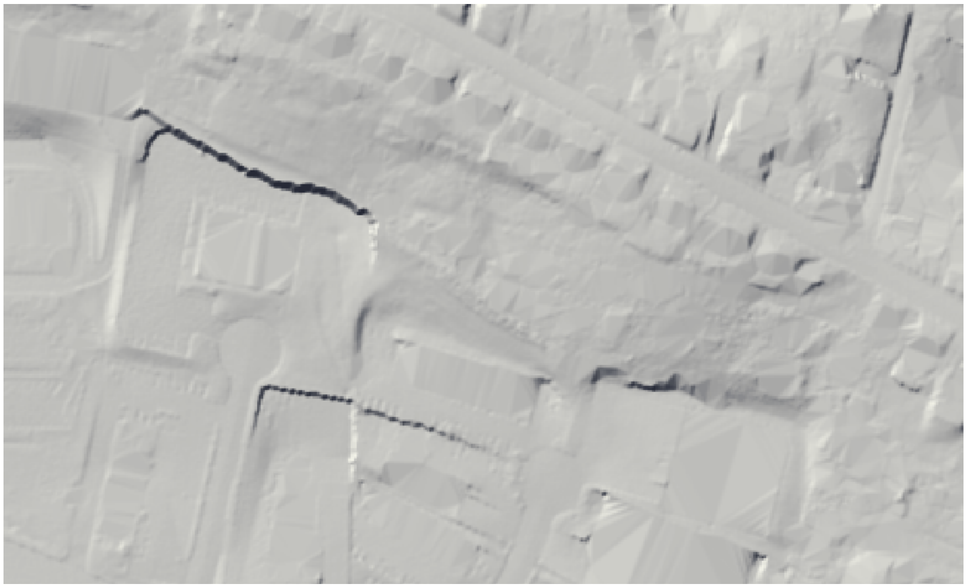


Figure 30: DTM for Jefferson City Area with Hillshade modeled in 30 inch pixels

Figure 31: DTM for Jefferson City Area from the legacy USGS National Elevation Dataset with Hillshade modeled in 10 meters pixels

DTMs can be generated from LiDAR data classified to the USGS LiDAR Base Specification [30]. Most government and commercial elevation services are DTMs. DTMs can also be generated from LiDAR data more fully classified to the ASPRS specification. In cases of the latter, vegetation and buildings are excluded from the process that creates the DTM.

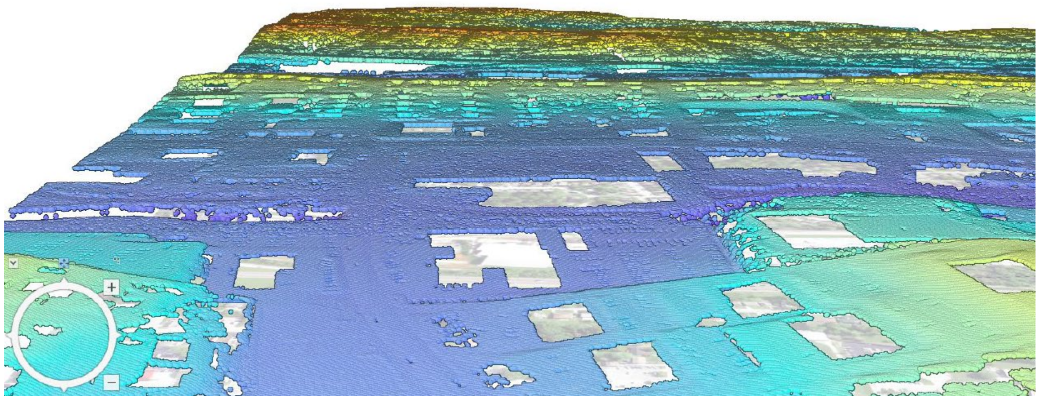


Figure 32: Vegetation and Buildings Excluded from Jefferson City Area to show Only Digital Terrain (oblique view)[47]

Note that when vegetation and building data are removed from LiDAR data to generate DTMs, there will be gaps in coverage where buildings and very dense vegetation are detected. These gaps are often filled based on the surrounding data points. This can present problems in certain cases, such as when a building is built into a hill, if an inappropriate method is used to fill in that gap. This document does not provide specific guidelines on which algorithm should be used to fill gaps.

The figure below shows a typical interface for classifying LiDAR data.

[47] See Jefferson City Area.

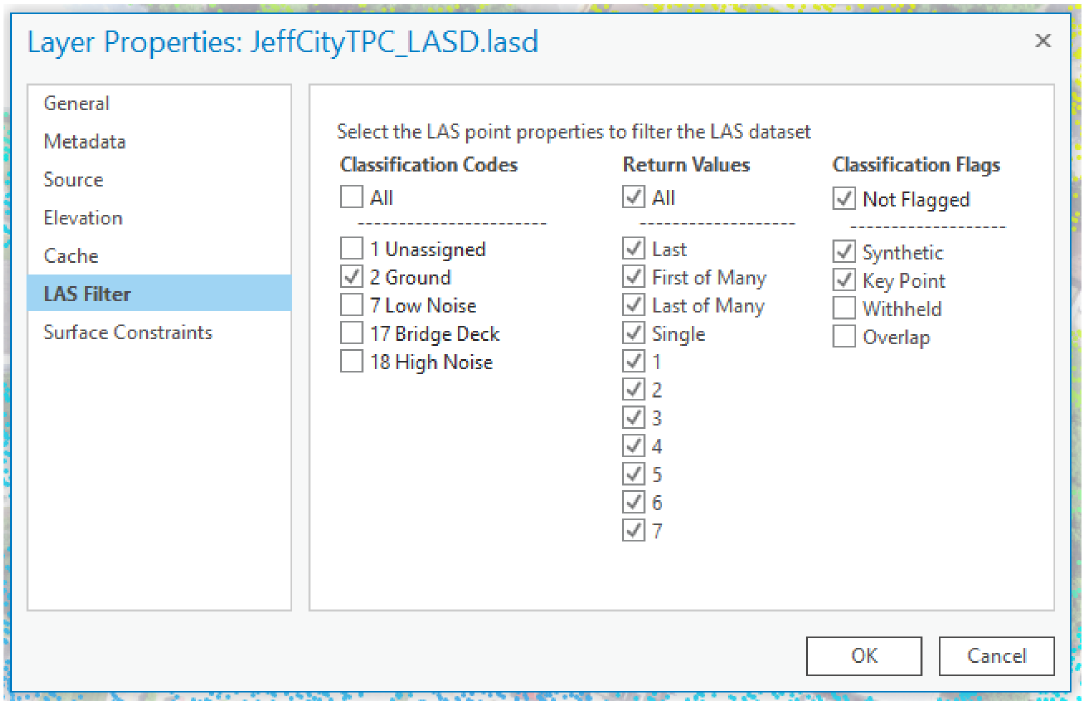


Figure 33: Example Software Interface Filtering Out LiDAR Points Classified as Other than Ground to Construct Digital Terrain[48]

3.3.4.2 Digital Surface Model (DSM)

Digital Surface Models (DSMs) are raster elevation data that model more than the bare-earth and include elements like buildings or vegetation that occur on the surface. While DTMs are important for NG9-1-1, DSMs are also useful for NG9-1-1 because they convey the actual physical dimensions of buildings and other structures in world space. Especially useful information conveyed in a DSM is the building height. As such, DSMs meet the needs of elevation Levels-of-Detail Three and Four in *Table 5: NENA Digital Elevation Model Level of Detail*.

LiDAR data collected at the USGS QL0, QL1, or QL2 level are a useful starting point for creating DSMs. For built environments that:

1. do not have much tree cover, or
2. primarily consist of buildings taller than most trees in the area.

[48] See Jefferson City Area.

DSMs may be created using LiDAR point clouds that exclude points classified as "ground" and first returns. As shown for the larger buildings in the southern part of *Figure 34: Non-ground and non-first return LiDAR points from Jefferson City Area to primarily show buildings and vegetation*. LiDAR points displayed this way are sufficient to determine structure rooftop HAE.

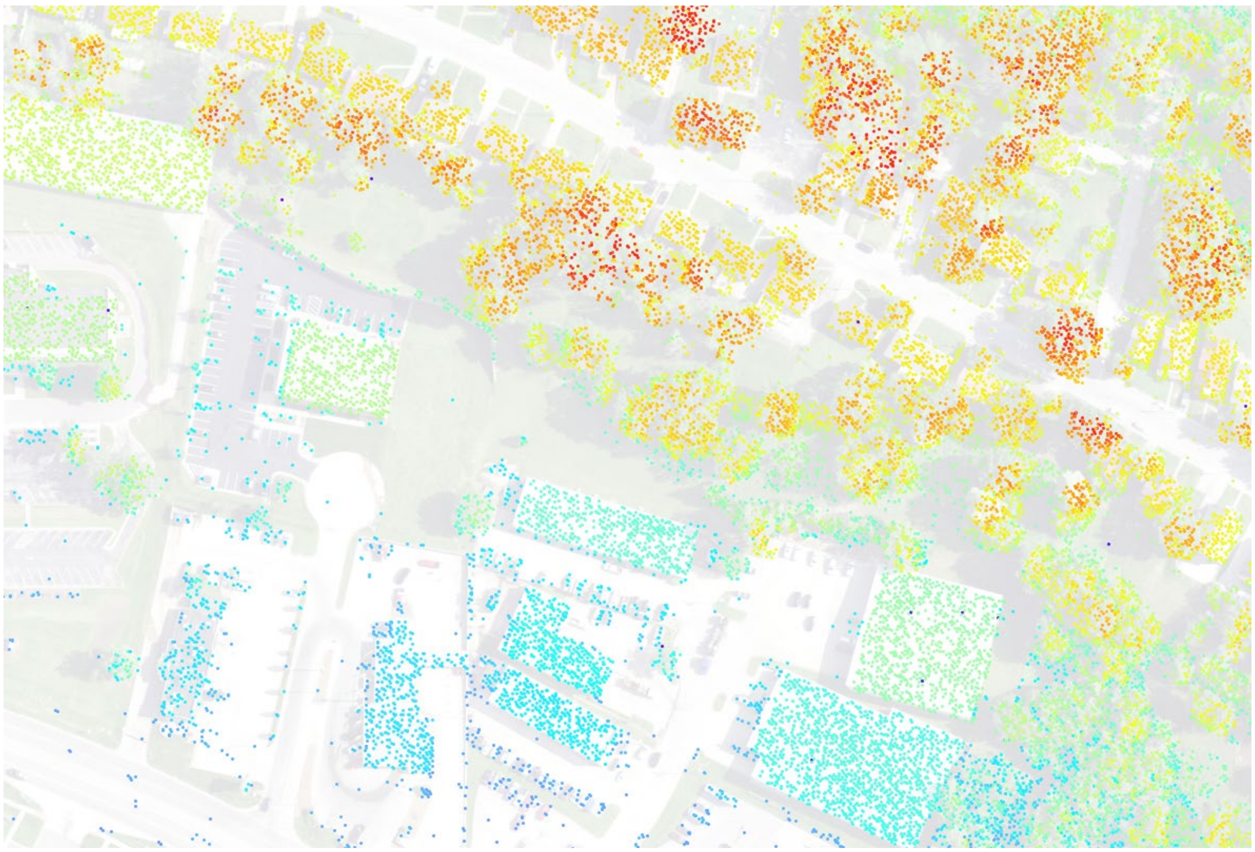


Figure 34: Non-ground and non-first return LiDAR points from Jefferson City Area to primarily show buildings and vegetation[49]

However, the same image demonstrates that this method is not suitable for other buildings in the northern part of the image where trees and branches cover roofs. This makes it difficult to determine Altitude for those points for the structure underneath tree cover. For

[49] See Jefferson City Area.

situations where the buildings are mostly single-story structures, a small pixel DTM may meet the needs as the ground Elevation will likely be the Altitude of entry into the building.

For areas with dense trees over multi-story structures, DSMs are more difficult to create from LiDAR data classified to the USGS LiDAR Base Specification [30] as the USGS specification is based on accurately modeling bare-earth surfaces. In these circumstances, DSMs used for NG9-1-1 SHOULD be generated from LiDAR data more fully classified to the ASPRS specification. In these cases, LiDAR points should use the *building* point classification *(Table 6: ASPRS Standard Point Classes (Point Data Record Formats 6-10))* to create DSMs that only show buildings. These surfaces are ideal for determining the elevation of multi-story buildings and for draping 2D imagery, but may be more expensive to produce.

Most government and commercial elevation services are DTMs and not DSMs because DTMs are generally more utilitarian. Construction of DSMs requires evaluating specific needs and ground conditions to determine if a point cloud classified for DTM production can produce a suitable DSM and the additional scope and cost of more fully classifying the LiDAR point cloud to include buildings and generating additional elevation models if it does not. DSMs and the more fully classified LiDAR point clouds that support them tend to exist in localities that have chosen to develop this data, or in certain emergency management and disaster response scenarios.

The figures below depict DSM for the Jefferson City Area in the original 30 inch pixel resolution product and an alternative resolution. As a result of the small pixel resolution in the first images, objects larger than 30 inches will be represented by more pixels. As such, buildings have more clear definition, roof peaks are distinguishable from edge of roof, and the shapes of vehicles are identifiable. Definition of these clear objects decreases when the pixel size is changed to 10 feet.

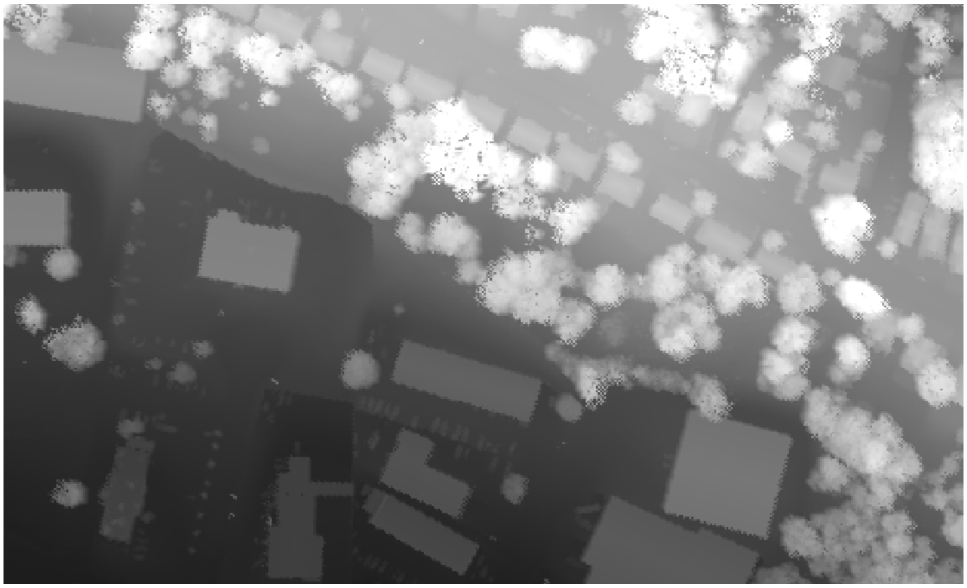


Figure 35: DSM for Jefferson City Area modeled in 30 inch pixels

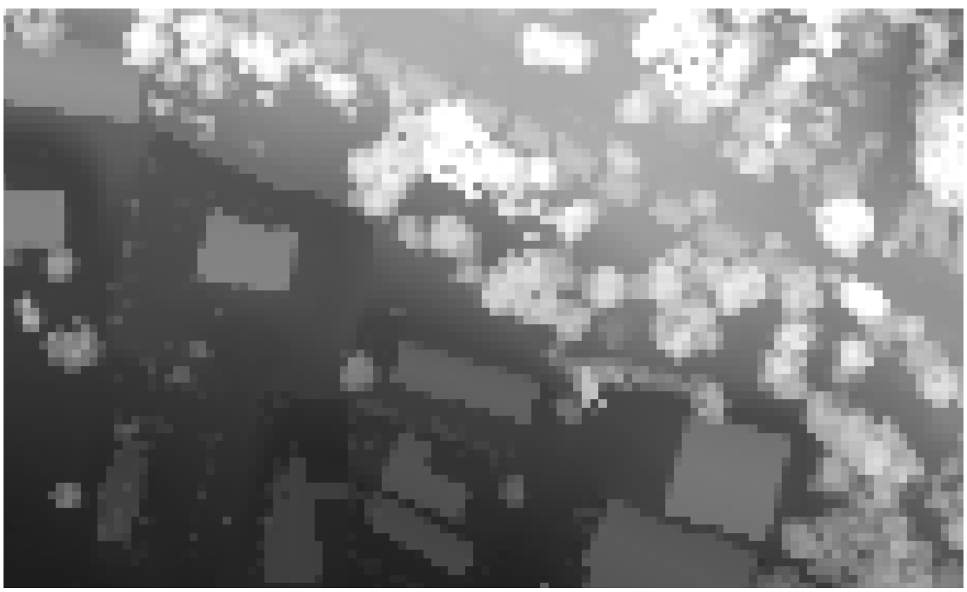


Figure 36: DSM for Jefferson City Area resampled from 30 inch pixels to 10 foot pixels

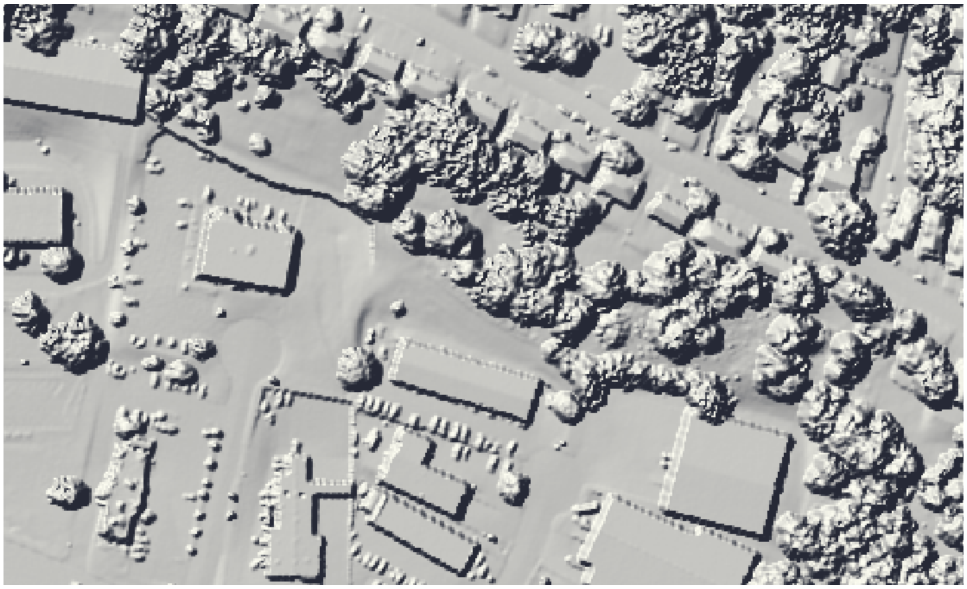


Figure 37: DSM for Jefferson City Area with Hillshade modeled in 30 inch pixels

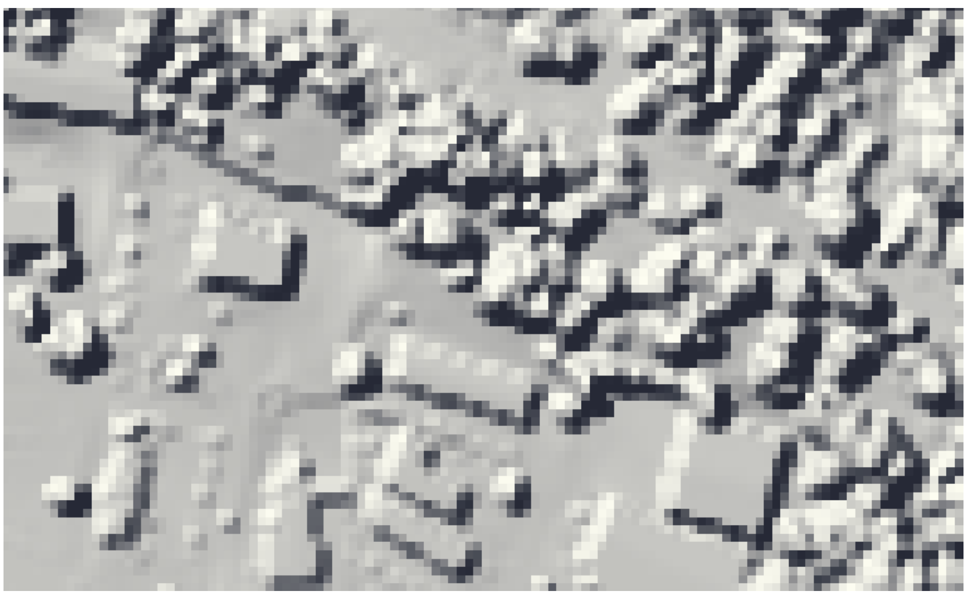


Figure 38: DSM for Jefferson City Area resampled from 30 inch pixels to 10 foot pixels with Hillshade

3.3.5 Sources of Elevation Models

DTMs, DSMs, and the LiDAR used to create them are available from several possible sources. A recommended course of action is to research existing data and determine:

- the best available DTM for your area in terms of year and pixel resolution;
- if the DTM was derived from LiDAR;
- when the DTM was derived from LiDAR, the QL level, the degree of classification, and if the LiDAR point cloud is available;
- if corresponding DSMs are available for all or part of your area.

After identifying existing elevation models, possible LiDAR point clouds, and the desired Level-of-Detail, there are several paths forward, including:

1. Using existing elevation models
2. Using existing LiDAR data and existing point classifications to produce new elevation models
3. Further classifying existing LiDAR point data to produce new elevation models
4. Developing new LiDAR data to produce new elevation models

Entities outside of the 9-1-1 community may have an accurate and precise elevation layer, usually derived from LiDAR. PSAPs and responding agencies should work with local, regional, or state agencies wherever possible to use the most authoritative elevation models in alignment with the desired Level-of-Detail. These models will usually be recent and have the smallest pixel resolution.

3.3.5.1 USGS Reference Terrain Data

The USGS provides publicly-available elevation data via The National Map [28], including 3-Dimension Elevation Program (3DEP) information. The National Map provides DTMs for most of the United States[50] at a minimum of 10m resolution horizontally and 3m vertically with 95% confidence that meet Levels-of-Detail One and Two.[51] The National Map also includes elevation derived from QL2 LiDAR at 1m resolution horizontally with 19.6 cm accuracy at 95% confidence for more limited areas of the United States.[52]

[50] U.S. Geological Survey, "About 3DEP Products & Services," accessed September 19, 2021, https://www.usgs.gov/core-science-systems/ngp/3dep/about-3dep-products-services.

[51] Note that the horizontal accuracy is actually 1/3 arc-second, which is roughly 10m for most of the United States depending on latitude. U.S. Geological Survey, *The National Map Seamless Digital Elevation Model Specifications: Book 11, Collection and Delineation of Spatial Data*, accessed September 19, 2021, https://pubs.usgs.gov/tm/11b9/tm11B9.pdf.

[52] USGS LiDAR Base Specification [30]

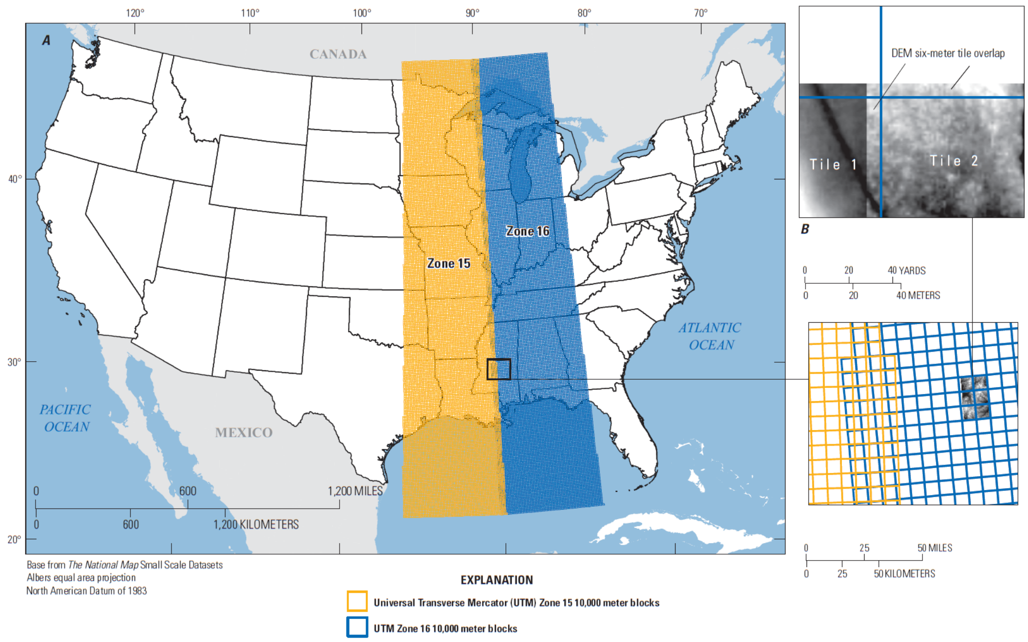


Figure 39: Overlapping DEM Information in USGS High-Accuracy Dataset

Resources at the 3DEP Product Availability Maps page [29] provides information on:

- Best available DTM resolution
- DTM production method
- DTM vintage
- LiDAR point cloud availability
- LiDAR point cloud quality level

While select aspects of the 3DEP data catalog are available by REST service, most are available by ftp for local download.

For the USGS' 1m/19.6cm data, horizontal accuracy is 1 meter divided into overlapping UTM zones and not a fraction of a second.[53] If a jurisdiction is near the edge of a UTM zone or in an overlapping area, implementations SHOULD provision their terrain data accordingly to ensure consistent results.

[53] U.S. Geological Survey, *1-Meter Digital Elevation Model Specifications: Book 11, Collection and Delineation of Spatial Data*, accessed September 19, 2021, https://pubs.usgs.gov/tm/11/b07/tm11-b7.pdf.

3.3.5.2 State and Local-led efforts

There have long been local and state-led efforts to produce more accurate DTM information; for example, over 10 years ago Pennsylvania provisioned statewide elevation data with vertical accuracy ranging from 20 to 60 cm statewide with 95% in cells approximately 1.5 meters wide; a locality may have executed a similar project, and if so, it SHOULD be used for 9-1-1 systems in that jurisdiction. Integrators SHOULD use terrain data with higher accuracy than the 10m horizontal/3m baseline provided by USGS' least precise layer, but MUST use terrain data at least as good as that.

States and large, mature local agency organizations may have large, centrally-managed GIS departments, who often provide services for agencies throughout their jurisdiction or multiple local jurisdictions from a central data set. These organizations have professional GIS experts that maintain an authoritative reference for GIS data. While these organizations may have DTMs similar to the state projects discussed above, they are also the most likely sources for DSM models, finely classified LiDAR point clouds, and the smallest pixel models. While the driving factors for these projects may originally be infrastructure modeling, stormwater analysis, or tree canopy analysis, the source LiDAR data or derived elevation models may also meet or serve as a point of departure for NG9-1-1 needs.

3.3.5.3 Commercial Elevation Services

There are several elevation sources available commercially that can enable the NG9-1-1 location workflow. One approach is through cloud services where commercial mapping services provide the elevation at a given point, usually via a REST API. Commercial sources may also support elevation information for points, lines or polygons. Specific recommendations for procuring commercial services are out of scope for this document.

3.3.5.4 Community-Driven Elevation Datasets

There are freely available, community-driven datasets ("crowdsourced") built by communities of volunteers that may aggregate government and other information. Dynamic, community-driven data SHOULD NOT be used during live 9-1-1 operations. However, it MAY provide a useful baseline for provisioning GIS data for 9-1-1, including elevation.

3.3.6 Location Datum Transformation Challenges

Note that not all mapping data uses the same reference frame; while WGS-84 is the standard for interfaces used in many systems including NG9-1-1, datasets maintained by the US government use the North American Datum (NAD), which is a different reference frame. Implementations MUST make conversions as necessary. While this document places no requirement on which datum should be used for locally provisioned data, note that most interfaces in internet and NG9-1-1 standards mandate that interactions between systems SHALL use WGS84.

A small amount of precision is lost when transforming between different datums; this should be minimal for a single conversion; for example, horizontal accuracy is typically impacted by 1 meter or less when converting from NAD83 to WGS84.[54] However, multiple transformations between WGS84 and a local reference such as NAD can compound errors. For example, only six conversions between WGS84 and NAD27 and NAD83, which also included conversion from arc seconds to decimal degrees, using commercially available GIS software for an arbitrary location in Seattle, Washington resulted in an error of about 200 meters. This is an extreme example, and in reality, a single transformation will have errors usually measured in centimeters. However, this demonstrates that errors of this kind can occur when location information is excessively transformed between different formats and reference frames and the original location is discarded.

This could happen, for example, if multiple parties make transformations to a location in a call flow and follow different or inconsistent conventions for their GIS systems. Accordingly, if such transformations are made, implementations MUST always maintain and convey a copy of the original location information, if available, and SHOULD NOT make transformations that are not necessary. Generally, transformations SHOULD only be used for internal processes and the results SHOULD NOT be passed to a downstream entity.

[54] See, e.g., Esri, "How To: Determine which NAD_1983_To_WGS_1984 Transformation to Use," accessed September 19, 2021, https://support.esri.com/en/technical-article/000005929.

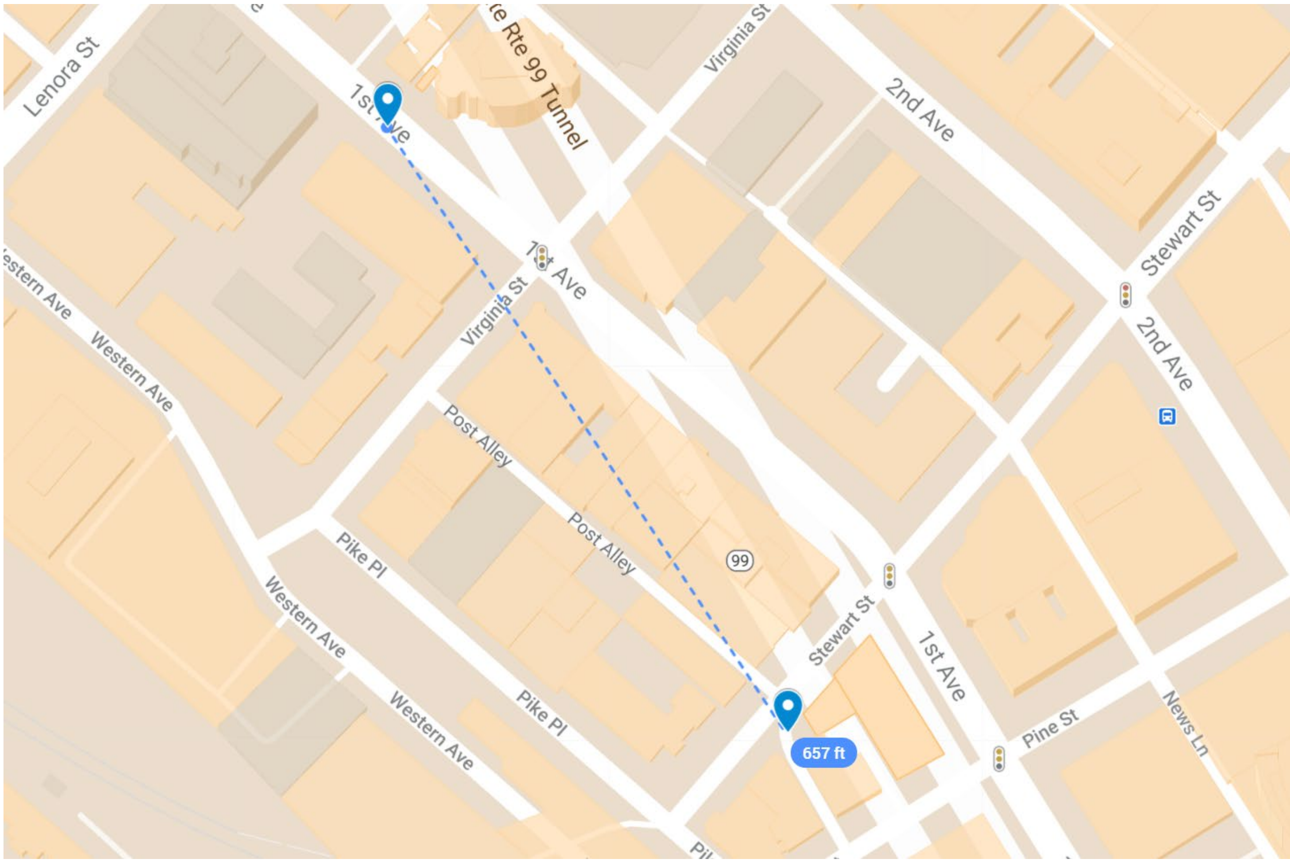


Figure 40: Visualization of Error from Inconsistent and Excessive Transformations

```
1,47.6083840,-122.3402550,LL WGS84(G1674),-2558592.51,6161284.31,UTM17N  NAD83(2011)
2,-2558592.51,6161284.31,UTM17N  NAD27,47 36 35.583, -122 20 30.202,LL WGS84
3,47.6098842,-122.3417228,LL WGS84(G1674),-2558594.20,6161507.62,UTM17N  NAD83(2011
4,-2558594.20,6161507.62,UTM17N  NAD27,47 36 40.983, -122 20 35.486,LL WGS84
5,47.6113842,-122.3431906,LL WGS84,-2558594.20,6161507.61,UTM17N  NAD27
6,-2558594.20,6161507.61,UTM17N  NAD27,47 36 40.983, -122 20 35.486,LL WGS84
```

Figure 41: Log from Conversion of Points

3.4 Implementing Dispatchable Location Methods

This section contains information on implementing Dispatchable Location methods. Several subsections provide information on conveying and operationalizing floor height information. Additionally, this section provides for a novel method to deliver method and quality of method information using Method Tokens.

3.4.1 Distinguishing Between Estimated Floor Level and Fully-Formed Dispatchable Location

A floor level is not a fully-formed Dispatchable Location per the conventions in this document; a fully-formed Dispatchable Location should include specific subaddress information, where it exists and/or where it is applicable, such as an apartment number or office suite in addition to the floor level. For certain structure types, there will typically not be any subaddress information provisioned or available, such as for each story or room in a single-family home. This may be true even in a multi-floor residence where floor would be relevant. Knowing this call is on the 3rd floor of a home is potentially very valuable, but there is quite likely no subaddress information assigned to or provisioned with different portions of such a structure.

An estimated floor level may satisfy regulatory requirements to meet wireless carrier obligations to convey a Dispatchable Location.[55] Wireless carriers and 9-1-1 Authorities are clear when setting local policies or procedures for handling dispatchable location. Such policies and procedures should clarify if the conveyed location information is a fully-formed Dispatchable Location *or* a Dispatchable Location that meets minimum regulatory requirements, which may be as limited as a floor level. As a general matter, locations conveyed with a legacy class of service of WDL2 and VMBL are expected to be fully-formed. See discussion of the legacy classes of service of WDL2, WDL1, and VMBL used

[55] See, e.g., "Dispatchable location includes additional elements such as floor level and room number that may be necessary to locate the caller." Accessed December 18, 2020, paragraph 45, from https://docs.fcc.gov/public/attachments/FCC-18-132A1.pdf. This document does not provide any legal advice.

with mobile and/or wireless services as discussed in Section 2.2.2 *Dispatchable Location* of this document.

3.4.2 Estimating a Floor Level

The following subsections provide information, requirements, and recommendations for estimating a floor level.

3.4.2.1 Estimating Floor Level with Location Services

Various technologies are capable of estimating the floor level of a caller, which can then convey that floor level to the 9-1-1 system with the 9-1-1 call. Examples include technologies that may be available through location services[56] or through third-party systems that can be integrated into the 9-1-1 calling technology or may be used by native location services on the device.[57] This document declines to recommend or comment on any specific methods or implementation, however, other than to acknowledge their technical feasibility.

The conveyance of an estimated floor level MUST include confidence and uncertainty and MUST follow standards for conveying a floor level when such standards are available. See Section 3.4.3

Conveying Estimated Floor Level.

Operationally, there may be little difference to the telecommunicator when a floor level is determined via location services as opposed to other methods such as a validated registered civic address, provided that the location conveyed is accurate; the floor level is conveyed with uncertainty and may be handled similarly operationally.

3.4.2.2 Floor Levels Assigned to Geography

Floor information can be pre-provisioned for arbitrary altitude ranges within a general geographic area instead of constructing 3D shapes for each specific structure with specific subaddress information. This method is feasible when the overall elevation as well as the altitude of each floor for a group of structures is highly uniform, such as housing developments or office parks.

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[56] See, e.g., previous proposals from Google for Emergency Location Services, https://ecfsapi.fcc.gov/file/1109433015344/ATTACHMENT%20--%20ELS%20PRESENTATION.pdf. This citation is illustrative only and does not constitute endorsement of any product or service.

[57] See, e.g., https://nextnav.com/pinnacle/. This citation is illustrative only and does not constitute endorsement of any product or service.

3.4.2.3 Finding Floor Levels with Site/Structure Points

The NG9-1-1 GIS Data Model [2] includes Site/Structure points that can be provisioned in 3D; these points should include subaddress information including Floor and should be oriented correctly in 3D space relative to the structure.[58] It is therefore feasible that a received Geodetic Location may estimate associated floor levels (and fully formed civic addresses) through resolving Site/Structure points contained within its uncertainty radius.

This method may not be more practical or effective than using 3D Room shapes. If there is suitable information available to correctly orient Site/Structure points in world space, there is also probably suitable information available to provision 3D Room shapes, and 3D Room shapes will resolve location queries more accurately. However, querying Site/Structure points with a geodetic uncertainty is a feasible method to determine estimated civic address information including subaddress elements like Floors. The telecommunicator may have no knowledge that this method was used as they will be presented with Civic Address information that includes estimated Floor(s).

For further information regarding visualization of Site/Structure points see Section 3.6.2 *Site/Structure Address Points*.

3.4.2.4 Using 3D GIS Information to Estimate a Floor Level

Later sections of this document provide more detailed information on how to provision 3D building and Room shapes in GIS data to meet the requirements in this document including estimating Floors. Ranging in effort and precision from low to high, see Section 3.6.1, *3D Via Procedural Generation* and Section 3.6.3.2 *Recommended Workflow New Construction: Importing 3D Room Shapes from Building Information Models*.

3.4.3 Conveying Estimated Floor Level

Standards work MUST include two values to describe a floor in order to accommodate for calculating and conveying uncertainty. The first value, *floor,* is the floor label. The second value, *floorInt,* is an integer that indicates where a floor is located vertically relative to the floors above and below it. Every system that contains civic addresses SHOULD provision *floor* and *floorInt* for each story for a structure.

floor is the floor label, which is human-intelligible and should match signage at that location. It is a string such as "Mezzanine" or "Floor 6" As described in Section 4.48 in the NG9-1-1 GIS Data Model [2].

[58] Note, "Elevation" as used in the NG9-1-1 GIS Data Model is height above the WGS84 ellipsoid, which is "Altitude" as defined in this document.

floorInt is the floor's cardinal number relative to other floors. *floorInt* is set at 0 at the main entrance[59] to the building, which is usually at ground level. It is an integer such as "0," "-2," or "5."

Below is a list of examples of *floor* and *floorInt*:

floor: Parking B2, floorInt: -2
floor: Parking B1, floorInt: -1
floor: Lobby, floorInt: 0
floor: Mezzanine, floorInt: 1
floor: Floor 1, floorInt: 2
floor: Floor 2,floorInt: 3

[59] The "main entrance" to any structure may be subjective and is impossible to standardize universally. Local implementations have to determine what constitutes the "main entrance" for a given structure.

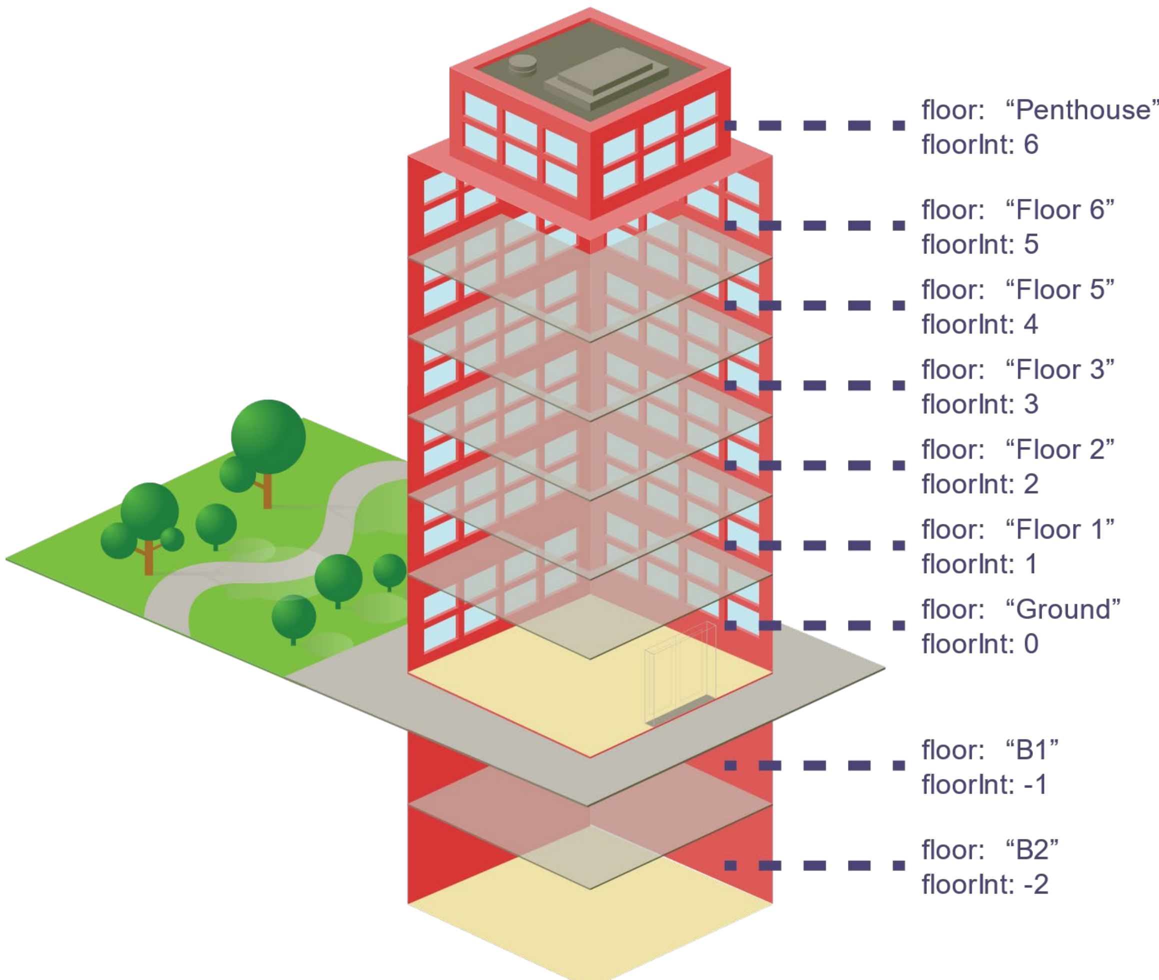

Figure 42: Illustration Depicting floor and floorInt for a Structure

Every multistory structure will have its own conventions for floor labels; the ground floor may be labeled "Lobby," "F1," "Floor 1," etc. The example above shows only one possible set of labels. *floor* is the value that will normally be conveyed to human beings such as to a telecommunicator or responder; *floorInt* is a value used when calculating uncertainty, and outside of diagnostic purposes, it is not normally intended to be viewed by an end-user. Field resources will normally be directed to a place with a name or label they can understand, such as 800 NENA Blvd, Mezzanine Level.

When conveying uncertainty, the center point of a range is not considered to be any more likely to be the actual location than any other point within it. This is true with geodetic locations and should also be true in standards action taken to convey uncertainty in civic or dispatchable locations. See Section 4.2.1 *Confidence and Uncertainty with Civic Location* for future actions for standardization.

The NG9-1-1 GIS system for a given set of 3D structure shapes and/or address points SHOULD provision both *floor* and *floorInt*. When both values are provisioned, the GIS system MUST be able to translate between *floor* into *floorInt* and vice-versa. The GIS system MUST also be able to resolve any location query that includes Altitude ("z axis") by responding with *floor* and MAY also respond with *floorInt*.

Two example payloads in JavaScript Object Notation (JSON) are shown below for a caller who is estimated to be on floor 6, +/- one floor. This is in a building with three basement levels, so floor "B3" has a floorInt of -3, and floor "Floor 6" has a floorInt of 6. These two formats represent two different options for consideration in future standards development. The first example shows a payload that lists all possible floors in an array of JSON objects, where the key is *floor* and the value is *floorInt*, and the second example shows a payload that lists the estimated floor as nested JSON objects *floor* that contains a string, *floorInt* which contains an integer, and *uncertainty* which conveys the floors above or below ("1" means "+/- 1 floor"). See – *Sample JSON Schemas for Floors* for schemas for these examples.

3.4.3.1 Sample Floor Level JSON, First Example

```
{
  "floors": [
    {
      "floor": "Floor 5",
      "floorInt": 5
    },
{
      "floor": "Floor 6",
      "floorInt": 6
    },
{
      "floor": "Floor 7",
      "floorInt”: 7
    }
  ]
}
```

3.4.3.2 Sample Floor Level JSON, Second Example

```
{
  “floor”: “Floor 6”,
  “floorInt”: 6,
  “uncertainty”: 1
}
```

3.4.4 Floor Height Estimation

Estimating the floor that a 9-1-1 caller is on provides actionable context to the telecommunicator and field responders, and is indeed a stated long-term objective of the FCC for vertical location requirements for 9-1-1.[60] As noted in this document, Altitude is not useful information on its own. Height is more useful than altitude, as it allows one to determine whether a location is reasonably likely to be located on the ground or a given distance above it, but probably not which specific floor that location rests on. Obviously, knowing the floor or possible floors a caller is likely to be on is useful information for responding to an emergency call. The following subsections provide some guidance on estimating a floor level associated with a 9-1-1 call.

3.5 GIS Requirements for Vertical Structure Modeling/Representation

Technological advances in GIS data generation and representation in 9-1-1 applications and systems now offer NCGS systems and PSAPs new opportunities to better visualize and utilize three-dimensional environments for enhanced situational awareness and response. However, provisioning and operationalizing 3D information for use in incident response comes with some challenges, both in data generation and in use interpretation.

3.5.1 3D Data Needs and Planning Considerations

For data preparation and integration, a new GIS creator should:

1. Consider that 2D map displays rely on nearby geography for viewer orientation and distance context during an emergency call. While the same consideration may be applied to a 3D perspective, a 3D map contains the same features as a 2D map, it also contains much more information as it adds a vertical dimension. For example, a 2D map, or top-down perspective, may contain roads, building footprints, local features, contours, and aerial imagery as a backdrop for the viewer to properly orient themselves with the local geography during a 9-1-1 call. A 3D oriented display, be it a static oblique (side view at an angle) view or a dynamic user manipulated view orientation from any angle, additionally requires that vertical also be considered for proximity relativeness of features (e.g., other nearby floors or rooms/elevators) to a location within a building.
2. Identify all data, and subsequent details, that are needed in the 3D attributed data

[60] FCC, Fifth Report and Order [4] at paragraph 35: "[. . .] we [the FCC] agree with public safety commenters that providing a floor level is the ultimate goal and therefore seek comment below on the feasibility of requiring CMRS providers to deliver floor level information in the longer term."

(e.g., for ECRF or map display) to provide orientation to the end-user.

3. Identify NGCS systems and the 3D supporting applications planned for implementation that are able to leverage this new 3D attributed data in a way that helps users of the information without confusing them.
4. Identify what 3D data attribution is needed for cross application data propagation and use; not all applications can make use of the same level of detail of data as every other application, and this may not be an impediment in all cases.

This document provides some practical guidance on how to fulfill these needs in later sections.

3.5.2 Basic 3D Building Representation – Extruded Structure Polygons

Extrusion of a building footprint can be used to create a basic 3D model of that building. Note that accurate and correctly georeferenced building footprints are not always available, and when not available, the following process cannot work. With extrusion, the footprint is used to 'extrude' a vertical shape to known or captured height (ex. 70m. to the top of the building). Extrusion is a process whereby a 2D feature is used to generate a 3D object when actual 3D features are not available. This process can be applied to points, lines, and polygons. Extrusion can be used to reflect positive values such as elevation of a feature or building as well as negative values for subsurface depths (underground). To generate positive or negative extrusion for a geometry feature an elevation base or surface must be anchored to establish the feature's base height. Extrusion can then be applied from the known base or surface location to generate a 3D representation of that feature. The feature itself in its most basic form is typically rendered as a single color, though each individual building polygon can be assigned a different color in order to aid the viewer in quick identification between buildings.

Factors to consider in rendering basic extruded building polygons for 3D buildings include but are not limited to:

Footprint - the dimensions of the building footprint

Base height - elevation of the building footprint

Building height - height of exterior building structure

Level spacing - one or more vertical distances between internal floors

Figure 43: Extruded Building Footprints[61]

3.5.3 Image Draping for Building Exteriors and Advanced 3D Wireframe Diagrams

Image Draping is the technique by which a raster image, typically an oblique aerial photo, can be placed over a DEM, which can include an extruded building, resulting in the image view of the sides of a building or structure being stretched along its length. This technique provides the viewer of a building so processed with an impression of 360 degree imagery coverage for the buildings or structures that the imagery has been draped on. Following this process, buildings can look as though they were photographed from the sides with the imagery draped over them showing windows and other entry points.

[61] Taken from https://developers.arcgis.com/javascript/latest/sample-code/visualization-buildings-3d/

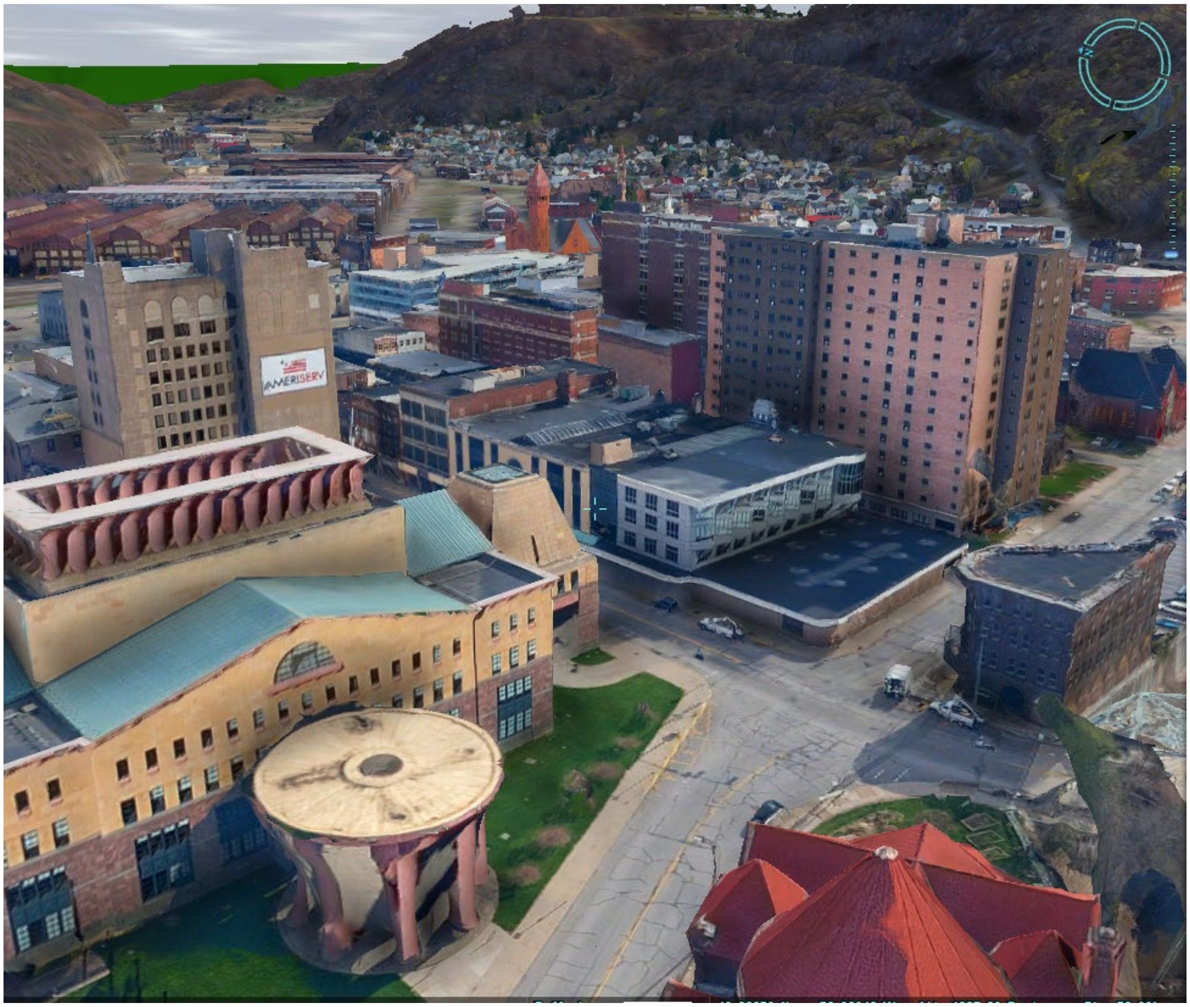

Figure 44: Image Draping on Machine-Learning Built 3D Building Models

Wireframe diagrams are a more advanced way of creating a building extent for draping imagery over, if that step is needed, and can more accurately reflect the variations in floor perimeters common in modern architectural designs. Wireframe diagrams consequently require more data to construct, sophisticated generation and rendering routines, and additional user expertise to create. However, they can provide a much more accurate view of buildings in a 3D display system.

For more information on these techniques see Section 3.6.1 *3D Via Procedural Generation*.

3.5.4 Internal Structure Rendering for Buildings

The next advancement on building an exterior rendering of buildings is to construct 'internal' representations of floors and room layouts so that a geodetic location can be resolved to a Civic Address, with subaddress elements including a floor level with a known confidence and uncertainty. There are a couple of general approaches to consider before embarking on what would likely be an even more complicated and expensive building data development plan:

- Basic – One way to start with internal building structures is to acquire or create a floorplan for each floor in a building, and depending on the software used, assign it an elevation/height within that building relative to the building's footprint/base level. Each floorplan could then be assigned floor information in addition to its vertical orientation in 3D space, which in turn can then be related to a civic address with subaddress elements.
- Advanced – In this approach each room within a building can be represented by a three-dimensional shape constrained by specific X/Y/Z values for at least six faces of it (for example a square or rectangular room has six faces). This approach requires a significant amount of data to be collected, collated, and converted into three-dimensional shapes representing rooms. It also requires significant investment in resources to both acquire and manage.

For more information on these techniques see Section 3.6.1 *3D Via Procedural Generation* and Section 3.6.3 *Bespoke Detailed Models and Building Information Models (BIMs)*.

3.6 Provisioning 3D GIS Information for 9-1-1

3.6.1 3D Via Procedural Generation

For unguided generation, footprints can be extruded from the surface with assumptions on floor height and starting floor elevation. This approach is low effort but may not yield sufficient accuracy. For a guided generation, floor heights can be determined from building-specific information. Manual or machine-learning guided imagery analysis can derive heights of floor delineations with external features such as windows. Floor height estimation processes should also utilize information gathered from inspections and/or occupants. This approach requires more effort and improves accuracy. See the following sections for more detail.

3.6.1.1 Extruding Building Footprints into 3D Shapes

Building footprints can be extruded into 3D shapes when a limited amount of additional information is available, such as building height and number of floors and subfloors. This is a transitional method; it is relatively easy to produce rudimentary building shapes through this method and while it may enhance situational awareness, it is unlikely to determine the exact floor level. However, it may be helpful in identifying a floor range.

This section provides an overview of some available methods; note that there are community driven/freely available references, some produced with AI.

When extruded into shapes (often prisms), footprints SHOULD be divided into horizontal slices (floors) and larger structures SHOULD be divided into quadrants (e.g., NE, NW, SE, SW) as noted in ATIS-0700028 [10].

Building footprints SHOULD be co-planar (or "flat"), meaning all vertices (or each "corner" of a shape) have the same Altitude. In some cases, the actual real-world footprint of a building is not co-planar. If the footprint is not co-planar in the GIS system, extrusions may produce unwanted results.

The coordinates of the centroid of the footprint polygon SHOULD be co-planar with the local reference frame at that point, so that the extrusion is orthogonal to the reference frame. The footprint is likely to be the ground floor. Note that when footprints are procedurally generated from imagery, the footprints may not necessarily correspond to the exact layout of the ground floor; they will represent what is observed from overhead.

Sample Building Footprints Generated from Imagery[62]

Split-level structures may have multiple "ground" floors. In these cases, multiple footprints SHOULD be used, if they can be determined. Imagery will not always depict multiple ground floors, so procedurally generated building footprints will not be aware of them.

[62] Taken from https://www.microsoft.com/en-us/maps/building-footprints, retrieved May 18, 2021.

Vector objects usually have an anchor point.[63] When constructing building footprints and/or 3D building shapes, the base of the building must have its anchor point defined. This anchor point may be determined arbitrarily, such as by a value entered during provisioning, or it may be determined procedurally. Implementations should assign anchor points according to a consistent methodology, especially when generating building shapes procedurally.

3.6.1.2 Importing 2D Floor Plans

For existing buildings, implementations may have available 2D floor plans, and may or may not have height information associated with those floor plans. Prevailing GIS software may have tools that allow the user to import and georeference floor plans, which may then be used to construct room shapes for GIS data. If height information is not available for 2D floor plans, it must be constructed. This process is labor intensive, and may require referencing LiDAR, oblique imagery, commercial 3D building data and/or site visits. It is possible to automate some or all of this work with advanced tools such as machine learning and AI. Specific methods are outside of the scope of this document.

3.6.1.3 Source Image Accuracy

To generate and extrude footprints for building shapes, an implementer will in most cases use aerial or satellite imagery. As of this writing in 2021, such imagery is widely available, often at no cost (but potentially with license or use terms that may constrain usage). This imagery may not align with the local reference frame (see Section 2.3). Implementers MUST verify, and if required, properly align the projection of any imagery with the local reference frame. Implementations SHOULD also use the highest accuracy and most recent imagery available; imagery should be available in most cases at 1 meter or better through freely-available datasets.[64]

To account for potential errors, when using methods described here, implementers MUST first ensure that any images used align with known GIS elements. Conversely, if satellite or aerial imagery cannot be made to line up with known GIS elements, implementers SHOULD verify that their known GIS elements are correct.

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[63] See, e.g., Esri, "Moving Anchor Points," accessed September 19, 2021, https://desktop.arcgis.com/en/arcmap/latest/extensions/aviation-charting/moving-anchor-points.htm.

[64] See, e.g., *What are the Technical Specifications for Google Imagery?* Accessed November 5, 2020 at https://support.google.com/mapsdata/answer/6261838?hl=en which specifies a target of 1m or better resolution. This citation is illustrative only and does not constitute endorsement of any product or service.

Imagery SHOULD be maintained and updated to represent significant changes in local geography and ground features. This includes new construction, changes in vegetation, and changes in topography. Local implementations SHOULD set requirements for aerial imagery used for operations, including the maximum age of imagery, minimum resolution, etc. As a consequence of natural disasters, such as tornadoes, hurricanes, lava flows or earthquakes, these changes may be accelerated.

3.6.2 Site/Structure Address Points

Site/Structure Address Points[65] in NG9-1-1 have historically been treated in two dimensions: a point with an X/Y coordinate for an address or subaddress location associated with a civic address. However, address points include a z-axis value—altitude—which can be used to resolve queries using 3D locations.

An Altitude measurement is included in the NG9-1-1 GIS Data Model [2] in the site/structure address point layer under "elevation." This has particularly important ramifications in large, multistory buildings such as high-rise apartments. A GIS database that maintains an address point with the correct subaddress elements and coordinates (including altitude) can assist in resolving queries for a 3D location. Implementations may provision address points according to local conventions that differ across jurisdictions; for example, implementations may provision address points at the entrance to a structure or suite, at its center, at a road or street access point, at a front desk/reception area or a different method. All Site/Structure points should be correctly oriented in 3D space, including with the correct altitude. Additionally, where appropriate Site/Structure address points should have the correct information to identify the floor level.

Determination of accurate Altitude values for address points may be automated by using a limited amount of information known about the building. Most multistory buildings maintain a uniform layout past the first or second story. For example, consider an apartment building that has:

- a ground floor of 12.9 m in height at 20m Elevation
- a "mezzanine" floor of 8.6 m in height
- 20 floors of residences all with a standard height 4.3 m

In this case a script could provide reasonably accurate Altitude values. Once this information is provisioned, the GIS system could return one or more address points that

[65] This is a preliminary name. This document defers to a future version of the NENA NG9-1-1 GIS Data Model [2].

are captured within and/or immediately adjacent to the caller's location in 3D. For a given area, an information-gathering project could provide the NG9-1-1 GIS operator with enough information about overall building and individual story heights to provision Altitude values for existing 2D address points. Altitude values that are provisioned with an automated method such as this SHOULD be validated.

Figure 45: Site/Structure Points Depicting Structure and Apartment Entrance Points

To support requirements described above (See Section 3.4.3 *Conveying Estimated Floor Level*), Site/Structure points SHOULD also have provisioned a floor level and floor label.

3.6.3 Bespoke Detailed Models and Building Information Models (BIMs)

All bespoke detailed models SHOULD be provisioned with at least four levels of detail with the appropriate address and subaddress information. Address and subaddress information MUST conform to the appropriate CLDXF standard [26]. These levels of detail are:

- the entire structure
- building quadrants or a logically equivalent volume
- each floor level
- each unit

The ground level of the structure SHOULD conform to the requirements for building footprints as described in Section: 3.6.1.1 *Extruding Building Footprints into 3D Shapes*. Bespoke 3D models MUST be properly oriented in world space.[66]

3.6.3.1 Hand-Crafted 3D Models

For most structures, implementations SHOULD NOT expect to develop bespoke building models by hand for every building within their jurisdiction. It is assumed that it would be prohibitively expensive to develop detailed models by hand for every building in the United States or North America. Implementations SHOULD develop detailed models for complex multistory structures of interest, such as those in densely populated areas or those that are expected to be densely occupied. Implementations SHOULD use other methods described in this document (such as automated generation; see Section 3.6.1 *3D Via Procedural Generation*) to construct building information for most structures in their jurisdiction, at least initially, and construct detailed hand-crafted models for buildings of interest or as finances allow. Ideally every building in every jurisdiction would be constructed by hand, and updated every day—but the workgroup believes this is infeasible.

Areas of special interest that may call for hand-crafted models include, but are not limited to:

- Convention Centers
- Stadiums
- Large Luxury/Hospitality Complexes
- Schools
- Community Anchor Institutions (e.g., public libraries)
- Government Buildings (e.g., courthouses)
- Critical Infrastructure Sites
- Nursing Homes
- Healthcare Facilities
- Large Commercial Multistory Buildings

Jurisdictions may also consider detailed structure modeling for any facilities identified in United States Department of Homeland Security Critical Infrastructure Structures,

[66] Note that as described in this document local GIS data may not use a WGS84 reference frame. Implementations that use a local datum other than WGS84 need to make transformations as appropriate.

especially in the Commercial Facilities and Government Facilities (which includes public schools) sectors.[67]

For new or recent construction, the workflow to build bespoke models for these structures may be available through the workflow described in Section 3.6.3.2 *Recommended Workflow New Construction: Importing 3D Room Shapes from Building Information* Models. This approach is much more efficient than building models by hand and should provide similar capabilities to locate callers indoors. When available, integrations SHOULD use the method described in Section 3.6.3.2 to provision bespoke building models.

3.6.3.2 Recommended Workflow New Construction: Importing 3D Room Shapes from Building Information Models

It is a common convention in Architectural and Engineering ("A&E") work—the practice of architecting and engineering structures—to provision Room volumes when laying out a structure according to common conventions when constructing a Building Information Modeling (BIM) scene. While the workgroup notes that BIM enjoys standardization in some markets under ISO 19650,[68] application of these standards is uneven and not mature in the United States and Canada, and the workgroup cannot recommend a consensus standard to build BIM to at this time. However, conventions and filetypes are generally compatible across prevailing A&E and GIS software suites, and this section describes a recommend workflow for importing Rooms from Architectural drawings into GIS software.

Finished architectural 3D models are of little to no immediate use to the 9-1-1 system; they contain many extraneous elements such as HVAC/electrical/plumbing systems, cabinets and fixtures, furniture etc. that have no utility for 9-1-1 geolocation purposes and increase processing overhead. Some elements, such as plumbing, electrical features, and furniture may be useful for public safety for other situational awareness or pre-planning purposes, such as fire-fighting, in the future; the placement of such elements in a drawing may not reflect final placement in reality or after improvements to the structure. These applications are outside the scope of this document but are noted for future study. An example of a finished architectural 3D model is below.

[67] See Cybersecurity & Infrastructure Security Agency, "Critical Infrastructure Sectors", accessed May 11, 2021, https://www.cisa.gov/critical-infrastructure-sectors.

[68] See ISO 19650 standards series, ISO 19650-1, ISO 19650-2, ISO 19650-3, ISO 19650-4 and ISO 19650-5, accessed December 7, 2020, https://www.iso.org/committee/49180/x/catalogue/p/1/u/1/w/1/d/0.

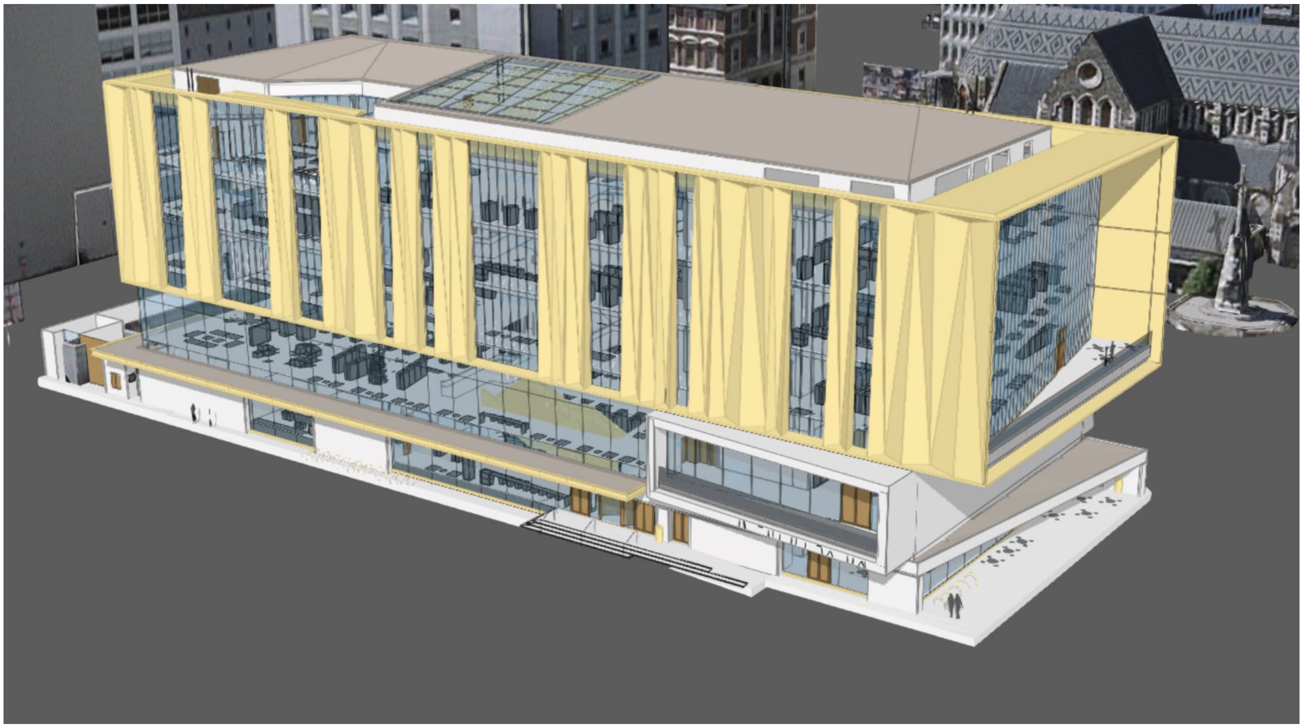

Figure 46: Example Finished Architectural 3D Model

When preparing architectural 3D models, 3D Room shapes are normally created. A Room is a simplified depiction of the area and placement of a 3D space bounded by walls, floors, windows, ceilings, and other surfaces which contain a logical functional area. An Example of a Room may be a 3D shape roughly representing a living room in an apartment, an office or a classroom. Rooms are not used for final architectural visualizations or renderings, but are used for other forms of analyses in building construction. Room shapes may also be exported to the 9-1-1 3D GIS system.

The figures below show the Room shapes for a hypothetical 2-floor structure. The first two figures show level 1 and 2 of this structure in a 2D view. Even though Room information is normally viewed in 2D, it contains 3D information. The third figure below shows a 3D rendering of this same information, with limited labels portrayed that correspond to the same 2D information.

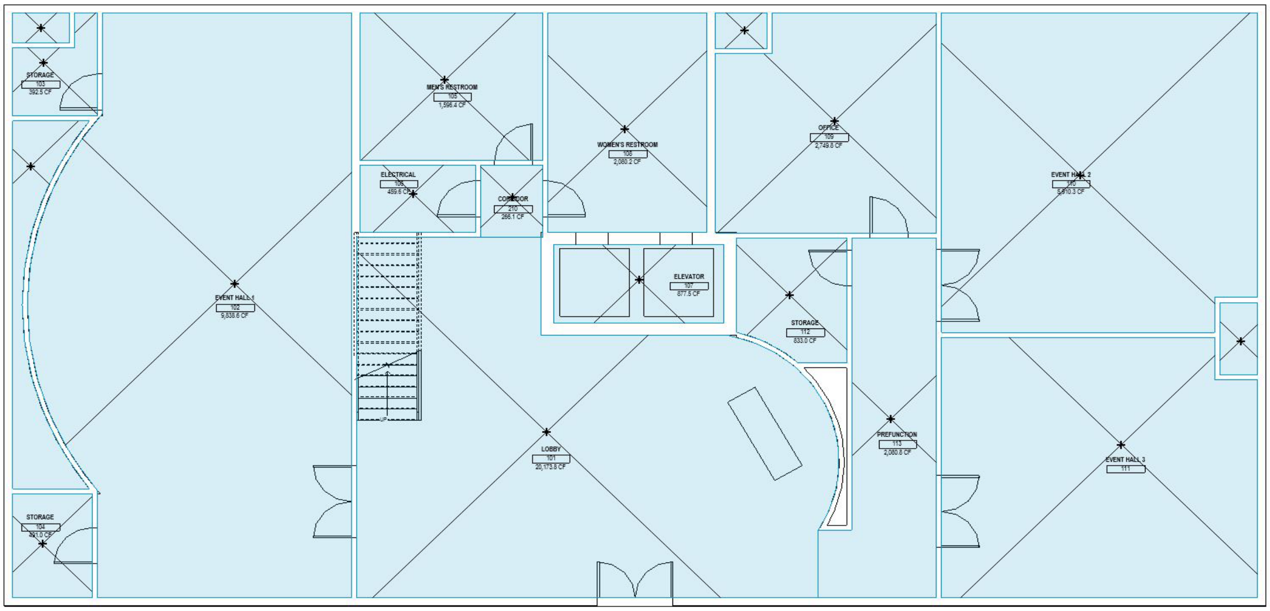

Figure 47: Level 1 of a Structure's Room Layout

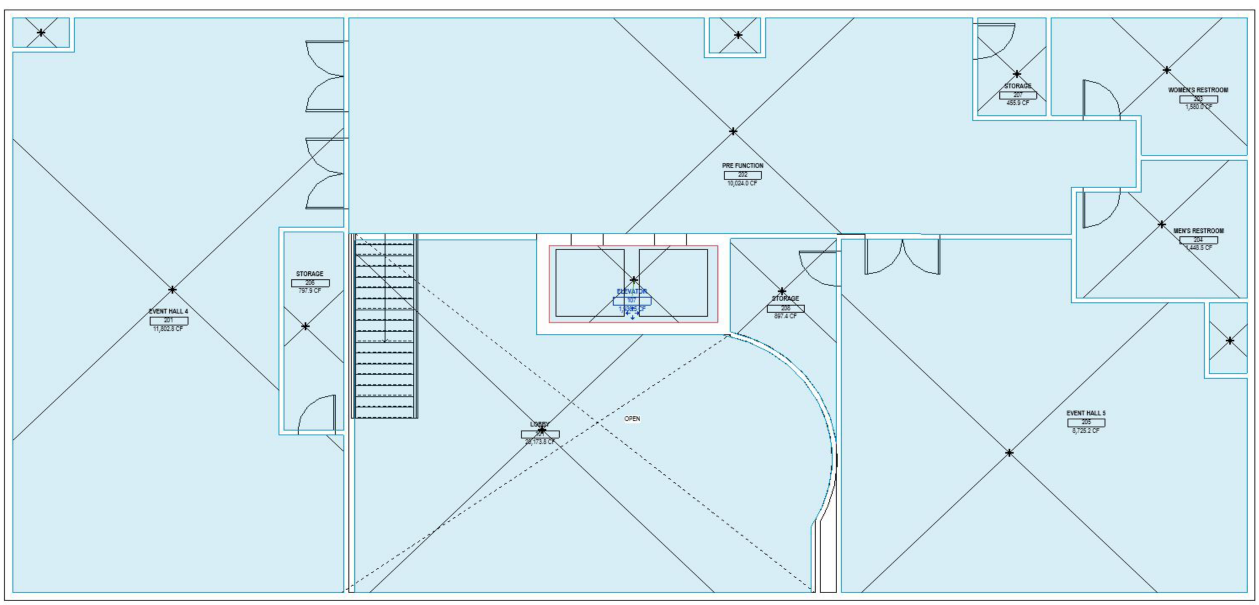

Figure 48: Level 2 of a Structure's Room Layout

At the initial architectural stage, BIM scenes have accurate dimensions but may not be properly oriented in world space. However, these drawings may be georeferenced as part of the permitting process, such as for civil engineering purposes. At this point the scene including Rooms and the overall building shape can be imported into the GIS system.

Most software programs on the market for A&E and GIS at least have compatible file formats. When the 3D Room shapes produced for A&E purposes can be exported from A&E software directly into GIS systems, they can drastically reduce the labor investment in provisioning accurate 3D GIS information for new and recent construction.

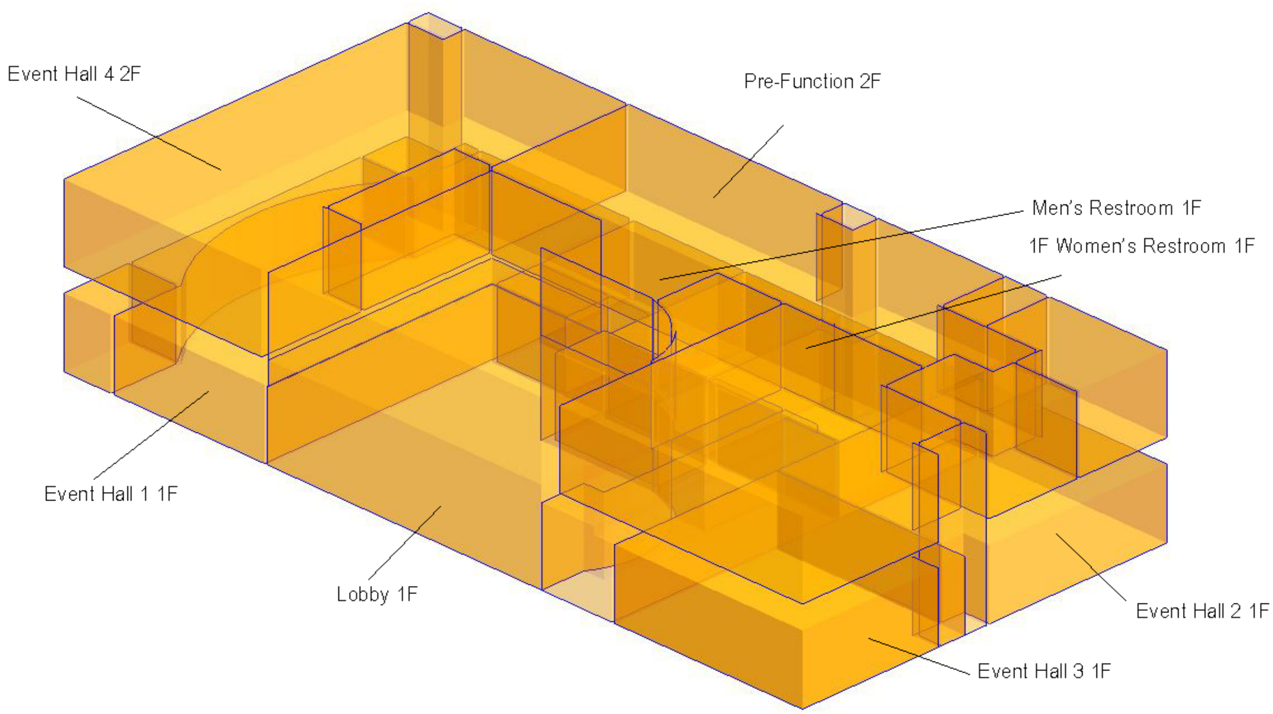

Figure 49: Sample Room layout in 3D with Limited Labels[69]

When georeferenced 3D building shapes with Rooms are available for new construction, address information will likely need to be provisioned by the 9-1-1 entity if not already provisioned by a third party through a separate process. 9-1-1 entities managing GIS data SHOULD work with their public permitting agencies to ensure access to BIM data where it exists as part of the permitting process, and SHOULD express their requirements to partner agencies to ensure they have access to the data.

[69] Taken from https://www.youtube.com/watch?v=JxlrCQFlgnM.

Note that finished structures may not always correspond accurately to architectural or engineering drawings; for example, a client may rent several office suites and demolish walls to combine multiple rooms into one functional space. While it would be ideal to monitor all such modifications and improvements and update GIS data accordingly; in the near term, it will be challenging to accurately record all of these changes with current practices and technology.

BIM scenes will have structural or negative space.[70] Because a Room is bounded by elements such as a wall, a floor, and a ceiling, there is structural space that is not included in Room information. Structural space typically includes empty space between walls, space reserved for utilities or ventilation, the area below a raised floor, etc. In some contexts, structural space may correlate with "non-conditioned" space,[71] as non-conditioned space is not typically occupied and the air is not treated for human comfort. The space within a Room reflects the area in which a caller is most likely to be located. However, it is possible that someone may place a call while occupying structural space, such as if trapped within a crawlspace. Structural space will not be typically included in the rendering of Rooms within a building. The figure below illustrates structural space in 2D .

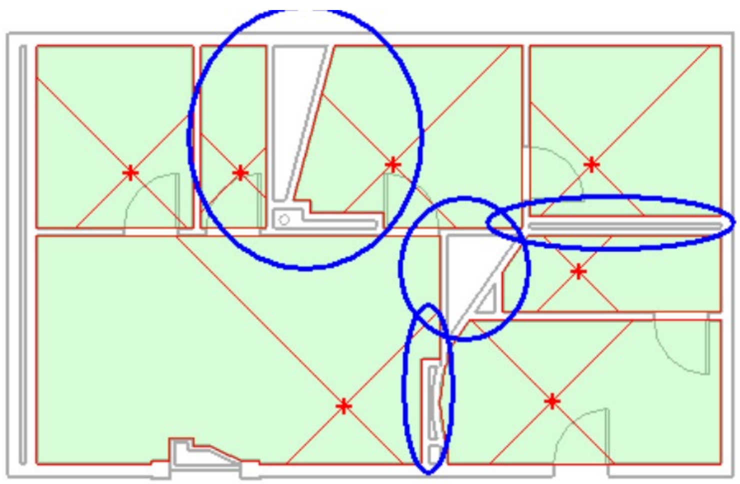

Figure 50: Structural Space Circled in Blue in 2D

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[70] See, e.g., Autodesk, "About Spaces," last updated August 23, 2021, https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/Revit-Model/files/GUID-B876A6F6-4091-40CA-ADCD-AA5D0EFC5EE3-htm.html. This example is used illustratively and is not meant to constitute endorsement.

[71] See https://www.energycodes.gov/resource-center/faqs/what-are-space-conditioning-types for more information. Retrieved 18 May 2021.

Structural space is not a concept that currently exists in standards for 9-1-1. This concept should be standardized and included in standards for 9-1-1 GIS and addressing. For example, a query may report the civic address of the building, the estimated quadrant and floor level, and that the location is within structural space. This may assist responders in determining that the individual is within an area that is not in a Room within the structure that has subaddress information available to assign to it. Until this convention is standardized, implementations SHOULD handle structural space in a consistent manner. For more information on recommendations for future work please see Section 4.1.7 *Provisioning and Subaddress Standards for Structural Space/non-Room Areas*.

3.6.3.3 Preparing BIMs for Use by 9-1-1

In order for BIMs to be usable for provisioning into 9-1-1 systems, they SHOULD include the following minimum set of data oriented in WGS84 world space:

- Whole building 3D shape
- Room 3D shapes
- Room name, number, and Floor
- Egress and access points for building, Rooms, elevators, stairs, and windows
- Altitude of the floor and ceiling of each Room
- Structural space 3D shapes

Implementations MUST confirm that world space is correct.

3.6.4 Requirements for Continuous Data Maintenance

This document discusses building relationships with non-9-1-1 entities to obtain recent and high resolution elevation data. However, the importance of continuous data maintenance cannot not be underestimated; datasets for emergency services, including and especially GIS information used for resolving queries, cannot be viewed as a one-time, initial acquisition. Implementations MUST maintain these relationships and workflows on an ongoing basis and they MUST establish a defined refresh/update cycle for maintenance of any data provisioned as described in this document.

For example, if new LiDAR data is needed or additional classification is needed to achieve the desired Level-of-Detail, 9-1-1 entities may benefit from working with outside entities on an ongoing basis as there may be opportunities to jointly fund such projects or otherwise share resources. Planning for a one-time LiDAR acquisition project is much different from a funding and resource perspective compared to a project that will need to be recurring on a regular refresh cycle. These same dynamics apply to all of the other datasets described in this document.

Work with non-9-1-1 entities may be especially useful when planning future refresh. For example, in some areas, DTM may not change significantly with any real frequency (as absent events like major construction or severe weather/natural disasters, the surface of the earth is generally relatively static), but DSMs are likely to continue to change with rapid frequency in many cases.

It is not sufficient to only create accurate GIS data that meets desired specifications one time; the data must be maintained over time. In some cases, it may be better to exclude specific information if it not feasible or practical to maintain the information on an ongoing refresh cycle. This applies when, and especially when, it is only feasible to perform a one-time acquisition; without regular maintenance a dataset will present increasing inaccuracies over time. For example, detailed building models may be misleading and harmful to first response if they cannot be updated to reflect major building renovations. In most cases it is more harmful to present incorrect information to emergency services than to exclude information altogether if a source dataset is not maintained. Accordingly, implementations MUST have methods to refresh and update provisioned GIS data to minimize incorrect information presented to emergency services.

4 Further Recommendations

4.1 NENA Standards Action Recommended

The following standards action is requested to be performed by NENA:

4.1.1 Support for Building Shapes

As of December 2021, NG9-1-1 GIS Data Model [2] does not have sufficient coverage for 3D building shapes to resolve queries in three dimensions. The data model should be updated to standardize handling of 3D building shapes for NG9-1-1. This document includes some initial concepts that are intended to be standardized and included in the NG9-1-1 GIS Data Model [2] and other standards. Note that these building shapes should also support Rooms and structural space. They should also be designed in a way that provides for the most frictionless import from BIM.

4.1.2 Add "Floor Integer" to GIS Models

The NG9-1-1 GIS Data Model [2] has a "Floor" field, but it is a string, not an integer. This is because the Floor field represents a floor label. For the purposes of conveying confidence and uncertainty, the data model SHOULD be updated to include an additional integer value that conveys a floor level. This value is used when conveying a range of floors. This document includes some initial concepts that are intended to be standardized and included in the NG9-1-1 GIS Data Model [2] under 3.3. This value must also be included in CLDXF [26] under 3.6.4.

Requiring an additional field be added and maintained to express an address' vertical placement (i.e. adding floorInt to elevation/Altitude and floor [label]) creates additional chances for introducing data errors or data inconsistencies, and may increase resource costs for creation, maintenance, and quality assurance/control. However, having a floor integer independent of the floor label provides an absolute measure that can be used to convey and operationalize vertical uncertainty and will assist first responders in arriving at the location of the emergency. The concrete benefit of being able to utilize vertical uncertainty in this manner outweighs the potential costs of provisioning and managing the additional data field.

4.1.3 Support for Other 3D Structures

The NG9-1-1 GIS Data Model [2] does not have sufficient coverage for other features that exist in three dimensions, such as road and bridge geometry and terrain. As noted in this document, standards for location queries should be updated to support all environments, including outdoors. Accordingly, while building shapes are a higher priority for standardization, the NG9-1-1 GIS Data Model [2] should be also updated to support other 3D structures, such as road geometry, terrain, and other structures with specific considerations in an emergency services context (e.g., bridges).

4.1.4 Harmonize Vertical Measurement Terms Across Documents

This document notes that definitions and conventions for vertical measurement terms are inconsistent, and sets forth clear and consistent meanings for vertical measurement terms (see Section 2.3 *Vertical Measurement Terms*). This document then makes consistent use of these terms throughout (Altitude, Elevation, and Height). The workgroup recommends that these conventions be adopted across all NENA documents.

4.1.5 Capture and Operationalize Changes in Features During Natural Disasters

This document describes techniques to provision terrain data and to generate building data from imagery. During natural disasters, these features may temporarily or permanently change. The workgroup notes that future work should address operational and technical best practices and standards to accommodate these changes and information made available during response, such as new imagery created during the incident.

4.1.6 Orientation of Site/Structure Points in 3D Space

This document notes some features of Site/Structure points and how they are provisioned, but notes some gaps for them to be suitable for 3D location purposes. The group requests that in future updates to 3D GIS provisioning, the following issues are addressed:

- Where an address point is provisioned relative to the 3D room shape an address point applies to (e.g., the shape centroid, on the "floor" of the shape, at the primary entrance, etc.).
- Whether address points should support sub-points, such as associated with one or more entrance and/or egress points).

4.1.7 Provisioning and Subaddress Standards for Structural Space/non-Room Areas

This document identifies structural space as a feature that will ultimately need to be included in 3D GIS information used to locate callers. Some examples include but are not limited to features such as the following:

- elevator shafts
- crawl spaces (overhead, beneath a floor or between floors)
- space between walls
- utilities (e.g., ventilation)
- dumbwaiters
- chimneys
- rooftop surface
- balconies/decks/exterior surfaces

These features may be considered a valid subaddress element and provisioned accordingly, or they may be treated like a new kind of feature. The following should be considered in doing this standardization work:

- provisioning of shapes
- common name
- subaddress elements
- registry needs
- relationship, if any, between real-world common names for structural space (if they exist) vs. naming conventions within GIS

4.1.8 Handling Z-Axis Confidence and Uncertainty for Legacy Data Exchange Formats

NENA legacy data exchange formats described in NENA Standard Data Formats for E9-1-1 Data Exchange & GIS Mapping [11] do not accommodate z-axis uncertainty clearly or consistently in a clearly-identified field as needed. As documented in Section 2.4 *Location Data Exchange Formats* z-axis confidence is determined and delivered as a discrete value; this is not accommodated in any version of legacy data exchange formats.

Ideally legacy data exchange formats should fully support the required z-axis information including confidence and uncertainty. Standardization for legacy data exchange formats, including ALI and E2, should be updated to accommodate z-axis need, but acknowledges that it may not be a priority for standards action.

4.2 IETF Standards Action Recommended

The following standards development world is recommended to extend or update existing emergency calling location standards promulgated by the IETF:

4.2.1 Confidence and Uncertainty with Civic Location

RFC 7459 [17] includes guidance for conveying uncertainty with civic locations. As described in this document, these guidelines are not sufficient for locating wireless emergency callers. These guidelines should be updated in a future RFC. Some recommended considerations for this work include:

- Whether it is sufficient to deliver a 3D geodetic location with DL, and whether that should be the normative case
    - If so, whether one method be considered primary and the other secondary, and under which parameters, especially if the dispatchable and geodetic location sources are independent of each other
- When a floor level is delivered, what it is that is delivered
    - A conveyed floor level SHOULD also have an associated integer and level of uncertainty
- When a floor level has uncertainty associated with it, how that is conveyed and what it means
- A means of conveying confidence associated with the estimated floor level
- What algorithm is used to determine C/U for civic addresses delivered in a DL
    - There may be a percentage chance that the DL is the correct address. If so, how that is determined? If there are multiple addresses of equal or unequal likelihood to be the correct one, how that is determined and conveyed?
    - In the case that a compound location is delivered (an x/y coordinate, possibly with a z-axis measurement, and also a floor level and/or subaddress information); what is the the relationship, if any, between the uncertainty for the estimated floor level/address conveyed with respect to the uncertainty associated with the z-axis measurement?

- Whether it is sufficient to consider a range of floors as a valid civic location. For example, if the system estimates the individual is on floor 5 +/- one floor, whether it is:
  - An array of integers (floor number, with ground as zero)
  - An array of strings (floor labels)
  - A multi-dimensional array that conveys floor number with C/U
  - A sequence of objects, possibly nested

4.2.2 3D LoST

RFC 5222 [3] describes Location-to-Service Translation, or LoST. There is some value in eventually performing LoST queries in three dimensions, which is possible when location is conveyed in three dimensions. A future RFC should expand LoST to support three-dimensional queries.

Additionally, though out of scope for this document, it is recommended that a REST/JSON interface for LoST be defined.

4.2.3 Revisions to PIDF

A future RFC should establish a convention for conveying geodetic location as a point with confidence and both horizontal and vertical uncertainty. It should also establish that confidence and uncertainty MUST be included with all geodetic locations, even if it is unknown, in which case the value is null. RFC 7459 [17] states that confidence defaults to 95% if the confidence parameter is not provided. As described in this document, in the United States, it should be assumed that the normal confidence level is 90%, while over-the-top solutions will probably use 67% or 95% confidence. A future RFC should state that confidence is NEVER assumed, and that confidence MUST always be conveyed, even if it is expected to be a static value (e.g., 90% in the United States).

As described in this document, RFC 7459 [17] includes a number of shapes, but does not include a cylinder. A future RFC should include a cylinder shape for representing uncertainty for emergency calls, and should establish that a cylinder is expected to be the normative shape for emergency calls that use location services.

PIDF needs to be updated to properly convey dispatchable location; as described earlier in this document, this is not supported with currently allowed methods. This work may be done by creating a standards document that adds an extension to PIDF and may coincide with work required to enable conveying Confidence and Uncertainty with a Civic Address.

RFC 5774 [33] implies that PIDF is capable of conveying an integer associated with a floor in addition to its plain-language label. However, this capability SHOULD be clarified in a future edition of emergency location RFCs and SHOULD conform with the requirements set forth in this document.

PIDF-LOINFOR should also be updated to have a dedicated field for conveying UBP.

NENA standards have migrated in recent years from XML data formats to JSON. To make PIDF-LO format consistent with other NG9-1-1 data formats, it is recommended that a JSON format for PIDF-LO be considered for a future major revision. However, considering that PIDF-LO is used by entities outside of NENA's community, it may not be worth the effort or disruption to implementations to do this work.

4.2.4 Updates to PIDF-LO to Maintain Feature Parity or Improve Upon Legacy Class of Service

PIDF-LO should be updated to fully support DL, such as by allowing separate Method and Quality Tokens, subordinate Methods and/or Location Objects, C/U for Civic Addresses, and other issues described in this document. This section provides some guidance for Methods for DL as well as proposed Quality Token and Place Type Token to provide feature parity with DL methods to consider in updating PIDF-LO. Note that implementing Place Type and Quality with Method may be sufficient for handling C/U for Civic Locations. However, utilizing Place Type would require significant provisioning for millions of structures and may not be feasible.

PIDF-LO contains an optional "Method" parameter to convey the method that was used to determine a location as noted in IETF RFC 4119 [11]. For example, if a PIDF-LO contains:

```
<gp:method>GPS</gp:method>
```

This indicates that the location was determined using GPS. Per IETF RFC 4119, each Method has a Method Token that is maintained in an Internet Assigned Numbers Authority (IANA) registry.[72] For a geodetic location Method, such as one determined with GPS, Assisted Global Positioning System (A-GPS) or DBH, confidence and uncertainty are explicitly conveyed. Civic Locations have no equivalent fields to convey confidence and uncertainty. Civic Locations have no equivalent concept of confidence and uncertainly at this time.

As discussed in this document, US carriers are required to deliver DL when technically feasible and cost effective to do so, and it remains a stated long-term objective of the FCC for this to be implemented. Over E9-1-1, the Class of Service (WCVC, WDL1, and WDL2) and Place Type (e.g., RSS, RMS, etc), as well as the availability of both coordinates and

[72] IANA, "Method Tokens," last updated April 22, 2019, https://www.iana.org/assignments/method-tokens/method-tokens.xhtml.

address information, is able to convey a DL [10]. With currently registered IANA method tokens and functionality for PIDF-LO, it is not possible to fully convey a DL to an NGCS or Call Handling Equipment because it cannot include C/U. Loss of DL functionality towards PSAPs when moving from Legacy E9-1-1 to NG9-1-1 should be avoided.

When a DL is delivered, a Geodetic Location should also be delivered, when both are available. Since each uses a different Method, it may be preferable to deliver multiple location objects, each marked with the appropriate Method Token. However, current NGCS and Call-Handling Software (CHS) providers cannot handle the delivery of multiple location objects. In the near term, a Compound PIDF-LO can deliver both Geodetic Location and Civic Location with a single Method. This is appropriate when the locations are derived from the same method source, and is acceptable when the locations are from different sources until NGCS and Call-Handling (CH) vendors support the delivery of multiple location objects. However, each Method should be marked individually and properly, especially when they differ.

The following tables list Methods, Quality levels, and Place Types. Note that Quality and Place Type are per [10].[73]

Table 7: Methods for MethodToken-QualityOfAddress

Method	Description
Derived-RevGeo	A full or partial Civic Location, which is not validated against an LVF, is derived by reverse-geocoding a Geodetic Location. The original Geodetic Location MUST also be delivered with the derived Civic Location. Used when a downstream entity other than the calling device reverse-geocodes a Geodetic Location it received from an upstream entity, such as location services/DBH.
DBH2	A Device-Based Hybrid system (typically on a mobile device) produces a compound location that includes a full or partial Civic Address in addition to the Geodetic Location normally expected from a DBH system. Distinct from RevGeo because, even if the DBH system uses reverse-geocoding to determine the Civic Location, the DBH system determines and delivers the Civic Location, not a downstream entity.

[73] Note that [10] under Place Type values references the IANA Location Types registry promulgated under [36].

Method	Description
Proximity	A Civic Location is provided using knowledge that the caller is at or near a specific registered address for that person's identity and/or their device, such as determining by analyzing the caller's Geodetic Location that they are at their registered home address or that they are placing a call from their home Wi-Fi.
Derived-RevGeo-LVF	A full or partial Civic Location, which is validated against an LVF, is derived by reverse-geocoding a Geodetic Location.
Manual-RESD[74]	A Civic Location is provided using knowledge that the calling device is a static device at a known, validated, *residential* address.
Manual-FIXED	A Civic Location is derived by knowledge that the calling device is connecting via a semi-static small-cell device that is at a known, validated, address, such as a pico/femtocell or that the calling device is a fixed cellular device.[75]

Table 8: Quality Levels

Quality	Description
CVC	The lowest quality level not expected to be dispatchable by either building zone or sub-address location.
DL1	Medium quality level that is expected to be dispatchable such as by building zone or quadrant but not with the precision of DL2.
DL2	The highest quality level that is expected to be dispatchable and is or is very near the caller's location.

Table 9: Place Types

Quality	Description
RSS	Single Family Residential – Single story

[74] The meaning for "Manual" is per IETF RFC 4119 [11]: "entered manually by an operator or user, e.g., based on subscriber billing or service location information."

[75] This is similar to wireless Phase 1 location information, except for the case that the service area for the small cell is so small that any device placing a call while affiliated with that cell will be reasonably close to it; e.g., within 50 meters of the registered address for that small cell.

Quality	Description
RMS	Single Family Residential – Multi-story
MTS	Multi-Tenant Residential – Single-story
MTM	Multi-Tenant Residential – Multi-story
CMS	Commercial – Single-story
CMM	Commercial – Multi-story
MUM	Multi-Use – Multi-story (building with both commercial and residential occupants)
MUS	Multi-Use – Single story (building with both commercial and residential occupants)

Some examples of Method, Quality and Place Type are below:

Table 10: Sample Method and Quality Examples

Method	Quality	Place Type	Description
Derived-RevGeo	CVC	RSS	Reverse-geocoding was used but the derived Civic Location for a single family home can only be resolved to approximately the area of an entire neighborhood or community.
Derived-RevGeo	DL2	RMS	Reverse-geocoding was used and the derived Civic Location can be resolved all the way to the room the caller is occupying in a multistory residential structure.
DBH2	DL2	MUM	A DBH system such as mobile location services has provided a Geodetic Location and a full or partial Civic Location, and the Civic Location can be resolved to an extremely high level of accuracy, such as the room a person is occupying in a multistory commercial/residential mixed use structure, or the exact floor level if only the Civic Location contains only a floor level.
Manual-FIXED	CVC	RSS	The call was placed from a device affiliated with small cell but for some reason the derived Civic Location for a single family home can only resolve to the area of

Method	Quality	Place Type	Description
			approximately an entire neighborhood (this is not an expected outcome and may indicate an error).

With this approach, until method and quality can be conveyed independently, Method used when conveying Dispatchable Location would be a concatenation of a dash-delimited Method Token and Quality level in a single string, which is then conveyed as a Method Token.

MethodToken-QualityOfAddress would be used to combine a Method Token with a Quality level in a single parameter.

While any Method could be combined with any Quality it is expected this combination will only be used for specific use cases. In the future, method and quality should be conveyed independently, but this interim approach allows for backwards compatibility with currently operating NG9-1-1/E9-1-1 systems and allows for conversions to legacy Class of Service when required.

This table shows the legacy Class of Service (CoS) code mapped to the equivalent NG9-1-1 Service Info with Quality using MethodToken-QualityOfAddress.

Legacy CoS Code	Legacy Value	NG9-1-1 Data Structure
C	VoIP Residence	pidflo:presence/tuple/status/geopriv/method=Manual and EmergencyCallData.ServiceInfo/ServiceType= digital and EmergencyCallData.ServiceInfo/ServiceEnvironment=Residence and EmergencyCallData.ServiceInfo/ServiceMobility=Fixed
G	Wireless Phase I	pidflo:presence/tuple/status/geopriv/method=Cell and EmergencyCallData.ServiceInfo/ServiceType=wireless and EmergencyCallData.ServiceInfo/ServiceMobility=Mobile

Legacy CoS Code	Legacy Value	NG9-1-1 Data Structure
H	Wireless Phase II	pidflo:presence/tuple/status/geopriv/method= (A-GNSS, DBH, E-CID) and EmergencyCallData.ServiceInfo/ServiceType=wireless or OTT and EmergencyCallData.ServiceInfo/ServiceMobility=Mobile
P	Dispatchable Location 1	pidflo:presence/tuple/status/geopriv/method=Manual-FIXED-DL1 and EmergencyCallData.ServiceInfo/ServiceType=wireless and EmergencyCallData.ServiceInfo/ServiceMobility=Mobile
Q	Dispatchable Location 2	pidflo:presence/tuple/status/geopriv/method=Manual-FIXED-DL2 and EmergencyCallData.ServiceInfo/ServiceType=wireless and EmergencyCallData.ServiceInfo/ServiceMobility=Mobile

This table shows the legacy Class of Service (CoS) code mapped to the equivalent NG9-1-1 Service Info without Quality information.

Legacy CoS Code	Legacy Value	NG9-1-1 Data Structure
C	VoIP Residence	pidflo:presence/tuple/status/geopriv/method=Manual and EmergencyCallData.ServiceInfo/ServiceType= digital and EmergencyCallData.ServiceInfo/ServiceEnvironment=Residence and EmergencyCallData.ServiceInfo/ServiceMobility=Fixed
G	Wireless Phase I	pidflo:presence/tuple/status/geopriv/method=Cell and EmergencyCallData.ServiceInfo/ServiceType=wireless and

Legacy CoS Code	Legacy Value	NG9-1-1 Data Structure
		EmergencyCallData.ServiceInfo/ServiceMobility=Mobile
H	Wireless Phase II	pidflo:presence/tuple/status/geopriv/method= (A-GNSS, DBH, E-CID, and Manual-FIXED) and EmergencyCallData.ServiceInfo/ServiceType=wireless or OTT and EmergencyCallData.ServiceInfo/ServiceMobility=Mobile
P	Dispatchable Location 1	NA
Q	Dispatchable Location 2	NA

Note: NG9-1-1 Data Structure for Legacy CoS Codes P & Q is pending clarification from NENA STA 010 Working Group.

4.3 Research into Crowdsourced Methods to Provision 3D GIS for 9-1-1

There is an emerging body of technology capable of capturing three-dimensional spaces using consumer technologies, such as LiDAR sensors on consumer smartphones. The industry is encouraged to explore the potential to use technologies like these to build 3D models for existing structures quickly, cheaply, and with a reasonable degree of accuracy. These methods may be crowdsourced. These technologies exist in an early state, and much work needs to be done for their output to be suitable for provisioning 9-1-1 3D GIS information, but they show promise.

Figure 51: 3D Scan of a Home Made with a Consumer Smartphone and Mobile Application[76]

[76] See https://www.sitescape.ai/blog/sitescape-3d-scanner-for-iphone12pro, accessed May 18, 2021. This example is used illustratively and for example only and does not imply endorsement of any product.

5 IANA Actions

5.1 Method Tokens

Per Section 4.2.4, IANA will be requested to enter additional Methods Tokens per RFC4119 [14].

Table 11: IANA Method Tokens

Token	Description	Reference
Derived-RevGeo	A full or partial Civic Location, which is not validated against an LVF, is derived by reverse-geocoding a Geodetic Location. The original Geodetic Location MUST also be delivered with the derived Civic Location. Used when a downstream entity other than the calling device reverse-geocodes a Geodetic Location it received from an upstream entity, such as location services/DBH.	This document.
DBH2	A Device-Based Hybrid system (typically on a mobile device) produces a compound location that includes a full or partial Civic Address in addition to the Geodetic Location normally expected from a DBH system. Distinct from RevGeo because, even if the DBH system uses reverse-geocoding to determine the Civic Location, the DBH system determines and delivers the Civic Location, not a downstream entity.	This document.
Proximity	A Civic Location is provided using knowledge that the caller is at or near a specific registered address for that person's identity and/or their device, such as determining by analyzing the caller's Geodetic Location that they are at their registered home address or that they are placing a call from their home Wi-Fi.	This document.
Derived-RevGeo-LVF	A full or partial Civic Location, which is validated against an LVF, is derived by reverse-geocoding a Geodetic Location.	This document.

Manual-RESD	A Civic Location is provided using knowledge that the calling device is a static device at a known, validated, *residential* address.	This document.
Manual-FIXED	A Civic Location is derived by knowledge that the calling device is connecting via a semi-static small-cell device that is at a known, validated, address, such as a pico/femtocell or that the calling device is a fixed cellular device.	This document.

This registry is first-come, first-served and does not require a document to populate. However, the whole of the workgroup makes this request through this requirements document.

5.2 Quality Tokens

Per Section 4.2.4, it is anticipated that IANA will be requested to create and maintain a registry for Quality Tokens. However, this topic may be addressed under future work described in 4.2.3 to revise or extend PIDF-LO.

6 Impacts, Considerations, Abbreviations, Terms, and Definitions

6.1 Abbreviations, Terms, and Definitions

See NENA Master Glossary of 9-1-1 Terminology, NENA-ADM-000 [1], for a complete listing of terms used in NENA documents. All abbreviations used in this document are listed below, along with any new or updated terms and definitions.

Term or Abbreviation (Expansion)	Definition / Description	WG Recommendation for Master Glossary
3GPP (3rd Generation Partnership Project)	Third Generation Partnership Project, the primary global standards development organization for cellular network standards.	DA
Altitude	The measurement of the device's orthogonal distance from the WGS84 ellipsoid. Also known as: Height Above Ellipsoid (HAE) Z Coordinate	N

CMRS (Commercial Mobile Radio Service)	A US FCC designation for any carrier or licensee whose wireless network is connected to the public switched telephone network; for practical purposes, this is the same as a "cellular network."	U
Dispatchable Location	"Dispatchable location" is a location delivered to the PSAP with a 9-1-1 call that consists of the validated street address of the calling party, plus additional information such as suite, apartment, uncertainty, and/or similar information necessary to adequately identify the location of the calling party.	U
Elevation	The orthogonal distance of the Earth's surface from the WGS84 ellipsoid at a provided location; i.e., the Altitude of the ground level.	N
Height	The difference between Elevation and Altitude for a given location; often referred to as "Height Above Ground Level" (AGL).	N
Height Above Ellipsoid (HAE)	The measurement of the device's orthogonal distance from the WGS84 ellipsoid. Also known as: Altitude Z Coordinate	N
Method	An optional parameter in IETF RFC 4119 which describes the way that the location in a PIDF-LO was derived or discovered. Methods are maintained in a Method Token registry by IANA. Example methods include "GPS," "Manual," and "DBH."	DA
Quality	An optional parameter proposed for a future update to PIDF that indicates the quality level of the associated Method for a Dispatchable Location.	DA

Room	A simplified depiction of the area and placement of a 3D space bounded by walls, floors, windows, ceilings, and other surfaces which contain a logical functional area.	DA
Stated Location	A location that is conveyed during call processing, usually verbally.	DA
Z Coordinate	The measurement of the device's orthogonal distance from the WGS84 ellipsoid. Also known as: Height Above Ellipsoid Z Coordinate	U

7 Recommended Reading and References

A list of notable references used in this document as well as some additional recommended reading is below. Additional references are included in footnotes throughout the document. Links are valid as of 29 June 2021.

7.1 References

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[4] Federal Communications Commission. *Wireless E911 Location Accuracy Requirements*, PS Docket No. 07-114, *Fifth Report and Order and Fifth Further Notice of Proposed Rulemaking*, November 2019.

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[11] National Emergency Number Association., *NENA Standard Data Formats For E9-1-1 Data Exchange & GIS Mapping*. NENA-STA-015.10-2018 (originally 02-010). Arlington, VA: NENA, approved August 12, 2018.**E**National Emergency Number Association. *NENA i3 Standard for Next-Generation 9-1-1*. NENA-STA-010.3-2021. Arlington, VA: NENA, approved July 12, 2021. **E**Internet Engineering Task Force. *A Presence-based GEOPRIV Location Object Format*. J. Peterson. RFC 4119, December 2005.**E**3rd Generation Partnership Project. *Universal Geographical Area Description (GAD)*. Hannu Hietalahti. 3GPP TS 23.032, January 22, 2015.**E**National Geospatial-Intelligence Agency. "WGS 84 Data & Apps," Office of Geomatics, last modified

August 5, 2021, https://earth-info.nga.mil/#tab_wgs84-res.**E**Internet Engineering Task Force. *GEOPRIV Presence Information Data Format Location Object (PIDF-LO) Usage Clarification, Considerations, and Recommendations*. J. Winterbottom, M. Thomson, and H. Tschofenig. RFC 5491, March 2009.**E**National Emergency Number Association. *NENA Standard for the Implementation of the Wireless Emergency Service Protocol E2*. NENA-STA-018.2-2021 (originally 05-001). Arlington, VA: NENA, approved February 17, 2021.

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[17] Federal Communications Commission. *Wireless E911 Location Accuracy Requirements*, PS Docket No. 07-114, *Fourth Report and Order*, February 2015.

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– Converting Uncertainties to Different Confidence Levels (Informative)

Some governmental regulatory agencies may require that all horizontal and vertical uncertainties be provided at a consistent confidence level (90% for all US wireless carriers). Supplemental data from non-regulated sources may be provided at different confidence levels, but it is critical to 9-1-1 operators that the uncertainty data they use be displayed at the same consistent confidence level. This may require that some horizontal and vertical uncertainties be converted to values that are consistent with regulatory requirements. RFC 7459 [17] gives the conversion equation as follows:

$$U_d = U_o \frac{erfinv\left(\mathrm{C_d}^{1/n}\right)}{erfinv\left(\mathrm{C_o}^{1/n}\right)}$$

U_d = desired uncertainty value (either horizontal or vertical)
U_o = original uncertainty value (either horizontal or vertical)
$\mathrm{C_d}$ = desired confidence value (example 0.90)
$\mathrm{C_o}$ = confidence value of original calculation (example 0.67 or 0.95)
n = degrees of freedom (2 for horizontal uncertainty, 1 for vertical uncertainty)

The inverse error function ($erfinv$) is not available in all computing systems (e.g., Microsoft Excel). Either of the following mathematically equivalent equations using the inverse of the gamma cumulative distribution ($gammainv$) function or the inverse of the cumulative standardized normal distribution ($normsinv$) function can be substituted with no impact to accuracy:

$$U_d = U_o \sqrt{\frac{gammainv\left(\mathrm{C_d}^{1/n},\ 0.5,\ 1\right)}{gammainv\left(\mathrm{C_o}^{1/n},\ 0.5,\ 1\right)}} \quad \text{or} \quad U_d = U_o \frac{normsinv\left(\frac{1-\mathrm{C_d}^{1/n}}{2}\right)}{normsinv\left(\frac{1-\mathrm{C_o}^{1/n}}{2}\right)}$$

Appendix A – Sample JSON Schemas for Floors

This appendix includes JSON schemas for the sample JSON payloads in Section 3.4.3 *Conveying Estimated Floor Level.* Note that these are examples rather than specific proposals; when actual schemas are defined, the names and types may be different, and members may be added or deleted. (E.g., "floorLabel" and "floorInt" might be named "floorLabelEst" and "floorIntEst" to reinforce that these are estimated values, or completely different names might be chosen.

A.1 Example 1

This example has an array of objects that contains multiple objects. The object properties are floor (string) and floorInt (integer).

```
{
  "$schema": "http://json-schema.org/draft-04/schema#",
  "type": "object",
  "title": "Estimated Floor Level",
  "description": "Example schema for conveying estimated floor level",
  "properties": {
    "floors": {
      "type": "array",
      "items": [
        { "type": "object",
         "properties": {
        "floorLabel": { "type": "string" },
        "floorInt": { "type": "integer" }
         }
        }
      ]
    }
  }
}
```

A.2 Example 2

This example has three values: a floor label (string), floor level (integer) and uncertainty (integer). This conveys an estimated floor +/- a number of floors.

```
{
  "$schema": "http://json-schema.org/draft-04/schema#",
  "type": "object",
  "title": "Estimated Floor Level",
  "description": "Example schema for conveying estimated floor level",
  "properties": {
    "floorLabel": {
      "type": "string"
    },
    "floorInt": {
      "type": "integer"
    },
    "uncertainty": {
      "type": "integer"
    }
  },
  "required": [
    "floorLabel",
    "floorInt",
    "uncertainty"
  ]
}
```

Appendix B – Case Study: Bexar Metro Altitude-Height Conversion Service

This document is reproduced courtesy of the Bexar Metro Area 9-1-1 Network, which covers Bexar, Guadalupe, and Comal Counties of Texas, including the San Antonio metropolitan area. It describes a conversion service used to convert Altitude into Height, serves as training material and provides general background z-axis location. Reproduced with permission. Appended to the final publication of this document.

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