Tacoma Public Utilities
Baseline Testing Report

Release 1.0
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Revision History

Revision Date		List of Changes	Author	Approval
09/20/2023	Initial Draft		MP	PR
1/30/2024	Release 1.0	Incorporated TPU comments	MP	PR

Contents

1 Executive Summary

Stantec conducted a wireless communications signal survey of the Tacoma Public Utilities (TPU) campus located at 3628 S 35th St, Tacoma, WA 98409. The campus consists of multiple buildings with various uses such as office space, fleet garage, warehouse, and other miscellaneous structures. The survey measured radio signal levels inside of seven buildings at the campus facility to determine how reliable commercial cellular signal and public safety radio coverage is within each building. Two measurements were also taken on the campus exterior at separate locations to analyze the overall macro environment of the local carriers' cellular networks and public safety systems.

Stantec performed the cellular signal survey utilizing commercially available pre-paid cell phones activated on each of the three major commercial cellular providers (AT&T, Verizon, and T-Mobile). The use of commercially available cell phones ensures that the testing emulates what a typical user would experience while on the TPU campus. The test phones were loaded with specialized cellular network analyzing software, which provided real time network conditions including signal quality. These receive levels were recorded manually at several locations throughout each floor of the surveyed buildings.

The survey results for cellular coverage were compared against the indicators for cellular 4G/5G LTE signals, which are summarized in the table below. To be thorough, both RSRP and RSRQ values were recorded during cellular testing.

		RSRP (dBm)	RSRQ (dB)
Excellent	Reliable Voice, Text, and data services	>=-75	
Good	Reliable voice and text service, with slight degradation of data services (>50%)	>=-95	>=-9
Fair	Voice and text services should work, however data will be degraded (<50%)	>=-105	>=-12
Poor	Unacceptable service. Voice and texts may fail, and data will be severely degraded.	<-105	<-12

RSRP Range: -140 to -44 dBm RSRQ Range: -19.5 to -3 dB

Source: "Key Performance indicators and Measurements for LTE Radio Network Optimization", (Wiley 2011 pgs. 230-232)

In addition to cellular coverage, signal levels for three public safety systems were measured including TPU 800 MHz, City of Tacoma 800 MHz and Pierce County 700 MHz. Control channels (constant carrier) for each of the three separate trunked radio systems were chosen as test frequencies in order to not disrupt system operation. The survey results for public safety coverage were compared against a -95 dBm signal level threshold, which is a code requirement for emergency responder radio coverage systems and a conservative threshold for land mobile radio systems in general.

Based on the above-mentioned criteria, the results of the cellular and public safety signal level testing across the TPU campus are summarized in the following table. Depending on number of levels per buildings, the results have been averaged. Actual measurements recorded at each building, level and test location can be found in the appendices.

	PUBLIC SAFETY SYSTEM			CELLULAR CARRIER		
BUILDING	TPU	CITY OF TACOMA	PIERCE COUNTY	AT&T	T-MOBILE	VERIZON
ADMIN NORTH	PASS	PASS	FAIL	POOR	FAIR	GOOD
ADMIN SOUTH	FAIL	FAIL	FAIL	POOR	POOR	POOR
ECC	FAIL	PASS	FAIL	POOR	POOR	GOOD
GARAGE	PASS	PASS	FAIL	POOR	POOR	FAIR
WAREHOUSE	PASS	PASS	FAIL	FAIR	GOOD	GOOD
WATER DISTRIBUTION	PASS	PASS	FAIL	FAIR	FAIR	FAIR
CRAFT SHOPS	PASS	PASS	FAIL	FAIR	FAIR	GOOD
OUTDOOR	PASS	PASS	FAIL	FAIR	GOOD	GOOD

For public safety, both TPU and CoT (City of Tacoma) fared well on upper levels of both admin buildings with passing signal quality. It should be noted that levels recorded for both agencies suffered dramatically and failed on the admin building basement levels. TPU and CoT also provided good passing coverage throughout the entire campus, with the ECC basement being the only failing area, once again bringing the building average down. It's unknown which Piece County radio tower site serves the TPU campus, but across-the-board all indoor and outdoor recorded signal levels for Pierce County were below the -95 dBm signal level threshold.

The Verizon cellular measurements throughout the TPU facility indicated good to fair coverage in all buildings, with the exception being the basement levels of Admin South. This may be due to the north admin building blocking macro coverage. T-Mobile presented questionable coverage for several buildings but did excel in the warehouse and showed good coverage outdoors. AT&T measurements indicate fair to poor signal levels at best.

TPU would benefit from the installation of separate, neutral host, fiber fed Distributed Antenna System (DAS) for both public safety and cellular applications to provide consistent and reliable communications throughout the campus.

1.1 In-building cellular coverage enhancement options.

There are a few options to improve cellular coverage on the TPU campus. The following solutions should be considered for providing reliable cellular coverage inside the buildings.

1. Neutral Host DAS
   - Would provide reliable coverage for each carrier inside the facilities.
   - Can be expensive to implement.
   - Can be owned and operated by TPU or could be negotiated with a carrier to own and operate the system.
   - Signal sources require commitment contracts with the carrier.
   - Over-the-air donor signals are unlikely to be approved by carriers due to the urban location and potential interference to their macro networks.
   - Would not enhance signals outside of the building.
   - Good solution to provide enhanced coverage to targeted areas.
     Cost: $2-$3 per square foot.

2. In-building Small Cells (Metro cells/Micro cells/Pico cells/Femtocells/etc.)
   - Small cells can be used to provide coverage inside of a facility, either directly or by feeding a neutral host DAS.
   - Requires internet backhaul, either TPU IT infrastructure or dedicated internet connections.
   - Each carrier will need to provide their own small cell to provide coverage. Limited to approximately 15K square feet of coverage per device. Therefore, each carrier would need to provide multiple devices for each level of each building.
   - Capacity is limited on each device to roughly 32-64 simultaneous users. Data throughput performance of connected devices will depend on the backhaul provided.
   - Cost $10K per carrier for every 15K sq. feet of coverage.

3. Utilize voice over Wi-Fi services while in the facility.
   - Requires each device to be capable of the service. Some older devices may not be capable.
   - Requires setting up service with the carrier's plan (typically included with most plans, but needs to be configured).
   - Enhanced 911 location issues with Wi-Fi calling adds complexity since Wi-Fi does not have location information necessary for E911 services.
   - Cost: Likely to be included in existing cellular plans (depending on carrier and plan).

4. External Macro cellular site(s)
   - Investing in external cell sites is not recommended as a solution for reliable in-building coverage campus wide. The median building penetration loss is just too great.
   - Would still not provide in-building coverage throughout the entire campus.
   - Carriers may be willing to invest in site if there is a good return on investment.
   - Requires negotiating with all three carriers to build a dedicated campus site for TPU. A carrier may be interested in investing in a site in the area if they don't already have coverage, while the others may not.
   - A strategically placed cell site would provide "fair" coverage in a significant portion of the campus, particularly in the outdoor areas of the campus.
   - Cost: $500K-$1M per carrier.

1.2 Emergency Responder Radio Coverage Options:

1. Over-the-air bi-directional amplifier and distributed antenna system (passive DAS)

   A bi-directional amplifier (BDA) installed at the TPU facility could potentially be fed over-the-air utilizing a channelized BDA optimized for signal reinforcement in 700/800 MHz public safety bands. This BDA is typically installed in an IDF or MDF and can be wall mounted.
   A directional donor antenna will need to be mounted as high as possible on the roof (or other nearby structure) to help clear any local clutter between the facility and radio tower site, and to increase isolation between the donor and service antennas.
   Multiple ceiling mounted service antennas will need to be installed on each floor of the facility to distribute the radio signals throughout. Half-inch rigid coaxial cable will be used to connect the service antennas back to the BDA in and IDF/MDF.

   - Would provide sufficient emergency responder radio coverage throughout the facility.
   - Emergency responder radio signals are separated from cellular enhancement system to avoid code compliance issues.
   - System can be scaled back if it is determined that coverage is not needed in certain areas of the facility.
   - Can be the cost-effective solution for meeting minimal coverage requirements.
   - Service antennas would need to be mounted throughout the facility / buildings and pathways obtained coaxial cable distribution.
   - Cost: $1.50-$2.00 per square foot.

2. Fiber fed bi-directional amplifier and distributed antenna system:

   A fiber DAS could be fed with an over-the-air BDA (similar to above) at a single location on campus. This head end locations would then feed remote amplifiers mounted in each campus building. Alternatively, the fiber BDA could be fed directly from a nearby radio site if reliable fiber (or similar) connectivity is available from the site to the TPU campus. This is a good solution for large buildings and facilities that have multiple buildings such as campus environments.

   - Would provide sufficient emergency responder radio coverage throughout the facility.
   - Emergency responder radio signals are separated from cellular enhancement system to avoid code compliance issues.
   - System can be scaled back if it is determined that coverage is not needed in certain areas of the facility.
   - A fiber DAS head end can be expanded to provide donor signal to other nearby facilities to address future emergency responder radio coverage requirements.
   - Service antennas would need to be mounted throughout the facility and pathways obtained for coaxial cable distribution. As well, remote units placed in IDF, telecom closets, etc.
   - Additional equipment complicated the design and implementation process.
   - Cost: $1.75-$2.25 per square foot.

3. Stand-alone BDA with targeted coverage:

Install stand-alone ERRCS DAS and distribute only in areas where survey indicated insufficient coverage. This reduces cost to the building owner but increases risk by failing to completely cover buildings. This would have the same type of equipment as mentioned for a complete DAS, except the antennas and cabling would only extend to areas where signal reinforcement was required. A solution like this is typically used where small spaces, such as a single subterranean level do not have sufficient coverage. However, multiple signal sources on a single campus are not recommended as it has the potential to cause adverse interference to surrounding radio systems.

2 Investigation

A wireless site survey gathers information regarding the actual measured in-building signal strengths of the wireless systems being tested. In this case, the systems of interest were the three major cellular networks (AT&T, Verizon, T-Mobile), as well as public safety agencies including TPU, City of Tacoma and Pierce County. Reduction in signal strength (attenuation) from an exterior source will vary greatly due to various factors. Actual field measurements provide a higher level of confidence and detail than can be obtained from mathematical modeling alone. This information makes it possible to point out areas where users may experience issues communicating within the facility and thus where signal reinforcement may be necessary.

A signal survey was conducted on September 7-8th, 2023 to measure signal levels inside of seven buildings on the TPU Tacoma campus. The site visit and survey provided insight as to the quality of coverage for the specified cellular and public safety services. The survey data within this report focuses on in-building signal level measurements as captured on the survey date.

2.1 Building Details

TPU provided floorplans for the campus buildings listed below, with the exception of the ECC which was not provided due to security concerns. ECC floorplans were estimated from information from the site visit and Google Earth views, and used for collection purposes only. Floorplans for the surveyed buildings are provided in Appendix B.

Building	Levels	Estimated Square Footage
ADMIN NORTH	5	168,900
ADMIN SOUTH	5	82,400
ECC	3	26,500
GARAGE	1	TBD
WAREHOUSE	1	TBD
WATER DISTRIBUTION	1	TBD
CRAFT SHOPS	1	TBD

2.2 Signal Measurement Equipment & Methodology

The test equipment utilized for cellular survey consisted of one pre-paid cellular phone programmed for each of the three major carriers (three phones total). To reduce the effects of different phone models and operating systems, the same phone model was used for each carrier.

- Samsung Galaxy A14 5G
- Android operating system version 13
- WILYSIS Network Cell Info App

For public safety testing, a Keysight model# N9918A spectrum analyzer was used. The unit has a current and NIST traceable calibration certification.

Customer Number: 1-628198-000
PO Number: HA2AX-RR
Certificate/SO Number: 48-HE38D-20-1

Date Received: June 13, 2023
Date Completed: July 27, 2023
Issue Date: July 27, 2023
Due Date: July 20, 2025

Manufacturer: Agilent/HP/Keysight Tech
Model Number: N9918A
Description: FieldFox Handheld RF Vector Network Analyzer

Serial Number: MY56077214
ID Number: 75645

Unit Barcode: 0900B361471

To characterize the in-building coverage, individual buildings were divided into twenty equal grids per floor (See Appendix B for floorplans with test grids). Several buildings were divided into lesser grids because of reduced square footage. A single measurement was taken for each cellular carrier and public safety service in each grid. Smaller buildings do not lend themselves to a 20-grid test since the measurements would not necessarily be decorrelated from each other. In these cases, grids sizes were chosen to represent a compromise between granularity and decorrelation of signals to adequately characterize the facility.

2.3 Survey Observations

2.3.1 Baseline Outdoor Measurements

Stantec made two baseline exterior signal measurements for each carrier / service for reference purposes. These consisted of ground level measurements that provide valuable engineering data on available donor signal quality. The signal levels recorded on the exterior of the campus are acceptable for most carriers, with the potential exception of AT&T which presented borderline level at the south test location. For public safety, both TPU and City of Tacoma systems displayed exceptional signal strength. The Pierce County signal strength was slightly questionable at both outdoor test locations, although would more than likely be acceptable with rooftop mounted donor antenna.

2.3.2 In-Building Measurements

Cellular

The following tables summarize the Reference Signal Received Power (RSRP) recorded at each TPU campus building during cellular testing.

(See Appendix A for complete listing of recorded signal levels and test locations)

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
ADMIN BUILDING NORTH AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL G	20	0	1	19
LEVEL M	20	0	4	16
LEVEL 2	20	1	8	11
LEVEL 3	20	2	8	10
LEVEL 4	20	9	9	2
ADMIN BUILDING NORTH T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL G	20	3	2	15
LEVEL M	20	6	6	8
LEVEL 2	20	7	9	4
LEVEL 3	20	4	10	6
LEVEL 4	20	11	9	0
ADMIN BUILDING NORTH VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL G	20	5	3	12
LEVEL M	20	2	9	9
LEVEL 2	20	7	9	4
LEVEL 3	20	4	10	6
LEVEL 4	20	17	2	1

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
ADMIN BUILDING SOUTH AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL B	20	0	0	20
LEVEL G	20	0	1	19
LEVEL M	20	0	0	20
LEVEL 2	20	0	1	19
LEVEL 3	20	0	0	20
ADMIN BUILDING SOUTH T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL B	20	0	0	20
LEVEL G	20	0	4	16
LEVEL M	20	2	4	14
LEVEL 2	20	0	4	16
LEVEL 3	20	0	4	16
ADMIN BUILDING SOUTH VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL B	20	0	1	19
LEVEL G	20	0	4	16
LEVEL M	20	0	7	13
LEVEL 2	20	0	5	15
LEVEL 3	20	1	8	11

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
ECC BUILDING AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	9	0	3	6
LEVEL 2	12	4	5	3
LEVEL 3	9	1	3	5
ECC BUILDING T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	9	0	2	7
LEVEL 2	12	2	5	5
LEVEL 3	9	1	5	3
ECC BUILDING VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	9	1	4	4
LEVEL 2	12	7	5	0
LEVEL 3	9	6	3	0

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
GARAGE BUILDING AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	14	1	1	12
GARAGE BUILDING T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	14	0	3	11
GARAGE BUILDING VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	14	5	6	3

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
WAREHOUSE BUILDING AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	14	1	9	4
WAREHOUSE BUILDING T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	14	7	7	0
WAREHOUSE BUILDING VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	14	8	6	0

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
WATER DISTRIBUTION BUILDING AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	20	1	11	8
WATER DISTRIBUTION BUILDING T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	20	5	11	4
WATER DISTRIBUTION BUILDING VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	20	2	14	4

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
CRAFT SHOPS BUILDING AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	6	0	3	3
CRAFT SHOPS BUILDING T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	6	1	4	1
CRAFT SHOPS BUILDING VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
LEVEL 1	6	4	2	0

	TOTAL TEST LOCATIONS	EXCELLENT / GOOD	FAIR	POOR
OUTDOOR AT&T CELLULAR TEST RESULTS (BASED ON RSRP)				
NORTH	1	1	0	0
SOUTH	1	0	1	0
OUTDOOR T-MOBILE CELLULAR TEST RESULTS (BASED ON RSRP)				
NORTH	1	1	0	0
SOUTH	1	1	0	0
OUTDOOR VERIZON CELLULAR TEST RESULTS (BASED ON RSRP)				
NORTH	1	1	0	0
SOUTH	1	1	0	0

In general, Verizon and T-Mobile performed the best, with AT&T providing weak on campus signal levels. This may be due to the north admin building blocking macro coverage. In general, carriers performed better on upper levels of buildings. This is expected since upper levels tend to have better line-of-site to the horizon and therefore less obstructions between the serving cell site and the measurement location.

Public Safety:

For public safety signal testing, Stantec utilized a Keysight Model# N9918A spectrum analyzer with current NIST traceable calibration certificate. The spectrum analyzer was utilized for displaying RF signal strength of the agreed upon test frequencies. The spectrum analyzer also provides an understanding of RF environmental conditions including spectral noise and signal attenuation introduced by building materials.

Signal levels for three public safety systems were measured including TPU 800 MHz, City of Tacoma 800 MHz and Pierce County 700 MHz. Control channels (constant carrier) for each of the three separate trunked radio systems were chosen as test frequencies in order to not disrupt system operation. The following table summarizes results captured by the spectrum analyzer. Results shown are divided by pass or fail criteria. The division is based on a -95 dBm signal threshold which

is a code requirement for emergency responder radio coverage systems and a conservative threshold for land mobile radio systems in general.

(See Appendix A for complete listing of recorded signal levels and test locations)

	TOTAL TEST LOCATIONS	PASS	FAIL
ADMIN BUILDING NORTH TPU TEST RESULTS			
LEVEL G	20	14	6
LEVEL M	20	20	0
LEVEL 2	20	18	2
LEVEL 3	20	20	0
LEVEL 4	20	20	0
ADMIN BUILDING NORTH CITY OF TACOMA TEST RESULTS			
LEVEL G	20	19	1
LEVEL M	20	20	0
LEVEL 2	20	20	0
LEVEL 3	20	20	0
LEVEL 4	20	20	0
ADMIN BUILDING NORTH PIERCE COUNTY TEST RESULTS			
LEVEL G	20	0	20
LEVEL M	20	0	20
LEVEL 2	20	0	20
LEVEL 3	20	0	20
LEVEL 4	20	5	15

	TOTAL TEST LOCATIONS	PASS	FAIL
ADMIN BUILDING SOUTH TPU TEST RESULTS			
LEVEL B	20	0	20
LEVEL G	20	9	11
LEVEL M	20	13	7
LEVEL 2	20	9	11
LEVEL 3	20	11	9
ADMIN BUILDING SOUTH CITY OF TACOMA TEST RESULTS			
LEVEL B	20	3	17
LEVEL G	20	19	1
LEVEL M	20	18	2
LEVEL 2	20	17	3
LEVEL 3	20	20	0
ADMIN BUILDING SOUTH PIERCE COUNTY TEST RESULTS			
LEVEL B	20	0	20
LEVEL G	20	0	20
LEVEL M	20	0	20
LEVEL 2	20	0	20
LEVEL 3	20	0	20

	TOTAL TEST LOCATIONS	PASS	FAIL
ECC BUILDING TPU TEST RESULTS			
LEVEL 1	9	3	6
LEVEL 2	12	11	1
LEVEL 3	9	9	0
ECC BUILDING CITY OF TACOMA TEST RESULTS			
LEVEL 1	9	5	4
LEVEL 2	12	12	0
LEVEL 3	9	9	0
ECC BUILDING PIERCE COUNTY TEST RESULTS			
LEVEL 1	9	0	9
LEVEL 2	12	0	12
LEVEL 3	9	0	9

	TOTAL TEST LOCATIONS	PASS	FAIL
GARAGE BUILDING TPU TEST RESULTS			
LEVEL 1	14	14	0
GARAGE BUILDING CITY OF TACOMA TEST RESULTS			
LEVEL 1	14	14	0
GARAGE BUILDING PIERCE COUNTY TEST RESULTS			
LEVEL 1	14	0	14

	TOTAL TEST LOCATIONS	PASS	FAIL
WAREHOUSE BUILDING TPU TEST RESULTS			
LEVEL 1	14	14	0
WAREHOUSE BUILDING CITY OF TACOMA TEST RESULTS			
LEVEL 1	14	14	0
WAREHOUSE BUILDING PIERCE COUNTY TEST RESULTS			
LEVEL 1	14	0	14

	TOTAL TEST LOCATIONS	PASS	FAIL
WATER DISTRIBUTION BUILDING TPU TEST RESULTS			
LEVEL 1	20	20	0
WATER DISTRIBUTION BUILDING CITY OF TACOMA TEST RESULTS			
LEVEL 1	20	20	0
WATER DISTRIBUTION BUILDING PIERCE COUNTY TEST RESULTS			
LEVEL 1	20	0	20

	TOTAL TEST LOCATIONS	PASS	FAIL
CRAFT SHOPS BUILDING TPU TEST RESULTS			
LEVEL 1	6	6	0
CRAFT SHOPS BUILDING CITY OF TACOMA TEST RESULTS			
LEVEL 1	6	6	0
CRAFT SHOPS BUILDING PIERCE COUNTY TEST RESULTS			
LEVEL 1	6	0	6

	TOTAL TEST LOCATIONS	PASS	FAIL
OUTDOOR TPU TEST RESULTS			
NORTH	1	1	0
SOUTH	1	1	0
OUTDOOR CITY OF TACOMA TEST RESULTS			
NORTH	1	1	0
SOUTH	1	1	0
OUTDOOR PIERCE COUNTY TEST RESULTS			
NORTH	1	0	1
SOUTH	1	0	1

In general, the TPU and City of Tacoma systems have good coverage throughout the campus, although suffer greatly in the south admin building basement levels. The Pierce County system has poor coverage throughout the entire TPU campus. Individual Spectrum analyzer screen captures for each of the three public safety systems are available upon request.

3 In-Building Coverage Overview

3.1 Distributed Antenna Systems

Distributed Antenna Systems are quite versatile in that multiple signal sources can be connected to simultaneously reinforce several different signals. For instance, a single DAS could reinforce several cellular carriers or public safety services at the same time. Combining both cellular and public safety services on the same DAS head-end and distribution is not recommended. Serious issues can be encountered when maintenance is being conducted on equipment by one of the service providers.

The most common installation of a DAS involves the entire building, but there are instances where they are only installed in certain targeted locations. In situations where only certain areas suffer severe coverage problems, it may only be necessary to reinforce signals in those areas.

A DAS is a network of ceiling antennas installed throughout a building that connect to a signal booster amplifying a specific wireless signal. The bi-directional amplifier (BDA) amplifies channels used by the radio system. A donor antenna is typically mounted on the roof of a facility with a BDA (or signal booster) housed in a telecom closet or other designated space. This would then feed a

series of horizontally distributed internal coverage antennas strategically placed via coaxial cable. See figure below for a diagram of the network system.

When designing a DAS, the donor signal is the most critical component. A DAS can distribute radio signals inside of a building with the same DAQ (Delivered Audio Quality) as the donor signal, at best. DAS systems add noise to the signal while also amplifying noise and interference. This slightly decreases the quality of the distributed radio signals as compared to the donor signal. Therefore, a reliable high-quality donor signal is paramount to implementing any DAS. Without it, a DAS will simply distribute a poor-quality signal throughout the building.

Other DAS design considerations include coordination with the licensee. System managers are careful to only authorize well designed BDAs on their systems. The FCC Licensees want to ensure the DAS design can meet their requirement standards and would not introduce interference into their network. However, a well-designed DAS is easily capable of providing signal enhancement without detriment to the existing donor radio network.

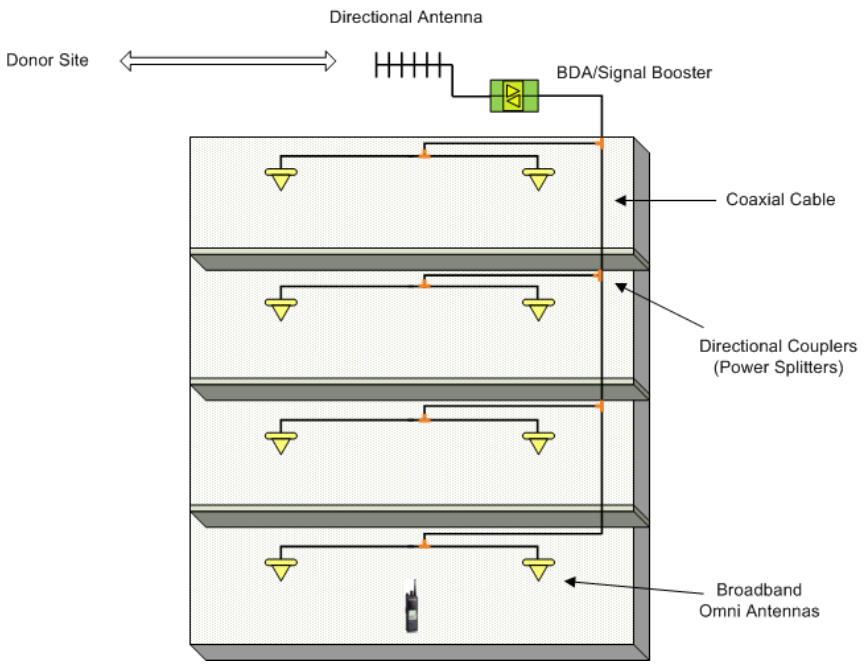
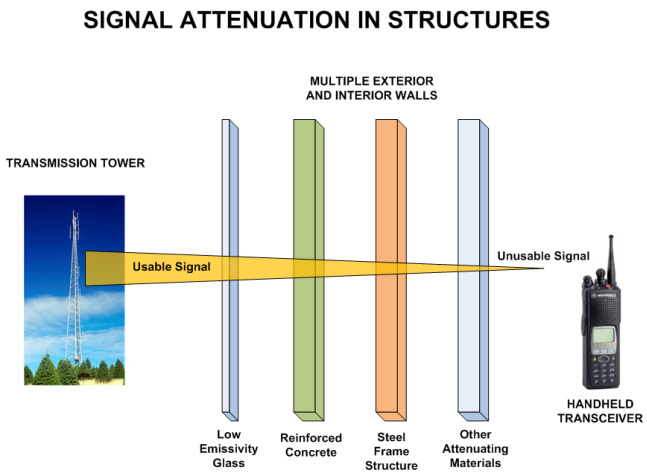


Figure 1: Distributed Antenna System Example

3.2 Attenuation Due to Modern Construction Materials

The challenge with many modern buildings is to be as energy efficient as possible. This mandates the use of insulating construction materials such as sheet-metal, concrete, and stone, in addition to low emissivity glass (also known as low-e value or LEV glass). These types of materials reduce the transfer of energy through building walls, lowering heating or cooling costs. Conversely, the same energy-blocking effects intended to isolate the building from exterior heating or cooling do an excellent job of reducing or attenuating other forms of energy, in this case radio frequency (RF) energy. For example, it is common to experience a 20 - 30 dB degradation in signal strength transitioning from outside to an inside or interior threshold.



In addition, building occupation and the interior office components (cubicles, dividers, steel shelving, cabinets, IDF and MDF infrastructure equipment, air handling duct systems and restroom construction) as well as human body absorption all contribute to RF signal attenuation within any structure.

3.3 Minimum Acceptable Signal Strength for Cellular

For LTE systems, there are various manufacturer and carrier specifications for minimum usable sensitivity of a handset, however in a real-world and faded signal environment (and properly engineered radio system), the target signal needs to be well above minimum signal levels for reliable data services. The following table summarizes the RSRP and RSRQ key performance indicator thresholds for LTE systems as used in this report.

		RSRP (dBm)	RSRQ (dB)
Excellent	Reliable Voice, Text, and data services	>=-75	
Good	Reliable voice and text service, with slight degradation of data services (>50%)	>=-95	>=-9
Fair	Voice and text services should work, however data will be degraded (<50%)	>=-105	>=-12
Poor	Unacceptable service. Voice and texts may fail, and data will be severely degraded.	<-105	<-12

RSRP Range: -140 to -44 dBm RSRQ Range: -19.5 to -3 dB

Source: "Key Performance indicators and Measurements for LTE Radio Network Optimization", (Wiley 2011 pgs. 230-232)

4 Recommendations

4.1 Cellular Signal Reinforcement

As indicated above, Cellular signals for all three carriers are mostly fair to poor in all buildings surveyed, which results in unreliable cellular communications while on site. A cellular signal enhancement system is recommended for all buildings surveyed, if the desire is to have reliable communications in the facility. If reliable cellular communications is not a requirement for a building, then those buildings could be eliminated from the initial design requirements. However, it is highly recommend that space, power, and connectivity to each facility be included in the initial design to allow for future expansion without further infrastructure upgrades.

An independent neutral host cellular fiber distributed antenna system (DAS) is recommended for the campus to provide the necessary cellular coverage. This should include the following:

Centralized head end location:

Designate a centralized location on campus where cellular head end equipment can be installed. This location should have easy access to internal campus fiber distribution as well as fiber connectivity to the street.

- Donor signals for a cellular DAS system are unlikely to be fed over-the-air. Carriers are likely to require fiber be brought to the head-end location from street vault.
- Space, power, cooling requirements will need to be coordinated with carriers. However, it is common for carriers to require a minimum of (2) racks per carrier plus additional (2) racks for TPU owned equipment. Additional wall space will also be required (8'x8' fire-rated plywood on wall).
- Head end will then distribute cellular signals to remote amplifiers mounted in telco closets throughout each building.
- Fiber systems are good for multiple carrier systems, large systems, and system where future expansion is anticipated. The head end for this system could be used to feed a DAS at another facility via a fiber connection as well. Carriers often prefer these types of systems due to the ability to control their signals on a sector by sector basis.

Remote amplifiers:

Designate a centralized location in each building, or each floor for larger buildings such as Admin North/South, where a remote amplifier can be mounted.

- Remote amplifiers will be spec'd to allow for multiple bands/services for up to three carriers with a single unit.
- Typical installations are wall mounted on 4'x8' sheet of fire-rated plywood when using passive coax distribution. If an active antenna system is selected, rack-mounted equipment may also be required in each building to provide Power over Ethernet connections.
- Space, power, cooling, and connectivity back to the head end will need to be coordinated depending on the spec'd equipment.

Distribution:

Provide connectivity from the remote amplifier locations in each building horizontally throughout each level.

- Distribution can be provided via ½" semi-rigid coax cable, if the spec'd equipment supports passive distribution.
- Distribution via CAT6A may be necessary for active antenna systems where Power-Over-Ethernet (POE) is required. This will depend on the final vendor equipment selection.
- Service antenna will be installed in the ceiling throughout each floor. In suspended ceilings, this will be installed below the ACT tiles. Antennas in hard lid areas or open ceilings will need to be surface mounted.

Opinion of Rough order of Magnitude costs: $2.00-$2.50 per square foot.

4.2 Public Safety Signal Reinforcement

As indicated above, public safety radio signals for the three entities surveyed (TPU, City of Tacoma, Pierce County) vary widely. The TPU and City of Tacoma radio transmitters appear to be closer to the facility than the Pierce County radio transmitters. The signal levels for TPU and City of Tacoma are above threshold for most areas within the buildings with the exception of the lower levels (L1 and below).

An independent 700/800 MHz public safety signal enhancement system is recommended for the lower levels of Admin North, Admin South, and the ECC to enhance the TPU radio signals which are utilized for day-to-day operations and the City of Tacoma which is required by Code (reference City of Tacoma fire code) for Emergency Responder coverage. If reliable coverage is desired for Pierce County 700 MHz then additional distribution may be necessary. However, it should be noted that the City of Tacoma and Pierce County systems are likely to be a single system in the future. Therefore, coverage from the City of Tacoma 800 MHz system may be sufficient for both systems.

Centralized head end location:

Designate a centralized location on campus where public safety head end equipment can be installed. This location should have easy access to internal campus fiber distribution as well connectivity to the roof for an over-the-air donor antenna(s) to be mounted.

- Donor signals for a public safety DAS system will be fed over the air.
- Space, power, cooling requirements will need to be coordinated. However, it is common for public safety DAS head end equipment to be wall mounted. Wall space will be required (8'x8') fire-rated plywood on wall).
- A minimum of (0.5) rack may be necessary for rack-mounted operations/maintenance console, and associated equipment.
- Head end will then distribute public safety signals to remote amplifiers mounted in telco closets throughout each building.
- Fiber systems are good for multiple carrier systems, large systems, and system where future expansion is anticipated. The head end for this system could be used to feed a DAS at another facility via a fiber connection as well.

Remote amplifiers:

Designate a centralized location in each building, or each floor for larger buildings such as Admin North/South, where a remote amplifier can be mounted.

- Remote amplifiers will be spec'd to allow for 700/800 MHz for up to three carriers with a single unit.
- Typical installations are wall mounted on 4'x8' sheet of fire-rated plywood when using passive coax distribution.
- Space, power, cooling, and connectivity back to the head end will need to be coordinated depending on the spec'd equipment.

Distribution:

Provide connectivity from the remote amplifier locations in each building horizontally throughout each level.

- Distribution can be provided via ½" semi-rigid coax cable.
- Service antenna will be installed in the ceiling throughout each floor. In suspended ceilings, this will be installed below the ACT tiles. Antennas in hard lid areas or open ceilings will need to be surface mounted.
- Fiber fed bi-directional amplifier and distributed antenna system:
  Would provide sufficient emergency responder radio coverage throughout the facility.
  System can be scaled back if it is determined that coverage is not needed in certain areas of the facility.
  Emergency responder radio signals are separated from cellular enhancement system to avoid code compliance issues.
- Opinion of Rough order of Magnitude costs: $1.50-$2.00 per square foot.

  Spare Hardware:
  Add in language for spares (N+1, and 10% spares)
  Add in language for training (TPU to own and operate system)

APPENDIX A: Tabular Test Results For Each Building

ADMIN NORTH

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
Ground	01	92.26	85.66	107.6	107/13	92/6	108/12
Ground	02	85.07	90.15	105.8	109/12	94/7	109/11
Ground	03	93.48	93.26	107.2	111/10	117/14	110/12
Ground	04	90.55	83.45	107.8	116/11	111/10	112/11
Ground	05	91.9	81.5	106.3	117/14	106/8	117/14
Ground	06	101	93.61	105.1	114/11	100/09	110/11
Ground	07	99.69	100.5	106.1	122/16	108/09	112/10
Ground	08	96.24	94.69	108.4	116/14	111/11	110/11
Ground	09	95.18	81.86	105.4	107/13	114/10	117/11
Ground	10	86.22	83.93	108	106/11	99/11	112/11
Ground	11	101.1	75.76	106.4	117/12	111/10	110/10
Ground	12	101.7	83.97	107.7	114/12	110/12	111/09
Ground	13	92.63	84.97	108.7	109/11	109/12	99/10
Ground	14	84.01	82.39	105.7	112/12	108/12	95/10
Ground	15	84.47	63.72	104.8	112/14	106/11	91/10
Ground	16	99.42	75.31	107.6	108/10	115/12	97/8
Ground	17	89.99	72.64	107	106/12	111/13	100/10
Ground	18	92.23	69.19	105.6	115/14	113/10	94/11
Ground	19	80.31	77.99	106.5	100/11	106/14	92/11
Ground	20	77.68	74.16	104.5	110/15	94/11	81/14
Main	01	77.02	77.81	107.8	107/11	88/11	105/14
Main	02	73.59	76.35	106.6	113/14	90/11	110/8
Main	03	75.07	71.5	106.3	110/10	97/11	105/8
Main	04	71.1	73.56	104.3	112/14	88/11	101/9
Main	05	75.5	68.11	102.2	105/13	91/11	102/9

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
Main	06	87.37	69.25	105.8	115/14	115/15	115/15
Main	07	90.7	83.33	108.1	121/14	107/6	111/10
Main	08	70.87	71.89	107.5	110/11	98/11	106/11
Main	09	87.26	83.09	108.4	106/12	85/11	100/11
Main	10	84.52	84.78	108.8	115/10	101/11	110/10
Main	11	94.68	69.48	107.9	115/12	116/11	112/10
Main	12	76.03	77.27	107.6	110/13	102/11	107/10
Main	13	74.14	82.8	107.6	110/13	84/11	106/9
Main	14	85.08	86.19	107.9	110/9	96/11	101/8
Main	15	94.59	75.19	106.6	114/10	113/10	102/11
Main	16	89.72	72.31	107.6	111/13	114/09	105/8
Main	17	91.35	84.65	107.2	101/11	109/10	100/10
Main	18	76.59	81.87	109.2	111/13	101/11	108/10
Main	19	82.71	87.66	107.5	101/11	107/7	95/10
Main	20	79.86	72.08	107.5	100/10	108/8	91/12
2	01	73.76	67.87	106.4	97/12	82/11	104/11
2	02	72.23	74.2	100.8	100/17	104/12	102/11
2	03	76.68	67.18	105	103/14	96/6	105/11
2	04	73.06	71.22	102.7	86/10	84/7	102/10
2	05	71.29	76.19	105.1	99/12	91/06	105/11
2	06	87.26	80.49	105.4	104/12	80/11	102/10
2	07	91.58	86.03	105.5	118/17	91/11	104/11
2	08	78.1	81.15	108.6	108/13	106/7	105/10
2	09	81.29	74.57	106.6	102/11	95/6	114/11
2	10	73.14	75.49	104.9	96/9	89/6	108/10
2	11	93.49	78.1	104.8	111/11	104/14	102/10
2	12	89.36	92.21	105.1	115/13	103/9	106/11
2	13	78.48	87.26	107	111/14	105/11	106/12
2	14	89.37	84.6	107.6	118/14	105/7	113/12
2	15	77.41	62.31	108.6	102/14	104/7	92/11

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
2	16	94.58	70.24	107.3	110/12	116/13	101/14
2	17	100.1	75.4	106.7	111/12	102/11	109/10
2	18	97.57	76.94	106.1	112/13	99/07	111/10
2	19	85.14	72.94	106.1	111/12	107/8	90/11
2	20	80.64	67.68	107.4	109/13	108/7	93/9
3	01	87.17	83.52	105	103/10	96/6	106/11
3	02	78.73	77.96	104.7	104/13	105/12	110/10
3	03	69.13	64.24	106.2	101/12	93/6	105/13
3	04	67.37	71.23	101.9	95/11	86/7	101/12
3	05	66.07	58.65	98.9	103/14	84/6	81/10
3	06	73.62	70.6	96.37	107/15	100/8	98/10
3	07	92.93	89.13	104.2	105/15	105/8	109/13
3	08	82.12	87.68	103.5	107/12	96/6	108/11
3	09	73.01	80.19	104.4	96/12	96/6	102/15
3	10	53.01	63.65	102.3	107/16	78/6	90/10
3	11	91.41	68.61	102.5	99/12	109/12	99/10
3	12	92.51	72.17	103.1	108/14	115/13	101/12
3	13	90.07	85.4	107.7	107/13	114/15	96/10
3	14	92.17	82.06	104.9	113/13	97/7	100/11
3	15	70.44	59.33	106.6	106/14	98/7	87/9
3	16	81.83	71.8	103.6	112/16	110/12	92/10
3	17	88.85	80.17	105.8	114/16	110/11	99/11
3	18	90.08	85.32	106.8	107/15	109/12	91/10
3	19	78.23	80.37	101.5	93/13	100/12	88/11
3	20	73.54	62.4	103.8	101/15	100/11	87/11
4	01	76.72	65.52	103.2	102/16	90/10	93/13
4	02	65.1	70.01	98.3	100/15	84/6	95/11
4	03	75.94	75.57	94.1	98/12	96/10	106/11
4	04	66.48	56.19	105.5	87/11	81/7	89/11
4	05	58.16	65.46	97.38	106/14	89/14	87/10

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
4	06	69.87	58.67	94.99	103/13	102/15	86/9
4	07	80.58	71.98	98.94	94/14	92/7	88/9
4	08	75.43	78.26	100.4	111/15	91/6	99/9
4	09	84.41	90.16	108.6	103/15	104/6	103/9
4	10	49.9	53	106.7	101/15	82/7	88/9
4	11	78.68	55.89	101.2	92/14	86/9	83/14
4	12	74.49	63.63	95.3	101/16	97/13	90/12
4	13	77.29	69.11	105.2	104/15	97/6	93/10
4	14	77.61	74.07	104.7	102/15	97/6	87/14
4	15	55.69	53.5	102.2	91/15	84/6	83/12
4	16	74.82	54.44	97.36	92/13	100/13	78/10
4	17	78.84	66.14	92.83	93/14	87/7	84/12
4	18	76.85	66.26	87.81	95/16	101/10	86/12
4	19	77.09	60.64	102.3	95/14	101/18	80/11
4	20	62.81	58.39	90.38	89/14	85/7	79/11

ADMIN SOUTH

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
Basement	01	99.05	92.79	109.5	122/16	124/15	115/9
Basement	02	108	106.8	110.3	136/20	129/17	128/18
Basement	03	104.5	108.5	110.5	124/18	127/17	none/none
Basement	04	110	107.1	108.7	none/none	128/19	120/1
Basement	05	100.3	100.7	108.5	111/7	114/11	110/10
Basement	06	107.2	97.94	108.4	126/16	124/14	109/8
Basement	07	108.8	105.9	109.9	137/20	135/20	125/17
Basement	08	109.5	111.3	105.8	138/20	131/20	138/20
Basement	09	108.5	106.2	107	133/20	113/13	109/9
Basement	10	103	101.9	108.8	122/14	114/11	117/11
Basement	11	107.3	105.6	107.3	126/15	none/none	115/10
Basement	12	108.2	111.6	110	none/none	136/20	123/13
Basement	13	109.5	109	109.4	none/none	none/none	none/none
Basement	14	105.4	103.4	110.2	133/19	121/13	115/10
Basement	15	95.17	93.01	107.3	121/12	108/11	107/11
Basement	16	107.3	109.7	108.4	none/none	none/none	120/12
Basement	17	109.8	107.5	110.3	none/none	none/none	125/15
Basement	18	106.7	110.9	108.7	none/none	none/none	135/20
Basement	19	107.8	108.1	109	136/20	127/15	121/12
Basement	20	95.32	94.65	107.8	119/13	106/11	99/10
Ground	01	88.67	81	106	116/10	105/10	113/12
Ground	02	94.89	81.62	107	113/14	112/11	114/11
Ground	03	97.31	84.84	108.9	118/14	111/9	117/14
Ground	04	90.04	80.6	106.2	116/11	102/7	111/10
Ground	05	83.97	72.27	104.7	104/13	111/12	99/10
Ground	06	99.58	92.32	106.1	116/12	114/18	114/12
Ground	07	101.4	93.68	107	120/16	107/9	114/13
Ground	08	103.5	96.47	107.7	114/12	106/9	117/12

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
Ground	09	88.23	89.54	105	112/14	97/9	101/17
Ground	10	101.9	78.78	106.3	115/13	116/10	106/9
Ground	11	87.58	83.67	107.5	114/11	117/12	105/10
Ground	12	96.47	86.35	108.5	118/13	118/11	111/11
Ground	13	103	93.82	105.3	124/17	109/8	118/15
Ground	14	99.22	84.5	106.3	120/15	108/10	112/11
Ground	15	91.91	85.07	107.8	116/13	112/10	106/10
Ground	16	95.87	83.1	109.5	114/12	109/12	107/12
Ground	17	91.01	75.02	105.4	110/12	105/11	102/12
Ground	18	104.9	81.69	107.1	121/16	114/9	116/12
Ground	19	102.4	78.99	107.1	119/15	112/9	111/12
Ground	20	93.56	77.42	106.2	116/13	107/9	112/12
Main	01	102	88.88	106.1	121/17	114/9	116/13
Main	02	89.59	86.27	105.2	114/13	108/10	116/11
Main	03	90.61	81.34	106.2	118/13	108/9	113/10
Main	04	85.67	70.79	106.7	114/10	118/13	115/11
Main	05	83.69	74	106.7	111/14	111/15	108/4
Main	06	92.71	87.04	106.7	117/13	113/10	106/13
Main	07	96.46	95.76	106.4	121/13	113/9	115/10
Main	08	98.4	95.58	104.7	119/16	108/8	115/12
Main	09	90.58	90.12	108	113/10	100/6	111/12
Main	10	81.84	77.21	105.2	108/12	92/10	109/11
Main	11	93.58	77.48	106.6	113/13	114/10	105/10
Main	12	97.21	90.12	106.1	119/13	114/14	104/10
Main	13	102.3	90.92	107.6	123/17	114/12	116/11
Main	14	90.02	86.65	105.5	115/14	104/9	112/11
Main	15	95.94	82.26	106.4	118/14	86/6	105/13
Main	16	100.9	81.32	108.9	109/13	111/12	104/12
Main	17	91.61	78.78	104.8	113/10	108/9	110/11
Main	18	85.55	73.72	106.8	114/11	104/9	99/8

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
Main	19	87.98	81.58	106.4	113/12	98/9	100/11
Main	20	89.6	78.13	105.4	112/12	109/12	102/8
2	01	94.05	90.31	107.3	113/15	109/11	116/11
2	02	94.28	88.64	108.8	111/13	109/10	117/11
2	03	94.38	85.75	107.5	121/14	122/13	115/10
2	04	79.26	83.43	105.9	117/11	113/14	112/10
2	05	75.97	70.84	106.2	109/15	112/10	102/8
2	06	96.43	89.9	107.6	115/14	115/12	119/15
2	07	98.43	90.22	105.9	115/12	116/10	112/13
2	08	102.4	99.84	106.3	110/11	104/8	106/13
2	09	83.7	95.67	106.3	113/12	113/13	101/11
2	10	85.73	78.27	106.1	109/10	112/11	109/10
2	11	102.4	95.39	108.8	116/15	115/13	115/11
2	12	105.5	87.68	106	121/15	119/14	109/10
2	13	103.2	89.71	107.8	121/15	111/11	104/10
2	14	96.94	90.41	107.7	118/12	104/8	106/9
2	15	96.87	87.83	107.5	114/11	120/12	99/11
2	16	104.2	88.49	108.1	114/13	102/10	113/12
2	17	104.7	77.77	107.1	119/13	108/13	112/9
2	18	103.2	92.4	106.9	115/15	116/14	119/12
2	19	91.46	88.77	104.4	115/11	103/8	107/12
2	20	88.99	73.39	107	103/11	110/12	96/10
3	01	95.87	86.03	106.2	117/13	105/12	112/10
3	02	98.45	84.95	109.1	114/11	106/13	113/11
3	03	91.78	87.65	108.1	114/9	119/11	112/13
3	04	96.26	83.89	107.1	110/10	114/10	108/16
3	05	65.88	67.59	104.8	116/10	102/7	100/8
3	06	84.16	84.58	107	115/14	107/13	109/11
3	07	100	90.23	107.7	120/14	112/12	116/12
3	08	80.32	86	107	111/12	103/9	117/12

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
3	09	83.35	84.51	108.8	119/12	116/11	113/11
3	10	79.85	74.92	107.7	116/12	113/10	105/9
3	11	86.34	93.03	105.8	111/15	118/14	112/12
3	12	107.4	88.07	106.5	112/11	114/12	108/12
3	13	97.97	81.22	105.6	115/12	107/11	107/12
3	14	86.87	71.78	105.6	110/10	112/13	99/10
3	15	101.6	82.89	105.4	109/9	113/13	99/10
3	16	96.38	73.5	103.6	116/14	112/14	97/10
3	17	96.11	79.44	104.8	112/12	115/13	99/10
3	18	94.74	86.29	106.3	112/13	110/10	104/11
3	19	85.81	75.54	106	108/12	105/10	93/10
3	20	71.02	72.53	104.6	108/12	109/13	99/12

ECC BUILDING

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
1	01				/	/	/
1	02				/	/	/
1	03				/	/	/
1	04				/	/	/
1	05				/	/	/
1	06	103.9	90.16	109.1	110/10	111/10	106/14
1	07				/	/	/
1	08	107.5	105.1	109	118/12	118/12	113/8
1	09				/	/	/
1	10	105.8	102.9	110.4	120/9	123/18	101/8
1	11	91.95	92.36	107.8	104/9	117/14	98/11
1	12				/	/	/
1	13	95.93	96.49	108.6	115/11	115/9	115/10
1	14				/	/	/
1	15	102.7	102.5	107	122/12	117/13	110/13
1	16	85.66	80.46	107.1	102/9	97/10	99/10
1	17				/	/	/
1	18	97.81	90.12	108.3	109/10	107/7	103/8
1	19				/	/	/
1	20	76.64	62.35	100.8	99/11	104/7	89/11
2	01	85.32	80.27	106	101/10	108/8	95/10
2	02				/	/	/
2	03	88.5	80.33	106.2	105/11	113/13	99/10
2	04				/	/	/
2	05	80.51	81.87	106.4	98/9	86/10	93/12
2	06	98.6	85.15	109	103/9	115/12	98/10
2	07				/	/	/
2	08	89.88	87.1	106.4	104/11	115/13	100/8

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
2	09				/	/	/
2	10	80.4	88	108.8	104/11	108/7	101/11
2	11	76.24	67.26	104.7	94/12	105/8	91/10
2	12				/	/	/
2	13	94.91	82.15	108	111/11	105/10	102/10
2	14				/	/	/
2	15	78.85	80.22	105.4	94/10	100/6	89/8
2	16	65.08	67.52	95.83	82/14	94/9	77/11
2	17				/	/	/
2	18	71.3	67.55	99.25	90/10	101/9	85/8
2	19				/	/	/
2	20	73.56	64.68	105.7	98/12	103/12	86/13
3	01				/	/	/
3	02				/	/	/
3	03				/	/	/
3	04				/	/	/
3	05				/	/	/
3	06				/	/	/
3	07	88.06	80.09	107.5	110/13	105/6	48/12
3	08	82.96	81.25	106.5	110/14	109/7	99/10
3	09	84.56	74.1	108.8	109/15	109/14	101/13
3	10				/	/	/
3	11	76.97	66.99	102.3	105/17	100/7	88/11
3	12	85.34	78.54	105	106/14	98/6	93/11
3	13	74.39	71.4	106	112/15	110/10	100/11
3	14	75.73	82.77	99.41	98/13	101/7	83/10
3	15	63.58	73.29	106.8	94/13	101/7	84/9
3	16				/	/	/
3	17				/	/	/
3	18	62.29	59.1	95.88	96/13	92/5	78/8

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
3	19				/	/	/
3	20				/	/	/

GARAGE

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
1	01	87.32	60.2	102.4	114/14	107/10	99/10
1	02	63.01	58.28	105.9	112/12	108/14	92/14
1	03	76.82	65.79	104.9	117/13	110/11	93/10
1	04	86.6	76.86	105	114/14	109/11	100/9
1	05	87.14	73.59	106.7	120/12	111/12	103/8
1	06	82.89	79.71	104.2	109/13	119/15	84/8
1	07	78.26	70.47	104.7	105/13	105/10	86/9
1	08	73.34	71.47	107.7	114/14	120/13	112/13
1	09	82.48	82.91	105.9	115/13	114/11	115/11
1	10				/	/	/
1	11				/	/	/
1	12				/	/	/
1	13				/	/	/
1	14	84.07	76.94	104.2	109/11	104/14	98/13
1	15	87.68	75.8	105	106/10	100/11	92/11
1	16				/	/	/
1	17				/	/	/
1	18	69.44	66.78	106.2	111/14	113/12	105/13
1	19	80.27	69.09	105	95/10	108/13	102/12
1	20	86.13	72.07	107.1	118/11	120/13	111/12

WAREHOUSE

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
1	01				/	/	/
1	02	88.94	66.79	102.7	103/12	101/7	102/2
1	03	78.41	70.24	102.3	98/8	93/6	102/14
1	04	67.73	53.1	103.4	92/10	90/6	93/11
1	05	66.11	59.21	105.8	117/15	101/15	89/10
1	06	57.43	61.25	103.3	114/13	88/6	94/11
1	07	57.59	59.13	103.4	109/13	94/6	91/15
1	08	81.15	67.02	102.8	103/12	103/9	93/12
1	09				/	/	/
1	10				/	/	/
1	11				/	/	/
1	12	57.74	51.4	105.6	103/10	92/9	103/8
1	13	77.12	66.67	103.4	104/11	95/6	99/12
1	14	71.5	67.4	100.9	102/13	93/9	85/13
1	15	91.58	57.68	101.3	107/13	101/7	93/11
1	16	85.55	71.63	104.1	105/14	100/11	105/11
1	17				/	/	/
1	18				/	/	/
1	19	83.16	55.52	98.55	97/11	102/6	95/11
1	20	91.34	64.42	103.8	97/11	105/12	98/10

WATER DISTRIBUTION

LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
1	01	77.76	62.96	106.4	102/7	104/6	102/11
1	02	70.52	70.16	106.7	103/9	101/6	102/11
1	03	71.54	68.95	107.2	107/12	109/11	104/10
1	04	76.96	72.17	105.9	108/11	106/6	108/12
1	05	85.33	82.43	107.9	113/15	98/6	108/11
1	06	66.49	61.56	107.9	93/12	98/6	103/10
1	07	71.79	64.14	106.9	104/10	107/9	104/11
1	08	79.07	71.59	106.2	112/12	100/9	105/12
1	09	76.51	72.36	105.7	109/10	106/6	108/12
1	10	80.98	81.39	107.8	117/14	101/6	106/8
1	11	72.45	67.92	104.5	103/11	101/13	96/11
1	12	78.64	70.24	104.1	106/10	105/6	100/9
1	13	93.28	75.75	108.6	102/10	94/6	97/11
1	14	67.26	75.69	104.5	104/10	98/13	100/11
1	15	79.89	85.84	104.1	110/12	97/6	102/12
1	16	74.3	73.06	107.9	104/10	91/7	94/10
1	17	69.1	75.96	105.3	100/12	91/7	98/9
1	18	54.48	56.76	102.1	98/10	84/6	87/11
1	19	73.72	67.78	109.4	100/9	96/13	97/11
1	20	73.62	60.15	104.9	99/9	91/6	96/10

CRAFT SHOPS

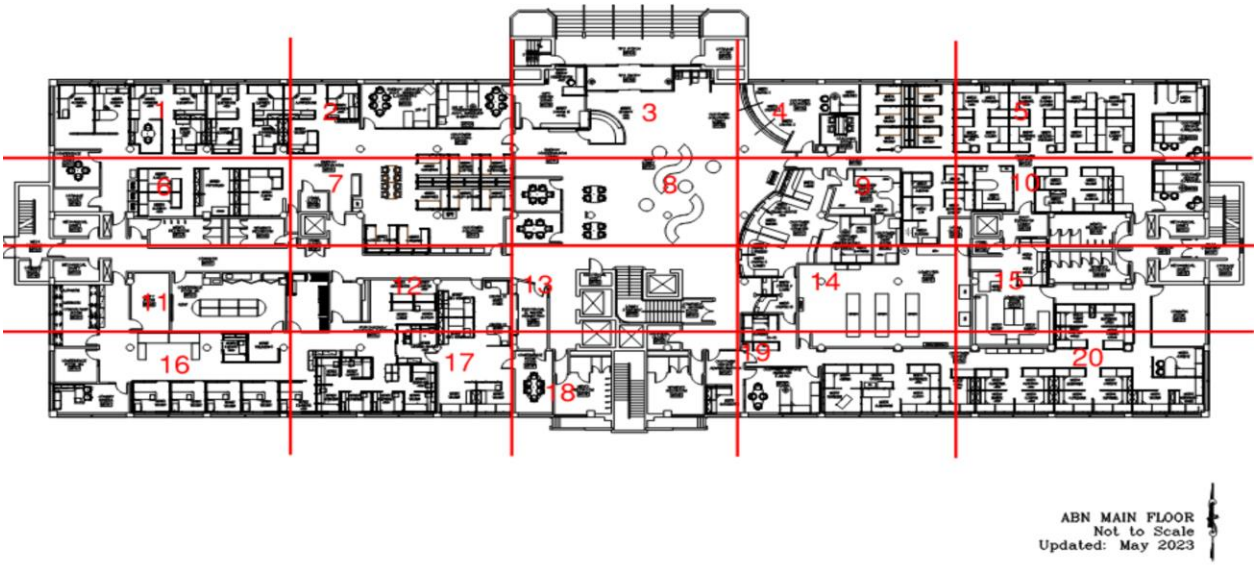
LEVEL	GRID	TPU -dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
1	01	79.63	59.04	105.7	105/13	99/6	98/12
1	02	86.79	84.29	103.5	108/12	101/6	93/11
1	03	81.08	62.71	103.7	106/14	99/7	90/9
1	04	73.25	67.01	107.3	99/13	94/6	92/14
1	05	92.49	64.94	105.7	105/15	107/13	96/12
1	06	79.79	67.67	101.6	109/16	98/10	89/10

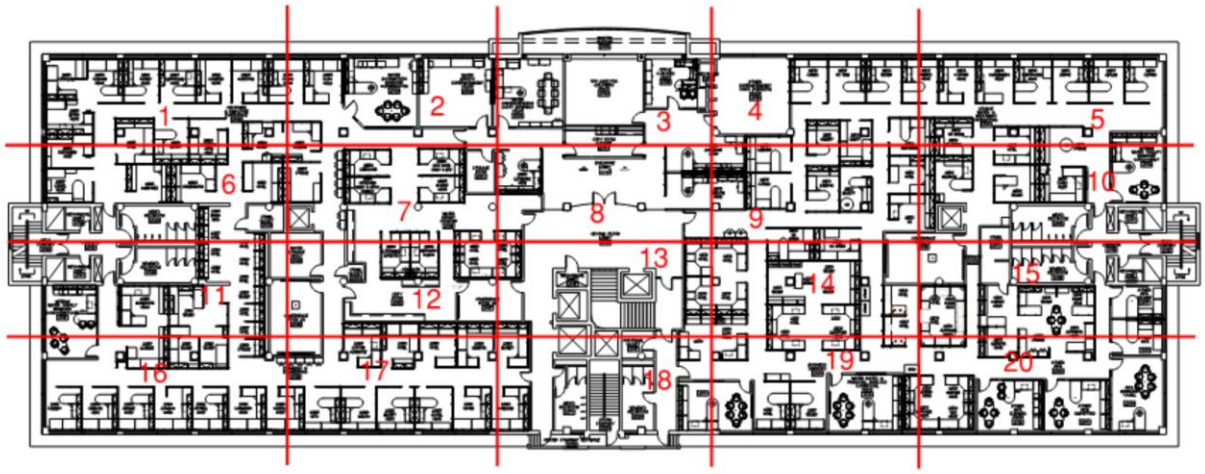
OUTSIDE

LOCATION	GRID	TPU - dBm	CITY OF TACOMA -dBm	PIERCE COUNTY -dBm	AT&T RSRP/RSRQ -dBm	T-MOBILE RSRP/RSRQ -dBm	VERIZON RSRP/RSRQ -dBm
Outside #1 55' S of ABS	North	66.7	47.68	96.24	91/12	90/9	67/10
Outside #2 100' E of craft shop	South	64.5	60.6	97.4	102/16	89/6	80/10

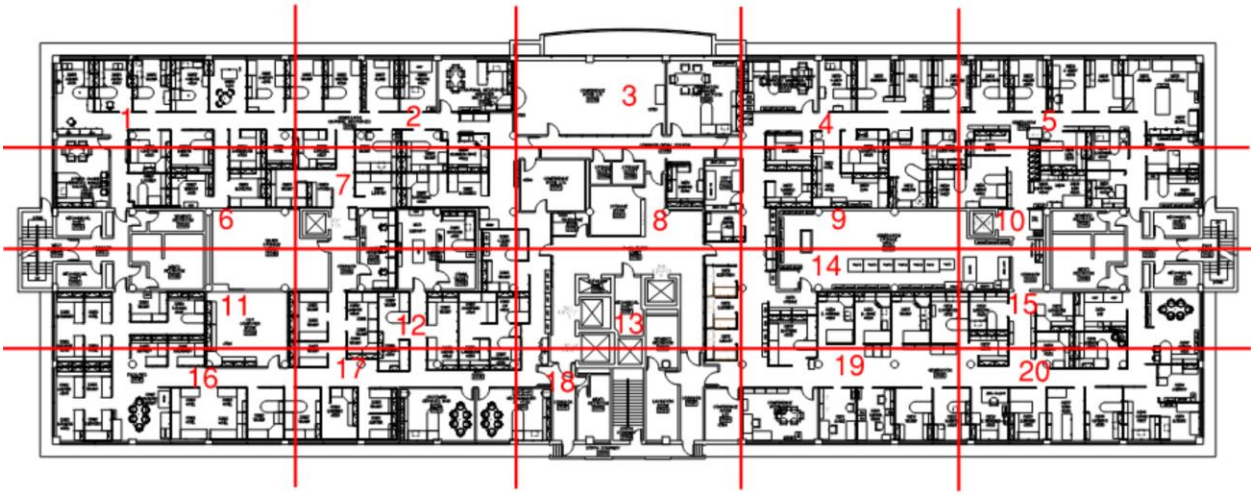
APPENDIX B: Building Floorplans With Test Grids

ADMIN NORTH

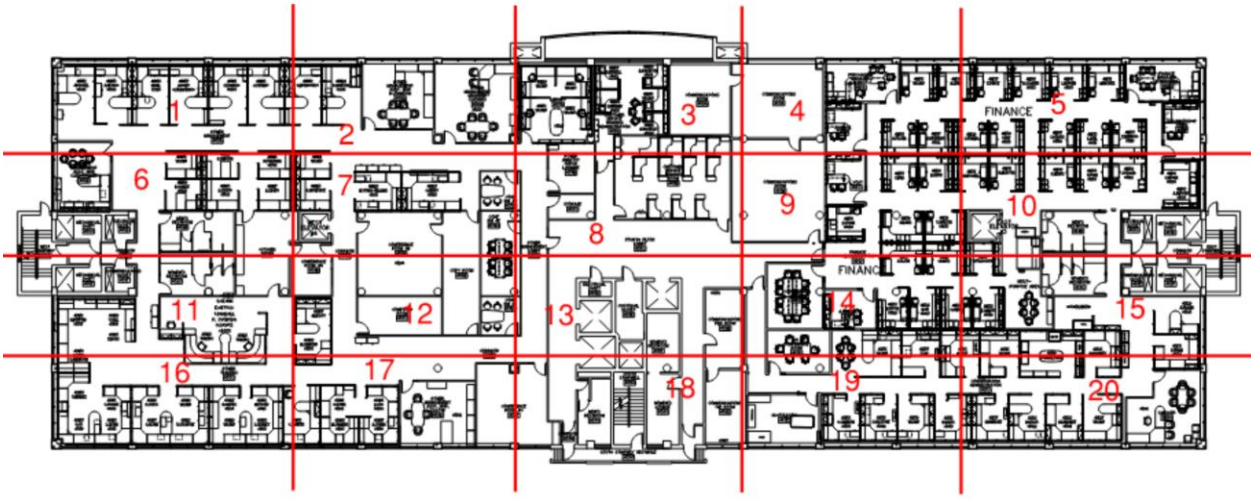




ABN 2
Not to Scale
Updated: June 2023

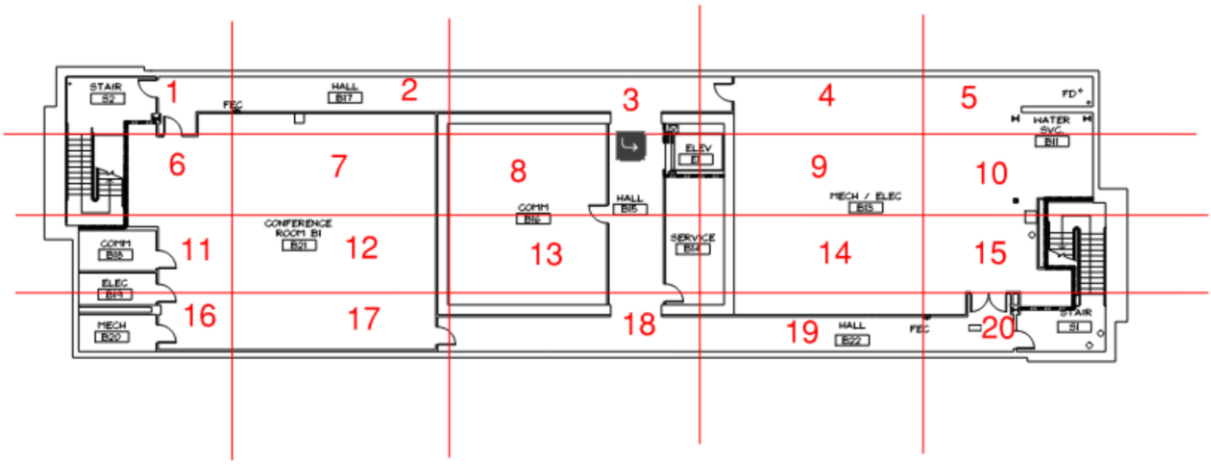


ABN THIRD FLOOR
Not to Scale
Updated: June 2023

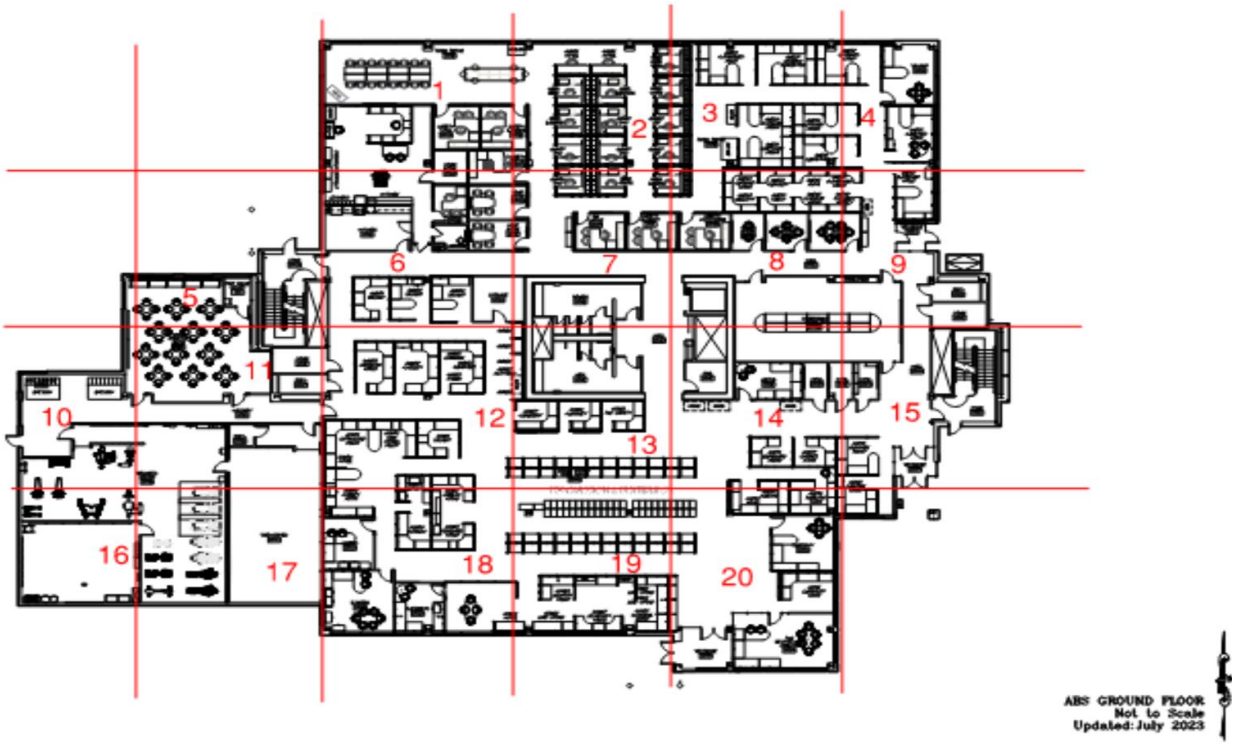


ABN FOURTH FLOOR
Not to Scale
Updated: May 2023

ADMIN SOUTH



ABS BASEMENT
Not to Scale
Updated: March 2019


1
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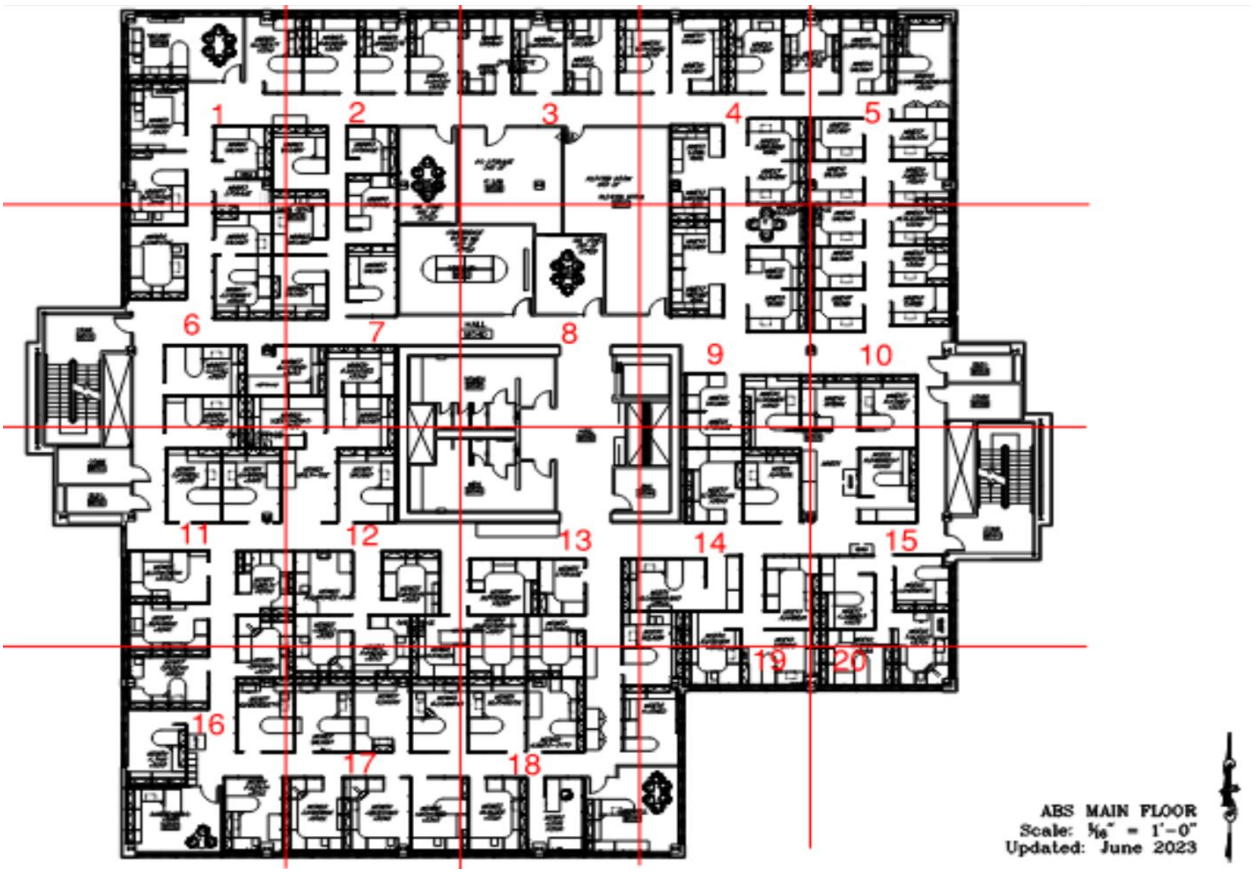
ABS GROUND FLOOR
Not to Scale
Updated: July 2023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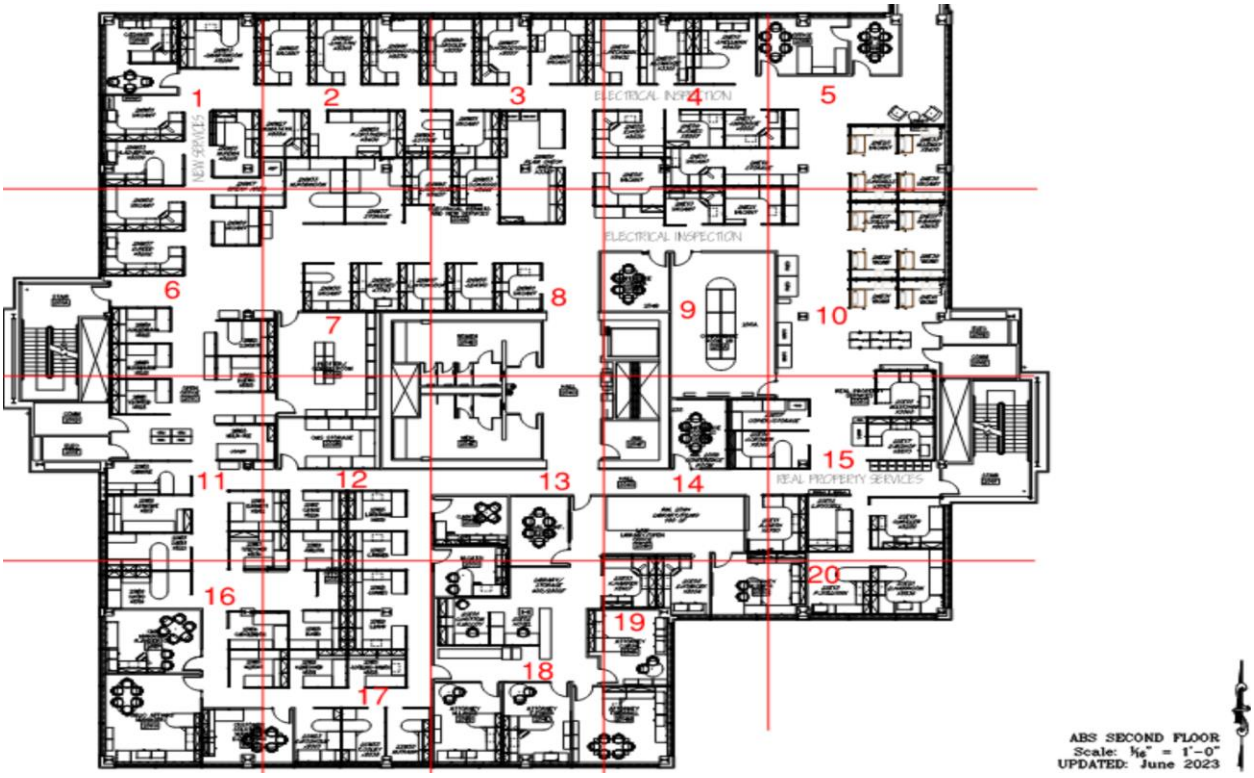
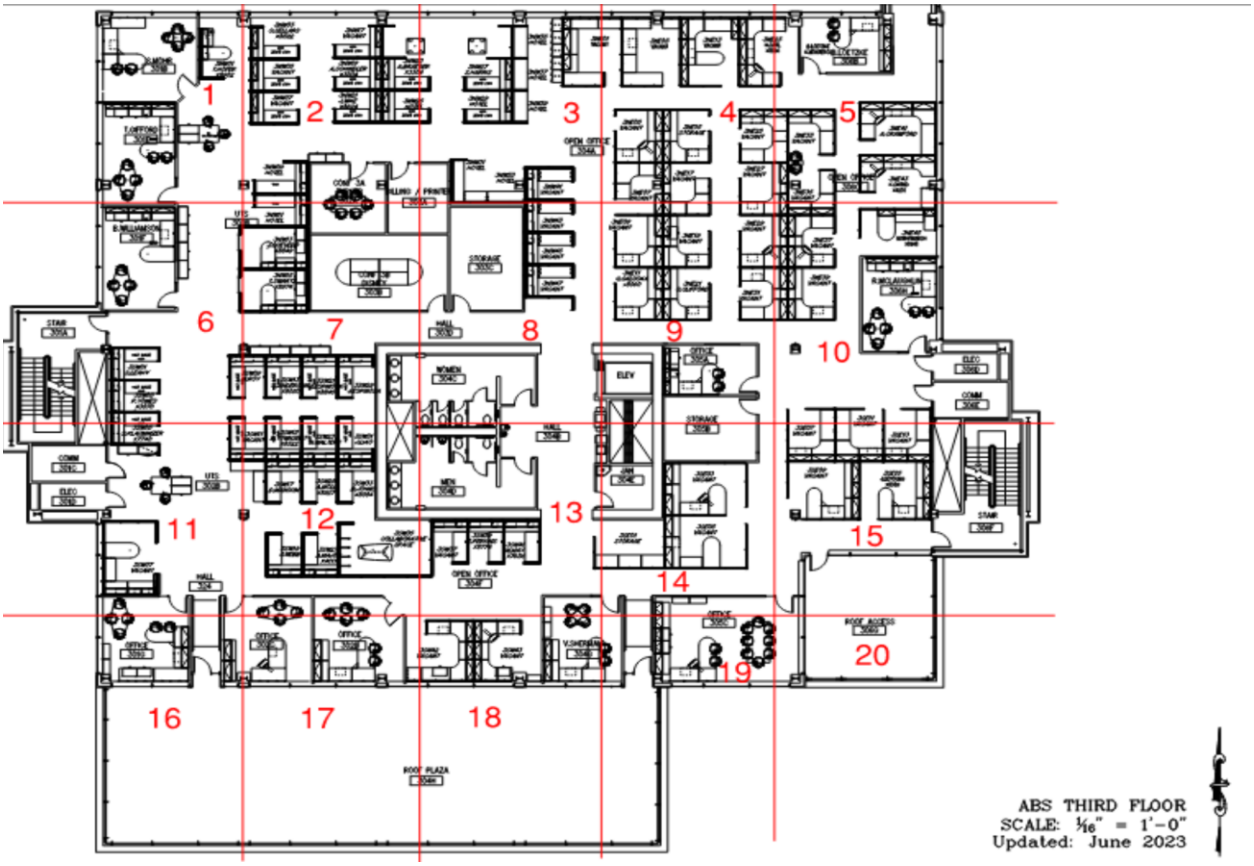
ABS MAIN FLOOR
Scale: 1/16" = 1'-0"
Updated: June 2023



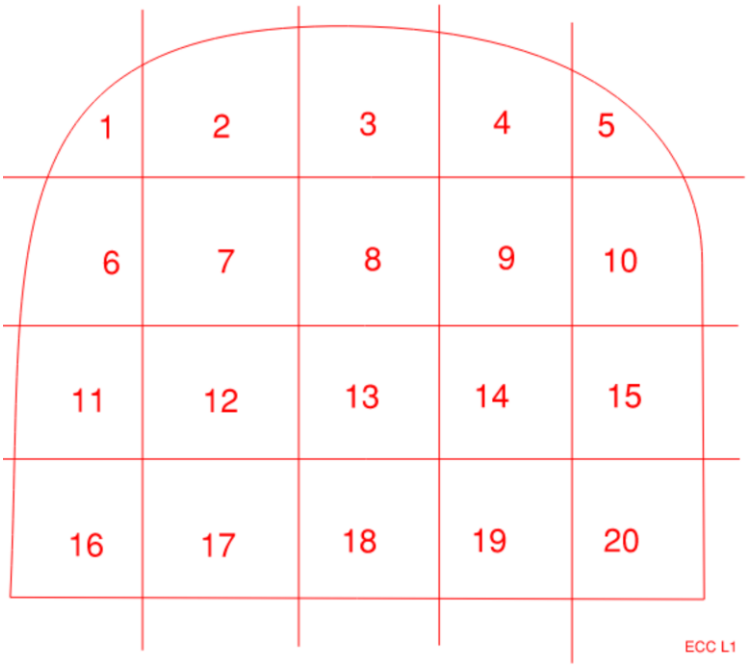
ABS SECOND FLOOR
Scale: 1/16" = 1'-0"
UPDATED: June 2023

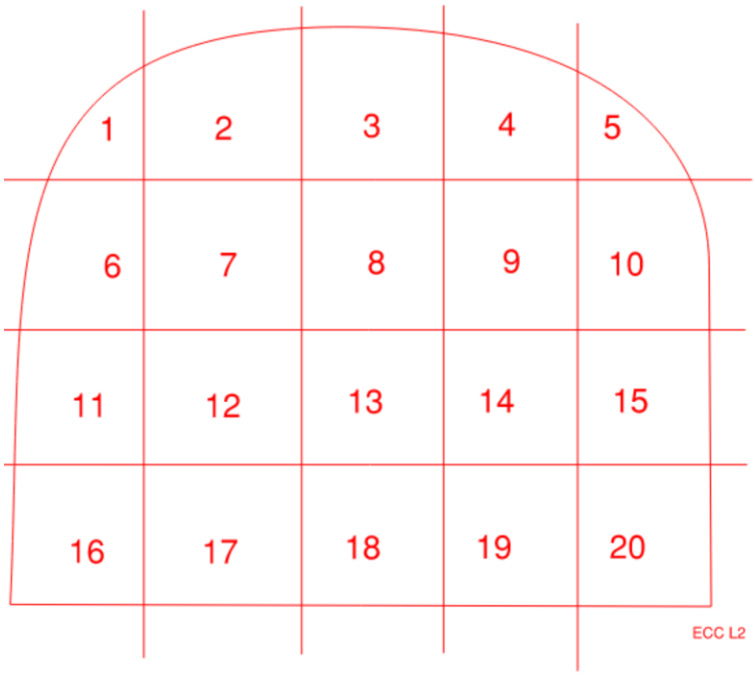


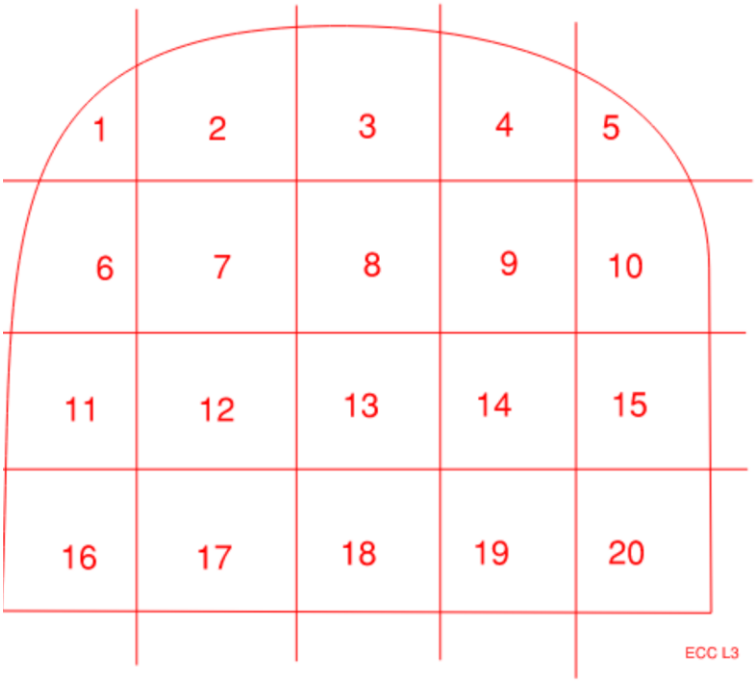
ABS THIRD FLOOR
SCALE: 1/16" = 1'-0"
Updated: June 2023

ECC BUILDING

FLOORPLANS ARE BASED ON GOOGLE EARTH VIEWS FOR SECURITY REASONS



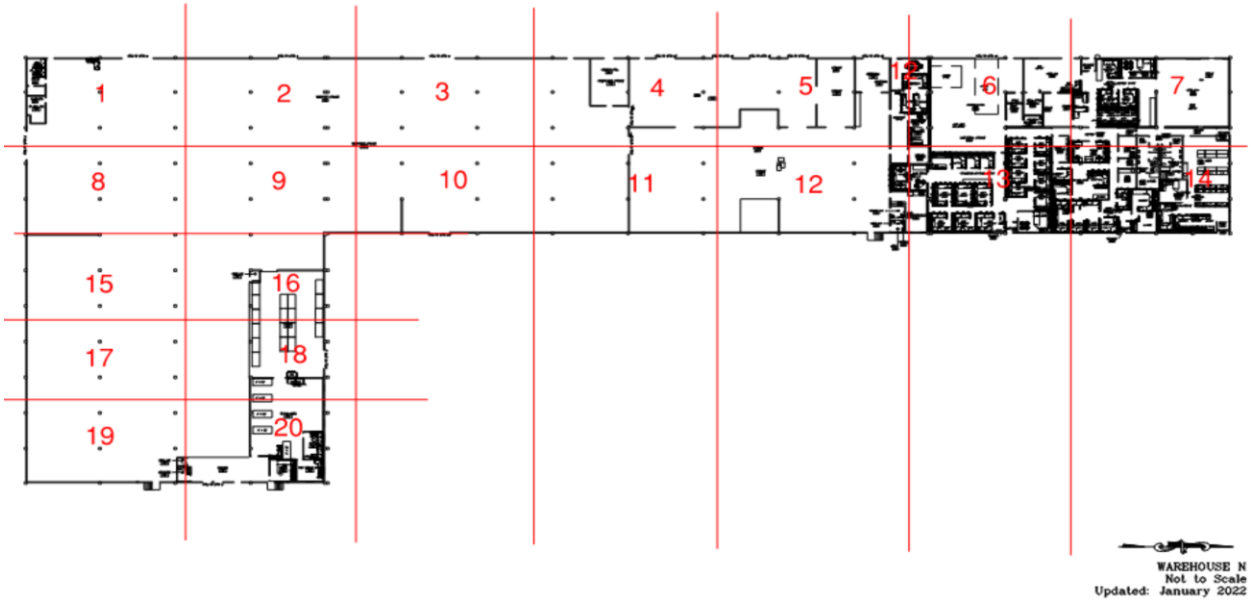




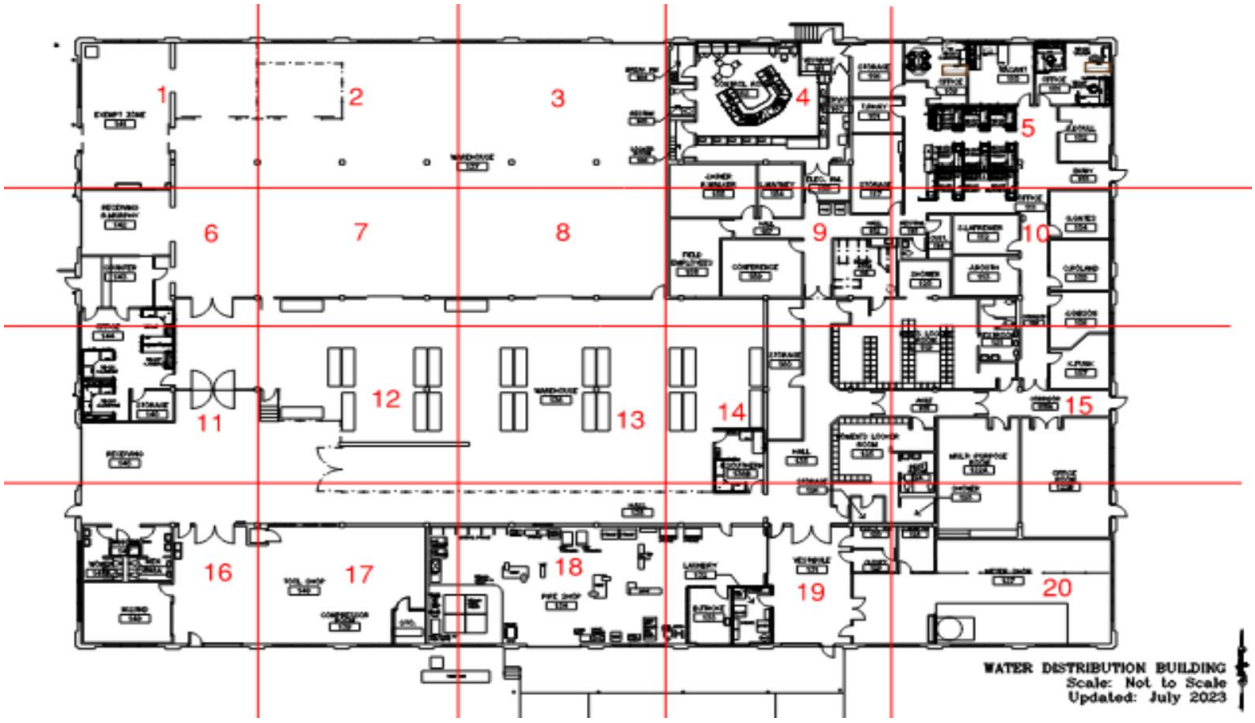
FLEET GARAGE

Garage 1
Scale: ½"=1'-0"
Updated: March 2018

WAREHOUSE

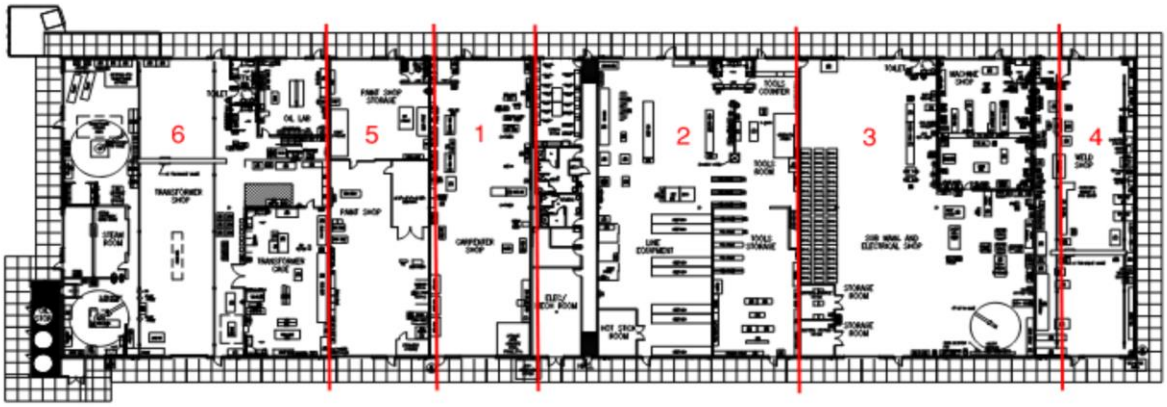


WATER DISTRIBUTION



CRAFT SHOPS

SURVEYED IN ADDITION TO ORIGINAL SCOPE



Shops Building
Scale: 1/32" = 1'-0"
Updated: March 2023

OUTDOOR