Technology Matrix from December 2014 PNT EXCOM Tiger Team Report

✓ = Yes
✓ = Yes, but …
✗ = No

CPNT TECHNOLOGY OPTIONS MATRIX

PNT/CPNT TECHNOLOGIES	OPERATING ENVIRONMENT: SPACE	AIR	SURFACE	SUB-SURFACE	PNT: POSITIONING	NAVIGATION	TIMING	ACCURACY (95%): HORIZONTAL	VERTICAL	TIME/FREQ	AVAILABILITY	INTEGRITY	CONTINUITY	TIME TO ALERT	COVERAGE	COVERAGE: INDOORS (✓/✓/✗)	BROADCAST MESSAGING	BROADCAST MESSAGING: INDOORS (✓/✓/✗)	TRL	GPS OUTAGE HOLDOVER: HOUR	DAY	WEEK	MONTH	TIME DISTRIBUTION: NOTE 1	NOTE 2	NOTE 3	NOTE 4	NOTES
PNT Systems																												
GPS (SPS)	✓	✓	✓	✗	✓	✓	✓	17 m	37 m	40 ns 1x10e-13	>0.98	≤1x10e-5/hr/SV	>0.9998/hr	10 s	Global	✗	✗	✗	9	✗	✗	✗	✗	✪				✪ Baseline Condition - GPS unavailable.
Multi-Constellation GNSS	✓	✓	✓	✗	✓	✓	✓	17 m	37 m	40 ns 1x10e-13	>0.98	≤1x10e-5/hr/SV	>0.9998/hr	10 s	Regional/ Global	✗	✗	✗	9	✗	✗	✗	✗	✪				✪ Multi-constellation interoperable GNSS provides no additional PNT resiliency.
eLoran	✗	✓	✓	✓	✓	✓	✓	Maritime and Surface: 8 -20 m Aviation: 307 m ✣	✗ ◉	< 50 ns ✣ Stratum 1 Freq 1x10e-11	0.999	Maritime: 3x10e-5 Aviation: 1x10e-7	0.999	10 s	Regional/Nationwide Time/Freq: Station Dependent P/N: Geometry Dependent (Previously Mostly from Alaska to the Mexican Border)	✓ (Time/Freq)	✓	✓	Maritime/Time/Freq: 9 Aviation: 7 ⌘	✓	✓	✓	✓	✪	✣			✪ Based on findings contained in 2004 Loran Evaluation Team Report and verified by Independent Assessment Team in 2006. ◆ Requires infrastructure (including monitor sites) to be restored to provide <100 ns precise time. ◆ 8-20 meter accuracy achievable based on signal monitors located around specific coverage areas (e.g., harbors) to provide real-tme differential Additional Secondary Factor (ASF) propagation adjustments. Precise time < 100 ns with a single differential monitor within 500 miles. Meets 556 m accuracy with Flight Technical Error (FTE) - with 307 m Navigation Sysems Accurcay. Highly repeatable accuracy for surface and maritime ◉ Aviation uses barometric vertical navigation (VNAV) with eLoran lateral navigation (LNAV) to support approach with vertical guidance
APNT (DMEs/RTs re-purposed)	✗	✓	✓ ✣	✗	✓	✓	✓	556 m (RNAV 0.3)	N/A for Aviation (Baro)	< 50 ns Stratum 1	0.999	1 x 10e-7	0.999	10 s	P/N: Geometry Dependent and Line-of-Sight Dependent Time/Freq: Line-of-Sight	✓ (Time/Freq) ⊙	✓	✓ ⊙	Pos/Nav: 9 Time Distrib: 4	✓	✓	✓	✓	✪	✣			✪ Final system requirements for FAA's APNT initiative are currently being discussed to meet US NAS PNT requirements. APNT could provide precise time to non-aviation sector users via high power (1 KW) L-band signals - restricted by line-of-sight considerations. ◆ Dependent upon GPS-independent source of time/time synchronization. ◆ Dependent upon line-of-sight considerations/area capacity and safety needs ◉ Dependent on frequency (DME spectrum 960-1215 MHz; RT Spectrum 978 MHz, 1030 MHz, and 1090 MHz)
Local RF Ranging (e.g., Locata, Trimble)	✗	✓ ⊙	✓	✗	✓	✓	✓	< 1 m	< 1 m	< 5 ns ✪ 1x10e-9	0.99	✣	0.99	✗	Local P/N: Geometry Dependent and Line-of-Sight Dependent Time/Freq: Line-of-Sight	✓ (Time/Freq)	✗	✓	9 (Current Use)	✓ ✣	✓ ✣	✓ ✣	✓ ✣	✪	✣			✪ Relative to and dependent on resilient on independent source of time and frequency. ◆ Requires "Locatalites" to be installed to provide Line-of-Sight coverage/good geometry for positioning ◆ Current system uses spectrum in unprotected band (2.4 GHz ISM) precluding its use for safety or security applications. ◉ Avionics could be developed to provide navigation where Locatalites were available
PNT Augmentation Systems																												
GPS Plus Augmentation (ABAS, SBAS, GBAS, or NDGPS)	✓	✓	✓	✗	✓	✓	✗	ABAS: 0.3 nm SBAS: 1.5 m GBAS: 16 m NDGPS: < 10m ✣	ABAS: ✗ SBAS: 2 m GBAS: 4m NDGPS: ✗	✗	ABAS: 0.99 SBAS: 0.999 GBAS: 0.999 NDGPS: 0.997	ABAS: 1x10e-7 SBAS: 1x10e-7 GBAS: 2x10e-7 NDGPS: 3x10e-5	ABAS: 0.99999/hr SBAS: 0.999999/15 s GBAS: 0.999999/15 s	ABAS: 10 s SBAS: 6 s GBAS: 6 s NDGPS: 6 s	ABAS: Global SBAS: North America GBAS: Specific Airports NDGPS: 92% of CONUS, AK, HI, PR	✗	ABAS: Global SBAS: North America GBAS: Specific Airports NDGPS: 92% of	✗	9	✗	✗	✗	✗	✪				✪ SBAS does not currently transmit time. Future potential distribution of time via SBAS GEOs is addressed below. NDGPS does not currently transmit time. Future potential distribution of time via re-purposed NDGPS is addressed below. ◆ SBAS accuracy based upon actual performance data collected over ten years of operation.
GPS Plus Local Augementation (RTK, RTN, and Differential Corrections)	✗	✓ ✪	✓	✗	✓	✗	✓ –	RTK/RTN: 4 cm Loc Diff: < 2m	RTK/RTN: < 5cm Loc Diff: ✗	✗	Varies	Varies	Varies	Varies	Local`	✗	✗	✗	9	✗	✗	✗	✗					✪ Use of RTK/RTN byy aircraft is to support photogramatry and or air surveys ◆ Supports local navigation in support off survey operations
Time/Frequency Systems																												
WWVB	✗	✓	✓	✓	✗	✗	✓	✗	✗	0.1 ms - 15 ms 1x10e-10 - 1x10e-12					CONUS + (Propagation varies greatly throughout the day)	✓ (Time/Freq)	CONUS + (Propagation varies greatly throughout the day)	✓ (Time/Freq)	9	✓	✓	✓	✓	✪				✪ Current 60 kHz NIST time and frequency reference broadcast
Satellite-Based Augmentation Systems (SBAS) Time	✓	✓	✓	✗	✗	✗	✓	✗	✗	< 50 ns Stratum 1					North America (potential)	✗	North America (potential)	✗	4	✓	✓	✓	✓	✪				✪ Assumes instantiation of "WAAS clock" based on 114 cesiums, independent of GPS, synched via TWISTT to USNO/NIST, and distributed via GEOs (i.e., WAAS Messaage 12). Requires directional receive antenna focused (mechanically or electrically) on GEOs to mitigate interference.
Oscillators																												
Temperature Compensated Crystal Oscillators (TCXO)	✓	✓	✓	✓	✗	✗	✓	✗	✗	10 ms/day 1x10e-8/1000s (cannot recover time) ✣	Varies	Varies	Varies	Varies	Local	✓ (Time/Freq)	Local	✓ (Time/Freq)	9	✓ 30 µs	✓ 10 ms	✗	✗	✪				✪ Can maintain time and provide frequency -- Cannot independently recover time. ◆ Sensitive to environmental variations.
Oven Controlled Crystal Oscillators (OCXO)	✓	✓	✓	✓	✗	✗	✓	✗	✗	10 µs/day 1x10e-11/1000s (cannot recover time) ✣	Varies	Varies	Varies	Varies	Local	✓ (Time/Freq)	Local	✓ (Time/Freq)	9	✓ 30 ns	✓ 10 µs	✗	✗	✪				✪ Can maintain time and provide frequency -- Cannot independently recover ◆ Sensitive to environmental variations.
Chip Scale Atomic Clocks (CSACs)	✓	✓	✓	✓	✗	✗	✓	✗	✗	5 µs/day 1x10e-12/1000s (cannot recover time)	Varies	Varies	Varies	Varies	Local	✓ (Time/Freq)	Local	✓ (Time/Freq)	9	✓ 5 ns	✓ 5 µs	✓ 10 µs	✗	✪				✪Can maintain time and provide frequency -- Cannot independently recover time.

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CPNT TECHNOLOGY OPTIONS MATRIX

PNT/CPNT TECHNOLOGIES	OPERATING ENVIRONMENT				PNT			ACCURACY (95%)			AVAILABILITY	INTEGRITY	CONTINUITY	TIME TO ALERT	COVERAGE		BROADCAST MESSAGING		TRL	GPS OUTAGE HOLDOVER				TIME DISTRIBUTION				NOTES
	SPACE	AIR	SURFACE	SUB-SURFACE	POSITIONING	NAVIGATION	TIMING	HORIZONTAL	VERTICAL	TIME/FREQ						INDOORS (✓/✓/✗)		INDOORS (✓/✓/✗)		HOUR	DAY	WEEK	MONTH	NOTE 1	NOTE 2	NOTE 3	NOTE 4	
Rubidium Oscillators (Rb)	✓	✓	✓	✓	✗	✗	✓	✗	✗	1 µs/day 5x10e-11/1000s (cannot recover time)	Varies	Varies	Varies	Varies	Local	✓ (Time/Freq)	Local	✓ (Time/Freq)	9	✓ 10 ns	✓ 1 µs	✓ 5 µs	✗	✪				✪ Can maintain time and provide frequency -- Cannot independently recover time.
Cesium Oscillators (Cs)	✓	✓	✓	✓	✗	✗	✓	✗	✗	5 ns/day 2.7 - 8.5x10e-13 /1000s (cannot recover time)	Varies	Varies	Varies	Varies	Local	✓ (Time/Freq)	Local	✓ (Time/Freq)	9	✓ 1 ns	✓ 5 ns	✓ 15 ns	✓ 30 ns	✪				✪ Can maintain time and provide frequency -- Cannot independently recover time.
Time/Frequency Distribution Systems																												
Network/Precision Time Protocol (NTP/PTP)	✗	✗	✓	✓	✗	✗	✓	✗	✗	10 ms - 0.1 ms 1x10e-7 - 1x10e-9	Network Dependent	✓ ◆	Network Dependent	Network Dependent	Network Dependent	✓ (Time/Freq)	Network Dependent	✓ (Time/Freq)	NTP: 9 PTP: 7	✓	✓	✓	✓	✪				✪ Dependent on resilient GPS-independent source of time and frequency. Systemic persistent deviations up to 100 ms are possible via the internet - depends very strongly on the stability of the network connnection between the client and server. ◆ NTP integrity requires client to utilize hash code and digital key.
Long-Term Evolution (LTE)	✗	✓	✓	✗	✓	✓	✓	50 m (E911)	✣	> 1 µs	Network Dependent	✗	Network Dependent	Network Dependent	Network Dependent	✓ (Time/Freq)	Network Dependent	✓ (Time/Freq)	4	✓	✓	✓	✓	✪				✪ Dependent on resilient GPS-independent source of time and frequency. Lack of integrity precludes its use for safety or security applications. ◆ Requires network infrastructure to achieve 3 m accuracy required by E911.
Fiber	✗	✗	✓	✓	✗	✗	✓	✗	✗	10 ms - 0.1 ms 1x10e-7 - 1x10e-9	Network Dependent	✣	Network Dependent	Network Dependent	Network Dependent	✓ (Time/Freq)	Network Dependent	✓ (Time/Freq)	6	✓	✓	✓	✓	✪	✣			✪ Dependent on resilient GPS-independent source of time and frequency ◆ Requires special, carefully controlled/dedicated infrastructure to maintain precise (<1 µs) time
NDGPS (re-purposed)	✗	✓	✓	✓	✓	✓	✓	TBD	✗	< 50 ns Stratum 1	Network Dependent	Network Dependent	Network Dependent	Network Dependent	Network Dependent	✓ (Time/Freq)	✓	✓ (Time/Freq)	4	✓	✓	✓	✓	✪				✪ Assumes use of NDGPS sites to either distribute GPS-independent time or act as mini-eLoran sites to fill gaps or provide differential monitors to provide "better" service/coverage
Other/Mode-Specific Systems																												
Inertial Measurement Units (IMUs)	✓	✓	✓	✓	✓	✓	✗	0.01 - 1000 m deg/hr drift rate	✗	✗	Varies	Varies	Varies	Varies	Local	✓ (Pos/Nav)	Local	✓ (Pos/Nav)	9	✓ ✣	✗	✗	✗	✪				✪ Assumes high-quality gyros/accelerometers and use of Kalman-filtered GPS position updating (other sensor updating is possible). Coasting performance degrades over time and depends upon quality of gyro used. ◆ Dependent on quality/cost of IMU and required performance
Vision Based (Light Detection and Ranging (LIDAR), etc.)	✗	✗	✓	✗	✓	✓	✗	1 - 20 m ✪	✗	✗	> 0.98	Varies	Varies	Varies	Local	✗	Local	✗		✓	✓	✓	✓					✪ Feature-based Radar/LIDAR systems can provide position/navigation capability, but have some dependency upon accurate map database. Currently radar is used for maritime harbor/inland waterway positioning and navigation (LIDAR may provide similar capability). Aviation radar is only used for surveillance and weather detection.
Radar/VHF Omni-Directional Radio Range/Distance Measuring Equipment (VOR/DME)	✗	✓	✓ ✣	✗	✓	✓	✗	DME/DME: 556 m (RNAV 0.3)	✗	✗	0.997		0.997		En Route, Terminal and Airport Domains ✣	✗	En Route, Terminal and Airport Domains ✣	✗	9	✓	✓	✓	✓	✪				✪ Currently only used by aviation for position (surveillance), navigation, and safe separation of aircraft. Time distribution application using DMEs and other sites described in APNT alternative. ◆ Current service volumes keyed to operations within the National Airspace System (NAS) in terms of signal levels, adjacent and co-channel interference, etc. Perfromance varies depending on surveillance system in use (e.g., 200-mile radar, 60-mile radar, airport surface, precision approach, etc.) ◆ Surface radar only available at specific airports and harbors
Integrated Multi-Sensor Solution LIDAR, Radar, IMU, Vision, Mapping, Wheel Sensors, and Dedicated Short Range Communications (DSRC)			✓		✓	✓		< 0.5 m ✪	✗	✗	> 99.998%	< 0.5 m	0.99998/hr	< 1 sec	Local ⌘	✗	✗	✗	7 ✣	✓	✓	✓	✓					✪ Integrated solution accuracy is very high but specific numbers are not available at this time. For example, the accuracy of a Velodyne High Definition LIDAR (HDL-64E) is less < 2 cm. ⌘ Equipment is colocated with the vehicle so it is a local solution that can work globally. ◆ System prototype demonstration in land/surface environment.