



U.S. DOT/Volpe Center

Vulnerability Assessment

**of the Transportation Infrastructure
Relying on GPS**

30th Annual ILA Convention and Technical Symposium

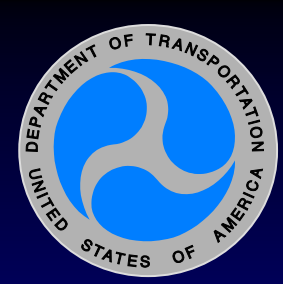
October 10, 2001

Dr. James V. Carroll



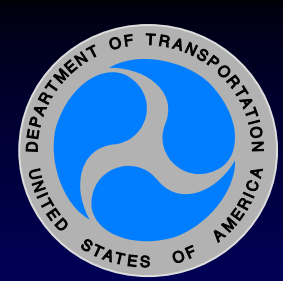
Main Message to the Civil GPS Community:

GPS provides many benefits to civilian users. It is vulnerable, however, to interference and other disruptions that can have harmful consequences. GPS users must ensure that adequate independent backup systems or procedures can be used when needed.



Briefing Outline

- **Background**
- **Risk, Vulnerabilities & Disruption Mechanisms**
- **Mitigating Vulnerabilities**
- **Findings & Recommendations**
- **Summary**
- **Conclusion**

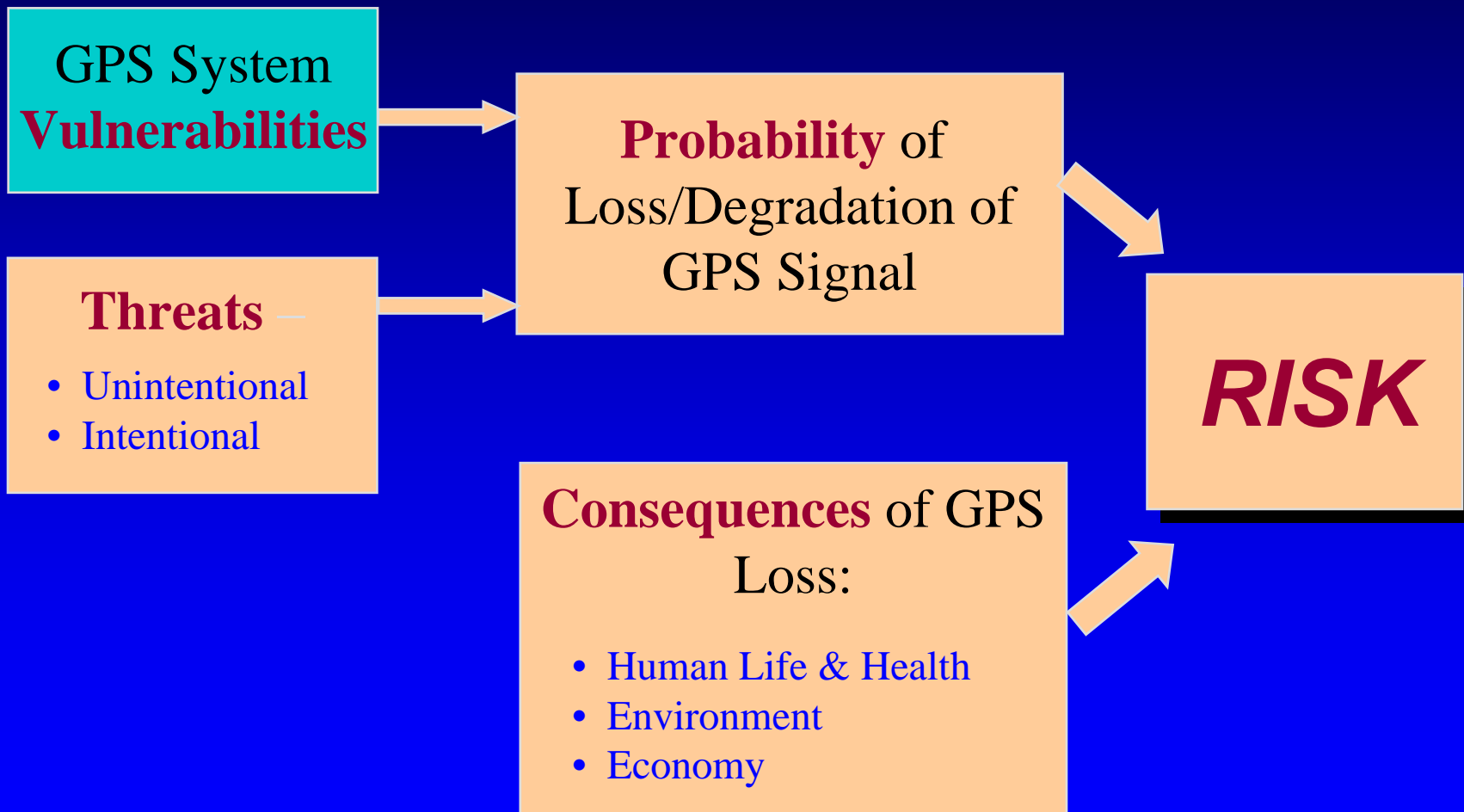


Assessment Overview

- **Report Assessed Possible Impact to Civilian Users**
 - GPS-Based Systems in the United States
 - Projected Over 10 Years
- **Covered All Transportation Modes**
 - Also Telecommunications, Banking, Commerce
- **This Briefing ••**
 - Examines Vulnerabilities
 - Recommends Mitigations
- **BOTTOM LINE:**
 - GPS Users are Vulnerable to Signal Loss or Degradation
 - Awareness & Planning Can Mitigate the Worst Vulnerabilities
 - ▲ The Vulnerability Will Not be Fully Eliminated



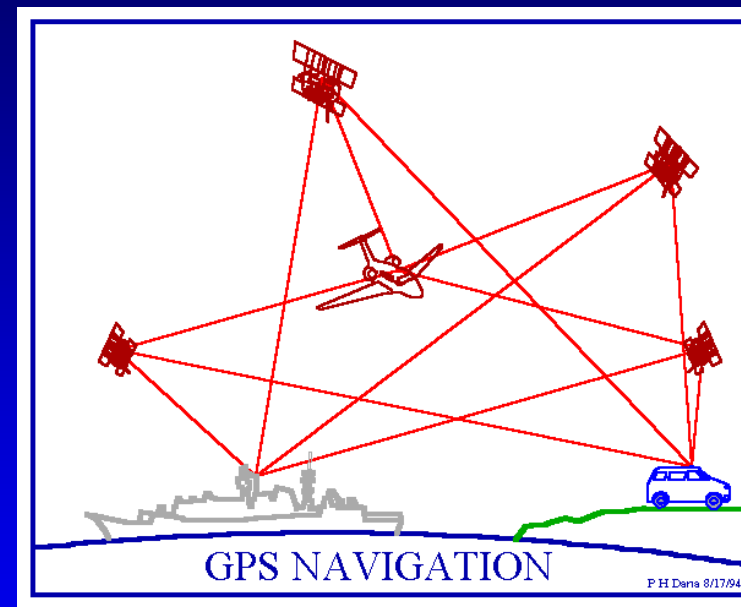
Risk Considerations

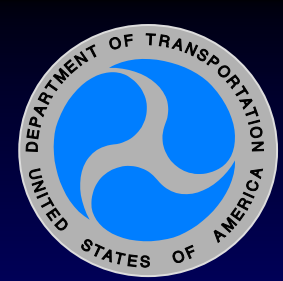




Civil Transportation Uses

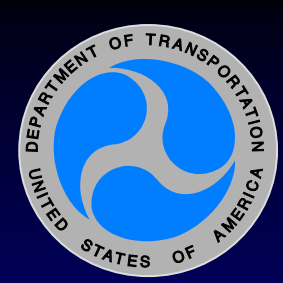
- **Aviation**
 - Navigation, ATC, Surface Guidance
- **Maritime**
 - Harbor, Inland Waterway
 - Traffic Service
- **Surface**
 - **Railroads**
 - ▲ Train Control, RR Crossings, Overspeed
 - **Intelligent Transportation Systems**
 - ▲ Emergency Response, Vehicle Control
- **Transportation Infrastructure**
 - Timing; Communication Networks; Power Grids





Civil Timing & Synchronization Uses

- **Global Fiber Networks**
 - SDH, SONET
- **Global Wireless Networks**
 - PCS, GSM, TDMA, CDMA
- **Transportation & Public Safety**
 - National Airspace System (VDL, NEXCOM, UAT)
 - Land, Rail, Marine
- **GPS Features:**
 - Low Cost, High Reliability & Performance
 - Big Asset for Synchronization of Digital Networks
 - GPS (and Cesium, Loran-C) - Stratum 1



Factors Impacting GPS Vulnerability

- **Very Low Signal Power**
- **Single Civil Frequency**
 - **Known Signal Structure**
- **Spectrum Competition**
- **Worldwide Military Applications Drive a GPS Disruption Industry**
 - **Jamming Techniques are Well Known**
 - **Devices Available, or Can be Built Easily**



**GPS Timing for
EW**



GPS System Vulnerabilities

- **Unintentional Interference**
 - Radio Frequency Interference (RFI)
 - GPS Testing
 - Ionospheric; Solar Max
 - Spectrum Congestion
- **Intentional Interference**
 - Jamming
 - Spoofing – Counterfeit Signals
 - System Damage
 - ▲ GPS Constellation, Ground Control Segment
- **Human Factors**
 - Errors, Over-Reliance, Lack of Knowledge/Training



1 Watt
Jammer



Disruption Mechanisms - Jamming

- **Jamming Power Required at GPS Antenna**
 - On order of a Picowatt (10^{-12} watt)
- **Many Jammer Models Exist**
 - Watt to MWatt Output
 - Lower Power (<100 watts); “Hams” Can Make
- **Jamming Signal Types**
 - **Narrowband**
 - ▲ Carrier Wave
 - Exploit C/A Code Spectral Lines
 - Possible to Produce Undetected, Inaccurate PVT Solutions
 - **Broadband**
 - ▲ Spatial Adaptive Antennas, Polarization Discrimination
 - **Spread Spectrum - PRN Modulation**
 - ▲ Effective at Much Longer Ranges



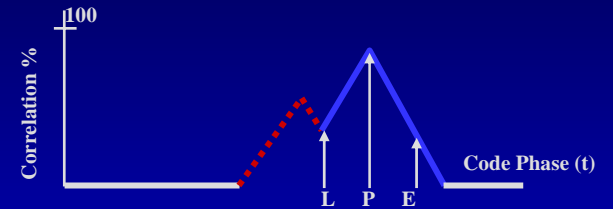
Russian Jammer



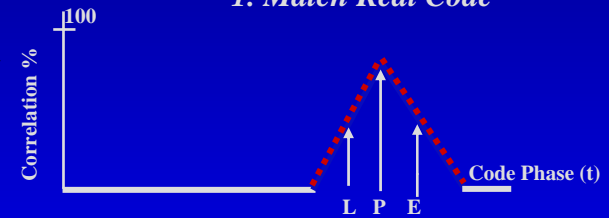
Disruption Mechanisms - Spoofing/Meaconing

- **Spoof – Counterfeit GPS Signal**
 - C/A Code Short and Well Known
 - Widely Available Signal Generators
- **Meaconing – Delay & Rebroadcast**
 - Applicability of EW Components
- **Possible Effects**
 - Long Range Jamming
 - Injection of Misleading Pos/Vel/Time Information
- **No “Off-the-Shelf” Mitigation**

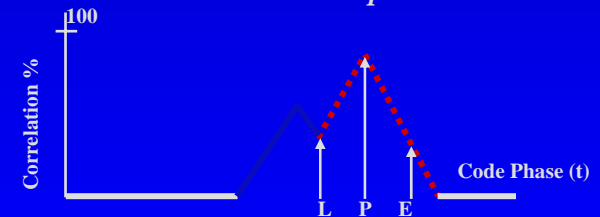
▲ Capture Range Gate



1. Match Real Code



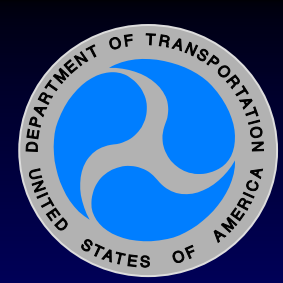
2. Capture



3. Pull Off

..... Spoof Code
—— GPS S.V. Code

Successful Spoof



Consequences of GPS Loss/Degradation



- **Depending on ...**
 - **Transportation Mode Involved**
 - **Duration of GPS Loss/Degradation**
- **Impact Can Be**
 - **Minimal** - Quick Recovery
 - **Operational** - Reduced Effectiveness & Efficiency
 - **Safety** - Potential Loss of Life, Environmental, Economic Damage
- **Timing & Synchronization**
 - **GPS Outage Can Disrupt Communications/Networks**



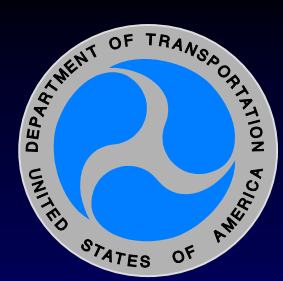
Mitigating GPS System Vulnerabilities

- **For Unintentional Disruptions -**
 - **GPS Spectrum Protection Efforts**
 - ▲ Mitigate Against Interference Sources
 - ▲ Jam-Resistant User Equipment
 - **GPS Modernization**
- **For Intentional Disruptions -**
 - **Military Anti-Jam Technology**
 - **Characterize Civil Spoof Effects\Observables**
- **Vulnerability Cannot Be Fully Eliminated**



Mitigation of User Risk

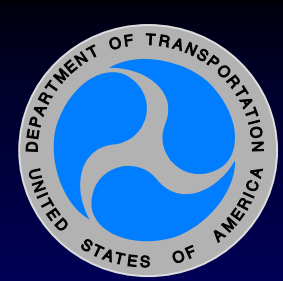
- **Implement Appropriate Mitigation Strategies**
 - For Each Individual Mode, Choose or Maintain Appropriate Backup System or Procedure
 - Be Cognizant of Timing Applications
 - Reflect Interference Impact in Application Designs
 - Implement Systems to Monitor/Report/Locate Interference
 - Assess Applicability of Military Anti-Jam Technology
- **Encourage User Training in Use of Backups**
- **Determine Tolerable Levels of Risk and Cost for the Critical Infrastructure Applications**
 - Determine Costs of Lowering Risks to an Acceptable Level



Findings (1 of 3)

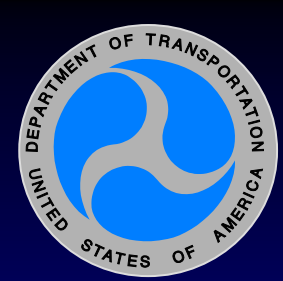
- **Transportation Community is Aware of Risks in Using Sole Means GPS in Critical Applications**
- **GPS is Vulnerable to Radiofrequency Interference**
- **GPS Augmentations (e.g., WAAS, NDGPS) Improve**
 - **Accuracy**
 - **Availability**
 - **Reliability**
 - **Integrity**

BUT: Use of GPS Can Still be Disrupted



Findings (2 of 3)

- **GPS Will Become an Increasingly Tempting Target as its Civil Uses Proliferate**
 - **Increasing Civil Dependence**
- **GPS is Susceptible to Unintentional Disruptions**
 - **Ionospheric, Solar**
 - **Blockage**
 - **Narrowband & Wideband RFI**
- **Use of GPS-based Timing Synchronization Must be Assessed, Application by Application**
 - **Transportation, Communications, Commerce**



Findings (3 of 3)

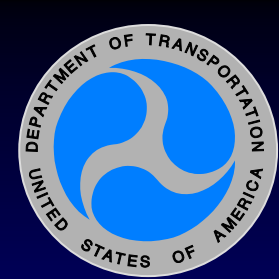
- **Military Experience: Hostile Interests Will Attempt to Disrupt/Destroy GPS if They See an Advantage in Doing So**
- **Risk Can be Reduced, but not Eliminated**
 - **GPS Cannot be Sole Source in Critical Applications**
 - **Safety of Civilians is “Number 1”**
- **Backup Systems or Procedures are Necessary for All Critical Applications Involving GPS**



Candidate Independent Backup Systems

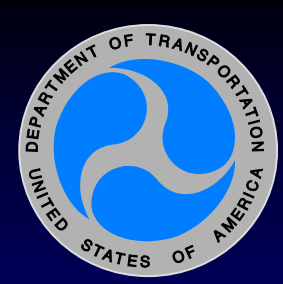
- **Ground-Based Aviation Systems - VOR/DME, ILS**
- **Inertial Systems**
- **Loran-C**
- **Other Satellite Navigation Systems**
- **“Procedures”**
 - **Missed Approach (Radar, Ground Support)**
 - **Maritime: Radar, Radio, Sextant, Lighthouse, etc.**





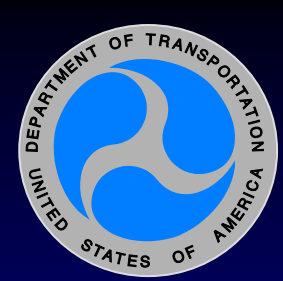
Upgraded Loran Can Play a Key Role

- **Very Difficult to Jam**
- **Covers Contiguous U.S., Portion of Alaska**
- **Can Support Many Transportation & Timing Applications**
- **Complements GPS, Inertial Systems**
- **“All-in-View” Receivers Can Mitigate Loss of a Loran Transmitter**
- **Data Messaging Capability for WAAS Signals is Under Consideration**



Loran-C Issue

- **System Continuation Remains “Under Review”
by DOT**
- **This Status Inhibits Industry Commitment**



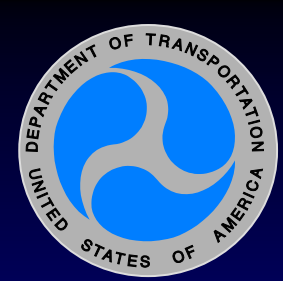
Recommendations (1 of 4)

- **Public Policy Must Ensure Safety if GPS Use is Lost**
- **Acceptable Level of Risk Must be Determined for Critical Applications**
 - **Costs to Lower Present Risk to this Level Must be Determined**
- **Continue GPS Modernization**
 - **More Civil Signals & Improved Code**
 - **Higher Broadcast Power**
- **Continue Spectrum Protection Activities**
- **Enhance Receiver Performance & Certification Standards in All Modes Where Feasible**



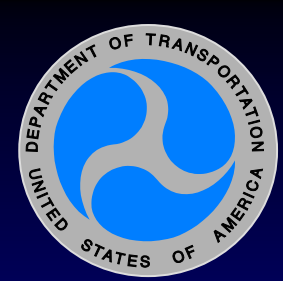
Recommendations (2 of 4)

- **All Critical Applications Will Require Timely Notice of Impending Loss of GPS**
 - **Reporting**
 - **User Training**
 - ▲ Recognize Impending Loss
 - ▲ Awareness of Backup Options
 - ▲ Knowledge of How/When to Switch to Backup
- **Civil Community Should Track Military Anti-Jam Developments for Possible Use**
 - **Anti-Spoofing Technology**
 - **Identify, Use Spoof Indicators**



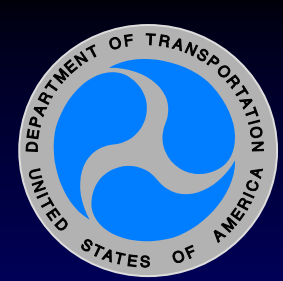
Recommendations (3 of 4)

- **Whenever Possible, Maximize Military-Civil Exchange of System Status, Incipient Threats**
- **Create Awareness of Need for Backups in Critical Applications**
- **All GPS Receivers Used in Critical Applications Need to Provide Integrity Warnings**
 - **Consider Autonomous Integrity Monitoring**
- **Augment, Enhance, and Implement Appropriate Backup Systems or Procedures**
 - **Assess Impact of GPS-Based Timing Loss**



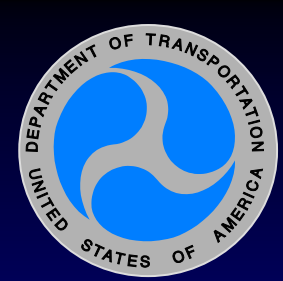
Recommendations (4 of 4)

- **Continue Re-Capitalization and Enhancement of Loran-C**
 - **Modes Should Assess Potential Role of “New” Loran**
 - **Firm Decision Needed Soon - Industry Needs Direction**
- **DOT Take an Active Role in Developing Roadmap for the Future Navigation Infrastructure**
 - **Federal Radionavigation Plan**
 - **Modal Agencies to Assess Risk Impacts**



Report Summary

- **GPS Vulnerability Can be Reduced but not Fully Eliminated**
- **Augmentations Can Provide Integrity, but are of No Benefit During & Following a Disruption**
- **GPS Disruptions also Impact Timing**
- **Increasing Use Makes GPS a Tempting Target**
- **Independent Backup Systems or Procedures Essential in Critical Civil Transportation Uses**



Conclusion

- **Report available from the U.S. Coast Guard Navigation Center website**
 - <http://www.navcen.uscg.gov>

“If the government expeditiously develops and executes a plan based on these recommendations, there is every reason to be optimistic that GPS will fulfill its potential as a key element of the national transportation infrastructure.”



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