



Statewide Real-Time Global Positioning System or Global Navigation Satellite System Network Implementation

Requested by
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Executive Summary

Background

Real-time Global Positioning System (GPS) or Global Navigation Satellite System (GNSS) networks (RTNs) are valuable tools with applications in a wide range of industries.

As Caltrans evaluates its growing reliance on Real Time Network solutions for transportation project delivery and asset management, it will be valuable to understand how existing, sustainable statewide RTN systems have been developed and implemented to determine how Caltrans may emerge as a lead or a partner in a statewide RTN in California. To assist with possible future decision-making, the Caltrans Division of Right of Way and Land Surveys requested an investigation of other state DOTs' experiences with RTNs, including their operation, maintenance, funding mechanisms, annual operational costs, cost recovery mechanisms and potential benefits.

To support this effort, CTC & Associates conducted in-depth interviews with representatives of six state departments of transportation (DOTs) that have well-established RTNs: Florida, Minnesota, New York, Oregon, Washington and Wisconsin. The complete set of survey questions is available in [Appendix A: Survey Questions](#), beginning on page 30 of this Preliminary Investigation.

Summary of Findings: Survey of Current Practice

To better understand transportation agencies' experience with statewide RTNs, we conducted an email and telephone survey with representatives from this select group of state DOTs. The survey gathered information in eight topic areas related to RTN use: ownership of statewide RTNs, funding, operation and maintenance, standards, software and hardware, user information, public/private relationships and best practices.

Ownership of Statewide RTNs

Most of the state DOTs surveyed own the statewide RTN. They also own most but not all of the individual Continuous GPS (CGPS) stations within the network. Similarly, the state DOTs typically own the network's computer hardware and software, although in both Florida and New York, separate state agencies own the state's computer equipment.

Washington State DOT is the sole exception to these ownership principles. The Washington State Reference Network is operated as a cooperative with more than 80 partners. Each of those partners owns and contributes at least one CGPS station to the network. Seattle Public Utilities owns the hardware and software for the network's central data processing.

Most of the respondents' CGPS stations are located on public lands, and almost none of the small number of stations on private lands had any associated permitting fees. In a few cases, however, station owners did pay a small lease if they didn't own the site.

All respondents except Wisconsin DOT require their end users to agree to disclaimers that limit the DOT's liability. None of the respondents reported any legal challenges made to the RTN.

Funding

Among the respondents, funding for RTNs and CGPS station maintenance generally comes from the state DOT budget. In Washington, however, funding for network operation comes from subscribers (users of the network who pay a subscription fee for network access rather than providing a CGPS station).

Comparing the operation costs of the RTNs was difficult. In Washington, annual operation costs are approximately \$1,300 per site, although due to the collective nature of the network, that amount includes only costs for operating the data center. Annual operation costs in Oregon are \$500 per site, primarily associated with software maintenance agreements. In Wisconsin, annual operation costs are \$6,000 per site, which includes equipment replacement costs but not salaries or telecommunication costs.

Only Florida has calculated a return on investment for its RTN, saving the state nearly \$1 million per year over purchasing subscriptions to private networks. That amount does not include benefits to end users outside the state government. In 2008, a private partner in Minnesota's network calculated a \$30 million savings to the state.

None of the DOT-owned networks charge a subscription or other annual fees to end users. The Washington State Reference Network has a fundamentally different model: Users can gain access by either contributing a station to the network (thereby becoming a partner) or by subscribing for \$1,900 per account (with discounts at five, 10 or 20 accounts).

Operation and Maintenance

Among the respondents, day-to-day administration of the RTN typically consumes the work of 1.3 to 2 full-time-equivalent (FTE) employees. In most states, a separate state information technology (IT) department is responsible for IT support. However, Wisconsin DOT provides IT support; and in Washington, a 0.8 FTE provides day-to-day administration while Seattle Public Utilities (SPU) provides helpdesk services.

Security standards differed significantly among respondents, ranging from Homeland Security standards to firewalls. Responsibility for station maintenance also varied; a different entity in every state is assigned to this task.

In general, partnerships are fairly informal. Several respondents consider station hosts to be partners, but these agreements involve sharing data rather than costs. Washington State's network, however is a true collective of about 80 partners, each responsible for operating its own station.

Ongoing network improvement efforts are also fairly informal. Florida, New York and Oregon are all working to incorporate data from GLONASS, the Russian satellite system.

Standards

Most respondents said that their network's CGPS stations generally follow National Geodetic Survey (NGS) construction standards, however, a few stations within each network are noncompliant. All state networks are aligned with the National Spatial Reference System.

State networks typically connect with neighboring states through informal data-sharing agreements.

Only Washington has standards to account for crustal motion. The state is divided into six regions of crustal movement; these regions are monitored to maintain 1 cm horizontal integrity and 2 cm vertical integrity relative to each other. Although Oregon does not have these standards, it does incorporate NGS adjustments.

Software and Hardware

End users typically need only an Internet connection to access real-time data. State DOTs use a mix of communications technologies, including broadband, wired and cellular modems.

User Information

All of the DOT-owned systems are free and accessible to any registered user. WSRN charges nonpartners for subscriptions.

States' user base includes a wide range of both public and private sectors, including surveying, mapping, construction, utilities, agriculture, and academia.

State DOTs typically provide two types of data products to their end users. 1. They provide real time correction services. These services come in two types, single base line corrections, and network corrections. 2. They provide archived GPS/GNSS measurement data from each of their CORS stations for post processing work.

All respondents offer single base line real time corrections in at least one of the following formats: RTCM 2.x, RTCM 3.x, CMR+, and CMRx. All respondents offer network corrections services in a range of multiple formats. The format range includes RTCM 3.x (MAX/iMAX, VRS, FKP), CMR+ (VRS), CMRx (VRS). The terms MAX/iMAX, VRS, FKP refer to the manner in which the Network correction is generated. All respondents provide the archived post-processed data in Rinex format. Three respondents (Minnesota, Washington, and Wisconsin) provide archive data in proprietary Trimble formats as well.

Except for a few isolated cases of in-kind support, none of the DOTs receives supplemental funding or donations from users.

Public/Private Relationships

None of the states have formed any type of partnership with private networks in their state, although some do co-exist with private networks.

Best Practices

Survey respondents offered several recommendations for implementing a statewide RTN:

- Train district liaisons to respond quickly to local network issues.
- Seek federal grants to help fund the network
- Partner with local agencies that have needed infrastructure.
- Build relationships with local equipment dealers.
- Create a strong wired network to ensure network reliability.

- Involve stakeholders from the start of the process.
- Keep the network independent from public sector IT.

They also reported some safety improvements associated with the RTN, primarily because surveyors spend less time driving to field locations, and once they are at the location, they can limit their exposure to traffic by working from the side of the road.

Gaps in Findings

Another approach that was considered for this Preliminary Investigation was a less in-depth survey of more states' experiences. The states we interviewed were selected because of their significant experience and expertise in statewide RTNs. Other states, however, may have useful information to provide.

While Caltrans is interested in learning how states worked with or absorbed existing RTNs, none of our respondents reported any RTNs operating in their states when the statewide RTN began.

We received limited information from respondents about how state networks account for crustal motion since this issue isn't relevant to most of the states surveyed. Interviews with states that face greater levels of crustal motion may provide more information.

Next Steps

Moving forward, Caltrans could consider:

- Joining the Regional Height Modernization Partnership, an initiative aligned with the National Oceanic and Atmospheric Administration and the NGS that provides federal grants to expand, replace and maintain an RTN.
- Consulting with additional states that have more limited experience with RTNs to gain their insight.
- Contacting states with greater levels of crustal motion or subsidence for more information about positional degradation of stations.
- Contacting South Carolina DOT about IT issues with its RTN, as suggested by Washington State DOT.

Detailed Findings

To gather information for this Preliminary Investigation, we conducted an in-depth survey by email and telephone with six state DOTs that have well-established RTNs: Florida, Minnesota, New York, Oregon, Washington and Wisconsin.

Representatives from these transportation agencies answered a customized series of questions that addressed eight topic areas related to their experience with RTNs:

- 1) Ownership of statewide RTNs.
- 2) Funding.
- 3) Operation and maintenance.
- 4) Standards.
- 5) Software and hardware.
- 6) User information.
- 7) Public/private relationships.
- 8) Best practices.

The full text of these survey questions is available in [Appendix A: Survey Questions](#), beginning on page 30 of this Preliminary Investigation.

Survey of Current Practice

Below is a summary of key findings from the survey, organized by topic areas related to state DOT experience with RTNs.

1) Ownership of Statewide RTNs

We began the survey by asking respondents to identify key issues related to RTN ownership, including CGPS station, computer hardware and software, and communications hardware ownership; the location of CGPS stations; and liability protection.

Network Ownership

When asked whether the RTN was owned, operated and maintained by the DOT or other state agency, or whether system administration and management were contracted out to a private company, respondents reported that the statewide RTN is generally owned and operated by the DOT. However, Washington's RTN is operated as a cooperative of more than 80 entities.

- Florida DOT owns and operates the Florida Permanent Reference Network (FPRN).
- Minnesota DOT owns the Minnesota Continuously Operating Reference Station Network (MnCORS), although certain stations within the network are owned by private companies or counties.

- New York State DOT owns and operates the New York State Spatial Reference Network (NYSNet).
- Oregon DOT's Geometronics Unit owns and controls the Oregon Real-Time GPS Network (ORGN), although about 70 of the network's 100 stations are owned by partners.
- The Washington State Reference Network (WSRN) is a cooperative of more than 80 cities, counties, utilities, state agencies and private entities. While the DOT is one partner, the network is owned by the cooperative. A partner is any entity that owns, operates and maintains an individual station.
- Wisconsin DOT owns all of the network software, all IT components, most of the GNSS hardware and most of the CORS monuments for the Wisconsin Continually Operating Reference Stations network (WISCORS). Partners contribute facilities and a small amount of hardware. Wisconsin DOT's Geodetic Survey Unit is responsible for network maintenance.

CGPS Station Ownership

Among the states that own their RTNs, the DOTs also own most of the CGPS stations in the RTN. Maintenance of stations that are not owned by the DOT varies from state to state.

- Florida DOT owns 75 to 80 percent of the CGPS stations in its network; the remaining stations are owned by local agencies. The state has a legal memorandum of agreement that allows data sharing. Maintenance of stations owned by local agencies is managed through informal coordination with local owners. Local agencies notify the DOT when network issues occur.
- Minnesota DOT owns all CGPS stations in the state except for approximately nine stations that are within the network but located in Wisconsin or Iowa.
- New York State DOT owns 46 of the network's 51 stations; New York City owns the remaining five stations, but the DOT manages the data from these stations.
- Oregon DOT owns about 30 of the network's 100 stations; the remaining stations are owned by ORGN partners. Oregon DOT monitors the network constantly; if a partner-owned station goes down, ORGN staff quickly notifies the owner. (A list of ORGN partners is available at www.oregon.gov/ODOT/HWY/theorgn/Pages/Partners-List.aspx.)
- Each individual station in Washington's network is owned by a public or private partner. Partners are responsible for station operation and maintenance.
- Wisconsin DOT owns most of the WISCORS components except the buildings where the receivers are housed. Since the state doesn't own the sites where the stations are located, the service levels from the site sponsors vary. For example, the network's COM0 station is located at an Interstate inspection station operated by the Wisconsin State Patrol, a Wisconsin DOT division. A full-time staff member at that site can address any service issues. However, the network's DAND station, located at a recycling center in a remote area of northwestern Wisconsin, is open only a few hours each month. WisDOT provides Internet service to this station with a MiFi modem (a wireless router that acts as a Wi-Fi hotspot), which is new technology for the area and not always reliable. Since the site doesn't have a full-time contact and the Internet technology is unique, DOT staff must always be prepared to make a 4.5-hour drive to troubleshoot any data communication issues.

Computer Hardware and Software Ownership

Only two states—Minnesota and Wisconsin—own the network’s computer hardware and software.

- Florida DOT owns its network’s computer software, but the Southwood Shared Resource Center, another state agency, owns the hardware. A state requirement mandates that any state agency owning more than five servers must turn them over to a state data warehouse.
- New York State DOT owns the RTN’s computer software. It previously owned the computer hardware as well, but the state IT department has since taken ownership of the hardware.
- Oregon owns all of the network’s software.
- In Washington, SPU hosts the network’s central data processing and owns the hardware and software. Before the network began, SPU owned the hardware and software for its own internal use. Since it had the capacity to expand, SPU opened the network for external use.

Communications Hardware Ownership

Communications hardware used for RTN operation is owned by various entities:

- Three states—Florida, Minnesota and Oregon—own the network’s communications hardware. At partner-owned stations in Oregon, the partners generally own the communications hardware, although in some instances, Oregon DOT purchased and installed modems at these sites if the partner didn’t have its own modem.
- In New York, the state IT department owns the RTN’s communications hardware.
- Wisconsin DOT usually provides the network’s modems and switches, but some partners prefer to use their own components. The DOT also pays for Internet service if the site has none or if it is inadequate for the network’s need.
- In Washington, individual station owners own the communications hardware necessary for transferring data from individual stations to the Internet.

CGPS Station Location

Most CGPS stations are located on public lands. In the few instances where stations are on private land, only Oregon reported permitting fees for a small number of sites.

- All Florida stations are on public lands. The state used to have agreements with private companies, however, about a year and a half ago, one of the companies went out of business without notice, leaving a “big gap in service” in Miami. Since then, Florida DOT has opted to only site stations on public lands, and it only partners with government agencies.
- In Minnesota, all but about a half dozen sites are located on public land.
- In New York, all sites are public except for one leased facility.

- All sites owned by Oregon DOT are on public land; none requires a permit, although the state is considering siting a few stations on U.S. Forest Service land, which would require permits. Some partner-owned stations are located on private land, and some of those require permitting fees, which are paid by the partner.
- Stations in Washington are located on both public and private lands. No permitting fees are charged, although small leases (a few hundred dollars per year) were required for two stations where the station owner wanted to locate the station on lands owned by another entity.
- Most Wisconsin stations are on public lands but a few are on private property.

Liability Protection

We asked respondents how the RTN provider protected itself from liability from end users, specifically whether the state had developed a legal disclaimer process and whether the process had been challenged.

- All respondents except Wisconsin require end users to agree to a disclaimer at registration that limits the DOT's liability. In four states—Florida, Minnesota, New York and Oregon—the DOT's legal department either developed or reviewed the disclaimers. None of the respondents reported that the RTN had faced legal challenges.
- A supervisor in the Minnesota DOT Geodetic Unit created the disclaimer, which was later approved by the DOT's legal department.
- In Oregon, the Geometronics Unit developed the disclaimer based on models from other networks; the disclaimer hasn't been approved by the DOT's legal staff. ORGN sends the disclaimer (available at www.oregon.gov/ODOT/HWY/theorgn/Pages/Account-Request.aspx) to end users when they create a new rover account, advising them that by using the account, they are accepting the disclaimer.
- The City of Seattle's legal department developed Washington's disclaimer (available at www.wsrn3.org/Geodesy.aspx), and it was reviewed by the legal departments of other partners. The state reviewed national and international disclaimers to ensure its network wasn't liable for bad data or responsible for any impact of natural disasters on stations.
- In Wisconsin, site partners review the agreements individually and revise the agreements as necessary. Wisconsin's agreements are initially for five years and extended for periods agreeable to the site partners. End users, however, are not required to sign any type of agreement.

2) Funding

We asked respondents to describe the RTN funding practices in their state, including ongoing software and hardware maintenance, real-time communications, network expansion and upgrades, and all associated labor costs.

RTN Funding

Day-to-day operations for four state networks—Florida, New York, Oregon and Wisconsin—are entirely DOT-funded. However, funding has also been augmented or achieved in unique ways:

- Florida's Southwood Shared Resource Center back-charges for computer use, and storage and costs are absorbed into the annual budget through that process. In 2012,

the state sought and was awarded funding to upgrade network hardware through the legislative budget. That funding also allowed the DOT to secure five years of software and individual site licensing, and to purchase additional equipment that can be used to replace stations as necessary. Those costs will not be part of the annual budget until 2018.

- In Minnesota, MnCORS is funded from two sources: The statewide survey scientific equipment budget contributes \$250,000 each year for replacing and repairing equipment; the Office of Land Management also spends \$25,000 to \$30,000 for licensing agreements.
- In Washington, partners who own and contribute individual stations to the network make initial investments. SPU purchases the software for the network. Subscribers—network users who pay a subscription fee rather than contributing a station to the network—pay operation costs.
- Although Wisconsin DOT has funded the passive and active network since 2011, it was initially started with grants from the Department of Commerce and the National Oceanic and Atmospheric Administration.

CGPS Station Maintenance Funding

Except in Washington, where operation fees are paid by subscribers, state DOTs generally fund CGPS station maintenance. Funding originates from a range of sources, including annual budgets and vendor contracts:

- While Florida funds CGPS station maintenance through its annual budget, it currently has no equipment replacement costs due to hardware it purchased as part of a five-year legislative budget request in 2012.
- Minnesota's statewide survey scientific equipment budget provides funding to replace and repair station equipment. The state replaces eight to 10 stations each year. The hosts of each site maintain the physical stations.
- New York funds CGPS station maintenance through a vendor contract.
- Oregon is responsible for funding maintenance of the station it owns, while partners are responsible for funding maintenance of their stations. However, Oregon DOT has occasionally assisted partners in need.
- Wisconsin DOT funds CGPS station maintenance through budget line items and State Planning & Research funds.

Annual Operation Costs

Annual operation costs for maintaining and operating an RTN vary considerably from state to state and station to station. Reported costs include different components, making an equitable comparison difficult. On the low end, Oregon's costs of \$500 per station are primarily related to software maintenance agreements. Washington's operation costs are about \$1,300 per site, which only includes costs to operate the data center. The highest reported costs were \$6,000 per station in Wisconsin, which includes replacement costs for equipment on a seven-year cycle but doesn't include employee salaries or telecommunication services costs.

State	Annual Costs	Number of Stations	Cost per Station	Notes
Florida	\$375,440	About 100	\$3,754	\$1.4 million obtained in 2012 to fund software licensing for five years and purchase 33 replacement stations when stations in the network require new equipment. Costs to renew licensing in 2018 unknown; discussions are expected to begin in 2015.
Minnesota	\$275,000	120	\$2,292	<ul style="list-style-type: none"> • \$250,000 from statewide survey scientific equipment budget for equipment replacement and repair. • \$25,000-\$30,000 from Office of Land Management for licensing agreements.
New York	\$120,000	51	\$2,350	Vendor operation and maintenance costs only. Salary costs for network management: about \$100,000 per year.
Oregon	\$50,000	About 100	\$500	Primarily maintenance agreements on software.
Washington	\$136,000	107	\$1,270	Data center operation only. Annual receiver and annual costs (not included here): about \$1.3 million, based on total investment of \$10 million and a seven-year station replacement cycle. Individual station operation is the responsibility of the station owner. Data center costs would not vary much regardless of network size. Estimated data center costs of a 300-station network (possibly appropriate for California): about \$200,000.
Wisconsin			\$6,000	Replacement cost of stations (typically replaced every seven years). Employee salaries and telecommunications services not included (part of the WISCORS budget).

Return on Investment

Currently only one state—Florida—has calculated a return on investment (ROI) for its RTN. Annual operating costs are \$375,440, while the cost to access a private network for approximately 60 crews within the state network would cost \$1,339,800. The savings to the state is \$964,360 (not including benefits to other end users).

While other states have not calculated an ROI, other preliminary measures such as cost-benefit analyses and private owner estimates suggest these agencies benefit from the network:

- The benefits to Minnesota DOT are about equal to the RTN's costs. However, the benefits for the Minnesota economy as a whole are much greater. In 2004, a private partner's ROI analysis estimated that annual benefits for all users (public and private) were \$3 million. In 2008, that estimate had grown to about \$30 million. Use of the network has continued to grow, and the DOT is encouraging broader use to maximize the value of the taxpayer investment.
- In New York, an initial cost-benefit analysis for creating the network found more benefits than costs, including savings in DOT surveying costs. Estimates suggest using the RTN saves at least \$130 per hour, or about \$5 million per year, for the network's users. While public end users also benefit from the data, the DOT's justifications did not include those benefits.
- Oregon's network has doubled its efficiency by eliminating the need to purchase both base stations and rovers since a base station can perform both functions.
- Washington's end users use a multiplier that is based on Germany's calculations, which estimates the RTN's fixed corrections save 100 euros (US\$130) per hour over conventional methods. The state conservatively estimates that Washington users save about \$5 million per year.
- Although Wisconsin doesn't track ROI information, user groups undoubtedly receive benefits from the network.

Cost Recovery/End User Fees

None of the DOT-owned networks charge end users a subscription or annual fee to help recover costs. Since the Florida RTN is a taxpayer-funded program, the state hasn't asked taxpayers to pay an additional fee. Similarly, New York anticipates the cost of administering these fees would exceed the amount the state receives from end users. However, some states are considering implementation:

- Oregon reserves the right to charge end users in the future, as noted on the network's account request page (www.oregon.gov/ODOT/HWY/theorgn/Pages/Account-Request.aspx):

At this time, Oregon DOT is authorizing Rover Accounts for ORGN rover users at no direct charge to the user. During this test period, use of the ORGN and its products will be at the users own risk. It is the responsibility of the user to verify the accuracy of surveys they perform using the ORGN and its products. During this beta test period, Oregon DOT will evaluate ongoing maintenance and upgrade costs for the GPS Network. In the future, Oregon DOT may charge reasonable subscription fees for rover accounts based upon cost recovery of the maintenance and upgrade for the ORGN; however, rover accounts for partners will continue to be provided at no charge.
- In Washington, real-time services are free to WSRN partners. Nonpartners can subscribe; costs start at \$1,900 for one account; \$5,700 for five accounts; \$10,000 for 10 accounts; or \$15,000 for 20 accounts.
- Wisconsin's Secretary of Transportation is closely examining the possibility of implementing user fees.

3) Operation and Maintenance

In this portion of the survey, we asked respondents to describe the key elements of the RTN's operations and maintenance, including day-to-day administration and maintenance, IT support, security standards, partnerships and system improvements.

Day-to-Day Administration Responsibility and Costs

According to respondents, day-to-day administration of the RTN is typically the work of 1.3 to two employees, except in Washington where day-to-day network administration is the work of a 0.8 FTE.

- In Florida, the FPRN manager in the DOT's Surveying and Mapping Office is responsible for overall system administration. The FPRN manager is also the head technician and head installer. One other staff member is involved in day-to-day operations. Florida's seven DOT districts also assist the state DOT. Each district has a liaison, who acts as the first response if a site goes down in that district. Annual labor costs are about \$100,000.
- In Minnesota, the Office of Land Management's webmaster is responsible for network software, while two employees in the Geodetic Unit are dedicated to the RTN: one in the field and one for the website. Network maintenance requires about 1.3 FTE; salary and benefits are approximately \$140,000 annually.
- RTN maintenance in New York requires 1.5 employees: one employee with a mapping title is responsible for day-to-day administration and registration approval on a full-time basis, while a surveyor spends half of his time working on the network. Total salary costs are estimated at about \$100,000 annually.
- Two geodetic land surveyors in Oregon are responsible for day-to-day system maintenance. Their work constitutes about 1.5 FTE, although having another person to serve as a backup would be useful.
- System administration in Washington requires about 0.8 FTE. Day-to-day system administration is the responsibility of SPU's surveyor and a backup operator. The surveyor spends about 60% of his time on the network, while the backup operator spends about 20% of his time.
- Wisconsin has one full-time network administrator and one half-time backup administrator. The positions are classified as geodesists or geodetic specialists with salaries of approximately \$60,000 per year, including overtime, expenses and benefits.

IT Support Integration

The RTNs in only two states—Minnesota and New York—receive IT support from a separate state IT department. MnIT, Minnesota's state IT organization, receives funding from each state department, so it's difficult to determine the direct costs for the RTN. New York DOT used to have its own IT group, but it has transitioned to a separate department. All IT requests for NYSNet go through the state IT department's support helpdesk. Funding and management are also that department's responsibility.

The remaining four respondents receive IT support through state and local agencies:

- In Florida, the Southwood Shared Resource Center provides IT support. The agency is reimbursed with funds from the DOT's budget, using the same budgetary system as all

state departments, although the DOT Office of Information Services contributes to the budget because it was previously responsible for managing the network.

- Oregon's network runs on eight servers in the state data center, a secure server farm operated by the state's Department of Administrative Services, which backs up and mirrors the network and has been able to restore access in half an hour when the network has gone down in the past. Funding for the Department of Administrative Services comes out of all state department budgets; Oregon DOT does not pay any fees directly for IT services.
- Washington has servers in two locations: the main servers are at the City of Seattle IT department, and backup servers are at a university geology lab. Seattle provides minimal IT support, and the servers operate independently from Seattle's computers to avoid firewall issues. SPU's surveyor provides helpdesk services for all of the network's end users. The network pays Seattle IT a small amount each year for hosting, which is taken from operations funds.
- Wisconsin DOT provides IT support to sites that do not have adequate service through the IT budget. This service is managed through the DOT's Bureau of Information Technology. On-site IT issues are resolved by network administrators and Internet service providers at that site.

Adherence to Security Standards

We asked respondents to describe how their network meets the IT security standards of the state's entire IT system. Practices vary among states, with most DOTs relying on firewall protection:

- Florida's RTN adheres to Homeland Security standards, with only one incoming IP channel.
- Minnesota's network is separated from the state's IT system through a firewall. Only the website and NTRIP caster are public.
- The IT network in New York is all internal to the DOT. The state uses Leica GNSS Spider security software.
- ORGN relies on the state data center's firewalls and the security built into Leica's NTRIP software. Oregon DOT has tried to hack into both and was unsuccessful.
- Washington has a set of firewall rules in place, and Seattle's IT department monitors and analyzes network traffic to warn against incursions. Although SPU has never had a breach, the network is separate from the city's servers, so if a breach occurred, it wouldn't affect the city.
- Wisconsin follows the security standards of the Wisconsin Department of Enterprise Technology and the requirements of individual site partners.

Station Maintenance

Responsibility for station maintenance is assigned to different entities in each state:

- In Florida the Southwood Shared Resource Center (the state data warehouse) maintains the CGPS stations owned by the state; stations owned by local agencies are maintained by that agency.

- Minnesota’s Geodetic Unit is responsible for station maintenance. A contact at each site performs some maintenance, but the Geodetic Unit is ultimately responsible and will repair or replace equipment on-site. MnDOT’s RWIS group is responsible for network issues.
- Technicians in New York’s surveying office maintain the state’s stations.
- In Oregon, the station owner—either Oregon DOT or the partner—is responsible for station maintenance. Oregon DOT has five regions, each with several maintenance districts, so on-site contacts can often perform basic maintenance. The DOT’s surveyors also occasionally assist with station installation.
- Washington’s station owners maintain their own stations. (Ongoing maintenance requirements of the stations are generally rudimentary.) However, SPU or university partners will assist with some technical issues. Network partners share equipment as necessary.
- Station maintenance in Wisconsin is performed by either the network administrator or an on-site staff member who is familiar with the DOT’s receiver and its IT configuration.

Partners in Network Operation

To better understand network processes, we asked respondents if they used university or other agency partners to enhance system operation. Four states—Florida, New York, Oregon and Washington—have partners, ranging from DOTs in adjoining states to Washington’s 80-partner collective. Several states consider station hosts to be partners, but these are informal agreements to share data, not costs.

- Florida DOT is trying to become a member of the Regional Height Modernization Partnership through the National Oceanic and Atmospheric Administration and the NGS. This partnership is a federal grant program that provides additional funding to expand, replace and maintain a network. Florida DOT recommended Caltrans consider joining the partnership as well.

The state also considers local agencies that host sites to be partners. In those cases, Florida DOT provides the hardware, but the local agencies pay for communications and electricity. The state DOT is expanding its use of this approach since it eliminates the need to find an additional site, and it improves the agency or city’s data accuracy because it’s local.

Alabama DOT is also considered a partner, as the state networks adjoin. The DOTs have an informal agreement to share data.

- Minnesota currently does not have any operation partners. Previously the University of Minnesota purchased and shared some systems from the DOT to conduct research on vehicle assists for buses. But those systems are currently Minnesota DOT’s responsibility.
- New York DOT partners with two surveying schools that have GPS receivers. Additional partners might include the vendor and the NGS.
- Oregon has several partners, including the Bureau of Land Management, city and county governments, area schools and the Veterans of Foreign Wars. A complete list of partners is available at www.oregon.gov/ODOT/HWY/theorgn/Pages/Partners-List.aspx.

- As a collective, Washington's network has about 80 partners.
- WisDOT is solely responsible for operating the WISCORS network.

Definition of Partnerships

When asked to explain the structure of these partnerships, including allocation of resources and cost sharing, most of the four respondents with partners described informal agreements for sharing resources, but not costs.

- Florida and New York have an informal agreement with its partners to share data, but there is no cost sharing.
- ORGN defines partners as an individual, agency or business that contributes substantially to the network's infrastructure. Some of these partners contribute stations, while others contribute facilities; Wasco County, for example, allowed Oregon DOT to build a station on its property. Beyond that, partner agreements are informal.
- In Washington, individual station owners are responsible for their own stations. In exchange for providing a functioning station, they receive network corrections.

Ongoing System Improvement Efforts

We asked respondents about future planning efforts to enhance their network operations with emerging technologies such as intelligent transportation, early earthquake warning or unmanned aerial systems. Both Florida and New York are working to add access to data from GLONASS, the Russian satellite network. Other states are less formal in their ongoing system improvement efforts.

- Florida's RTN has upgraded from a GPS-only network to a GPS-GLONASS network, which supports the U.S. network of GPS satellites and the satellites from GLONASS, the Russian network.

The DOT is currently converting all of its analog communications to digital, and reconfiguring the network to better cover the state by moving sites or adding new stations. Adding capacity for digital communications will allow the state to purchase licenses from the vendor when extra signals become available. The state anticipates purchasing licenses to support Compass (the Chinese network), Galileo (the European network) and a new L5 frequency band to carry signals for safety and aviation use. However, these technologies probably will not be viable until 2018.

- Minnesota doesn't have a formal improvement program. Although the DOT hasn't adopted new technologies recently, it routinely upgrades receivers and software, and keeps up with National Geodetic Service adjustments to coordinates.
- Instead of an ongoing improvement program, New York DOT usually waits until other DOT offices contact the agency for improvements. However, the RTN has upgraded about half of its network to include GLONASS data.
- Oregon doesn't have a defined, regular process in place for enhancing its system. Instead, the state makes improvements (including implementing GLONASS availability and preparing for an anticipated Cascadia earthquake) based on budget availability and user requests.
- Washington's partners and subscribers expect that the network will improve over time. Currently, the network is testing precise point positioning (PPP) services, which is

already useful in some applications. A hybrid PPP-RTK (real-time kinematic) augmentation network may ultimately (in five to 10 years) replace RTK satellite navigation, which would allow for a smaller network without requiring cellular technology to get corrections.

- Wisconsin DOT is currently investigating the possible installation of Trimble T4D software on segregated servers to monitor bridges and dams. WISCORS is also a component for implementing the WisDOT 3D Technologies Plan (www.maasto.net/documents/Zogg%20-%205A%20-%20WisDOT%203D%20technologies.pdf) for design and construction.

4) Standards

Another topic area in the survey addressed standards or specifications regarding RTN operation, including construction and station stability, and positional degradation due to crustal motion or subsidence. We also asked respondents whether the RTN was aligned with the National Spatial Reference System and how the state addressed RTN system integration with abutting states.

Minimum Construction Standards for CGPS Stations

When asked to describe the state's minimum standards or specifications for construction and stability of CGPS stations, respondents reported that most networks typically follow NGS construction standards. Florida DOT also tries to meet these standards at core sites, including concrete block buildings more than five years old and concrete footers. However, meeting standards is not always possible, resulting in a few noncompliant stations:

- Wherever feasible, Minnesota follows NGS recommendations for concrete pedestal mounts. If a building mount is the only option at a Minnesota site, the DOT tries to secure stations on a brick building. At a few network sites, stations are mounted on metal sheds because it is the only option. However, NGS has accepted many of MnDOT's stations into its network, so the state is fairly confident in their stability.
- Oregon follows its own standards to ensure the best-quality antennas and other equipment (such as SCIGN mounts for antennas). Partners do not always meet the state standard in stations that they construct, and while that is permitted, the network monitors the quality of the data through quality control programs to evaluate stability and multipath, and it only keeps that data in the network if the data is acceptable.
- Washington has three levels of standards. The most exacting are stations that follow UNAVCO Plate Boundary Observatory standards for drill brace mounts; these stations are suitable for the most precise scientific purposes. At the next level are stations that meet NGS standards; all but a handful of stations in the network meet those standards. The third level is not really a standard at all; stations are permitted in the network without necessarily meeting any construction standard, but the network can remove the station from the network if the station doesn't provide adequate data accuracy.
- WISCORS offers a description of field components at <https://wiscors.dot.wi.gov/TrimblePivotWeb/fieldcom.htm>, including current designs for concrete pillar monuments (36-inch diameter by 12-foot deep concrete foundation, with an 8-foot top concrete obelisk 20 inches square at the bottom and 12 inches square at the top) and a description of welded stainless steel tube building mount monuments.

Alignment with National Spatial Reference System

All of the respondents' networks are aligned with the National Spatial Reference System.

- Florida DOT observed five consecutive days of data across the entire network, adjusted them holding the NGS-CORS stations as fixed constraints and adjusted all non-CORS stations to match the (2011) 2010.00 realization.
- Minnesota's network can receive 1996, 2007 or 2011 corrections through the NTRIP caster. Since many stations are accepted into the NGS network, adjustments have been easily accepted.
- Most of New York's stations are national CORS stations.
- NGS often invites Oregon to present the state's methods at webinars as a model for other states. ORGN worked with NGS when NGS converted from the NAD 83 (CORS96) epoch 2002.00 datum realization to the NAD 83 (2011) epoch 2010.00 datum realization in 2012. ORGN converted in 2013, using least squares adjustment through the NGS Online Positioning User Survey (OPUS) Projects software, submitting five days that had high pressure over the entire state. Details about the conversion are available at www.oregon.gov/ODOT/HWY/theorgn/Pages/Coordinates.aspx.
- The Washington network joined the National Spatial Reference System in 2004. At least 10% of Washington's stations are national CORS. The network hasn't made all stations national CORS because of the amount of tectonic plate movement in the state. The network constrains to whichever stations haven't moved out of tolerance, based on a minimum of two weeks of data.

Integration with Abutting States' RTNs

State networks typically connect with neighboring states through informal data-sharing agreements.

- Florida has an informal data-sharing agreement with Alabama DOT, as discussed in **Partners in Network Operations**. The state's connections with Georgia are limited to city-owned stations since Georgia's statewide network is private and earlier partnerships with private companies that went out of business without notice left gaps in data. (See **CGPS Station Location**.) Florida DOT has data-sharing agreements with these cities.
- Minnesota has informal data-sharing agreements for approximately nine stations located in Wisconsin and Iowa.
- New York connects with neighboring states as if they were rovers in the field, entering a username and password like other network end users. The state requires other networks to do the same for data sharing.
- In addition to an informal data-sharing agreement with Washington, Oregon has worked with individual stations in Idaho and California to ensure that all are aligned to the National Spatial Reference System so coordinates can be interchanged. When Oregon made adjustments, it held stations in neighboring states fixed from the national NGS CORS.
- Washington connects with stations in Oregon, Idaho and Canada. WSRN has stream sharing agreements with Oregon on a one-to-one basis: Oregon gets a stream from one Washington station for each stream that Washington gets from Oregon. WSRN also swaps data streams with a couple of networks in Canada. (Canadian networks are not allowed to sell subscriptions in the United States, and WSRN isn't allowed to sell

subscriptions in Canada.) A few Idaho stations are members of the Washington network because Idaho doesn't have a state network. If Idaho does form a state network, WSRN will likely form a data-sharing agreement with it.

- Wisconsin DOT has not brought in neighboring states because of licensing issues and software limitations. But its goal is to bring in eight border stations from Iowa, Minnesota and Michigan.

Standards to Account for Positional Degradation Due to Crustal Motion or Subsidence

We asked respondents about positional degradation of the stations that resulted from crustal motion or subsidence, specifically, whether the state had minimum standards (such as regional subnets requiring periodic updates) to account for and address crustal motion. Only one state—Washington—has standards to account for crustal motion; positional degradation in the state is monitored centrally.

All of the remaining states except New York have informal processes for addressing positional degradation or subsidence. Crustal motion and subsidence are not significant issues in New York.

- The Gulf Coast states use Florida's stations as a benchmark to monitor how far they are sinking.
- Minnesota has nightly adjustments, but positions are typically stable.
- Oregon does not have a formal plan in place but adjusts its stations with NGS' adjustments. NGS is moving away from fixed-plate data that is fixed to the North American Plate, probably to a system of constant coordinates, which will be useful for Oregon since it is located on multiple plates. In its last change, which covered about 10 years, a couple of centimeters of differential movement occurred in eastern Oregon, 4 to 6 cm in western Oregon and as much as 13 cm along the coast.
- A University of Wisconsin—Madison geology professor monitors WISCORS stations for stability issues that might go undetected by coordinate monitor, although these issues are generally related to antenna failure or snow buildup. A consultant analyzes positional data each time the system adds stations or upgrades software.

Determination of Regions Based on Different Rates of Crustal Motion

We asked Washington DOT if its system is broken into regions based on differential rates of crustal motion and how the boundaries for those regions were determined. The state has six regions based on geographic regions of crustal movement as well as regions where the tropospheric profile is higher than others—stations in the mountains have to be closer together, while stations in eastern Washington (where crustal movement is slower) can be farther apart. The regions are monitored to maintain horizontal integrity of 1 cm relative to each other, and vertical integrity of 2 cm relative to each other.

5) Software and Hardware

We asked respondents to describe what software and hardware end users are required to have to access real-time data, and to explain what communication frameworks or technologies are used by the network.

Requirements for End User to Access Real-Time Data

Typically RTNs only require an Internet connection to access real-time data. Additional technical requirements follow:

- Along with Internet access, Florida users require an account, a receiver capable of receiving corrections and a communications device. According to an FAQ on the FPRN's website (www.dot.state.fl.us/surveyingandmapping/FPRNfaq.shtm), corrections are available through the Internet via NTRIP and TCP/IP protocols, so any network-ready GPS receiver will allow access.
- New York's network permits access via several protocols, although it prefers that rovers use the NTRIP protocol.
- Oregon end users need a GPS receiver that is at least Radio Technical Commission for Maritime Services (RTCM) 2.3 capable, with RTCM 3.x recommended. Most new receivers will meet that standard. All logins are based on an NTRIP username and password; no static IP address is necessary.
- In Washington end users are required to access data through the NTRIP protocol. Real-time corrections are only delivered through the NTRIP caster. Those are easy to acquire, with clients available in the public domain.
- Wisconsin end users must have a rover that supports networked transport of RTCM via Internet protocol and a data-capable cellphone or modem with a data package from the cellular provider. Multiple rovers can be connected to the network simultaneously, but each needs a unique login.

Communication Framework and Technologies in Use

Respondents reported that RTNs use a mix of communications technologies, including broadband, wired or cellular modems.

- About half of Florida's stations use a DSL modem, while 30 percent use cellular modems. The remaining 20 percent use an old, analog system that is being phased out.
- Minnesota's system uses PCP and NTRIP casters.
- New York uses a wired network.
- Oregon primarily uses a wired network, although some sites connect via cellular. The UNAVCO Plate Boundary Observatory (a significant partner in the network) has a couple of sites, mainly in the mountains, that use point-to-point radio to send a signal that the observatory owns at Oregon DOT.
- Washington uses a wide mix of technologies; any that can deliver data to the Internet with less than 1 second of latency are acceptable. A broadband modem is preferred, although hard-wired DSL is acceptable. Dial-up was used at one station 10 years ago and is still technically possible. Satellite communications generally do not meet the latency standard, but other technologies are usually acceptable.

- Wisconsin provides correction data in either RTCM or Compact Measurement Record (CMR) format. Six mount points are available to WISCORS users, depending on the equipment they use.

6) User information

To better understand the RTN user base, we asked respondents about their end users, including who was eligible to access the network, industry sectors represented by their users, data products available to end users and user registration fees.

System Availability to Outside Users

- All networks surveyed for this Preliminary Investigation are accessible to any registered user. Florida imposes some “common sense” limits about the number of accounts permitted to a single user to discourage large survey companies from streaming raw data.
- Most systems are free. WSRN in Washington charges for subscriptions, although even nonregistered users can access static files at no cost.

System Users

Respondents reported that network end users represent a wide range of industries, including surveying, mapping, construction, utilities, agriculture, public agencies and academics.

- Florida—Approximately 2,000 user accounts with representatives from:
 - Florida DOT Surveying and Mapping.
 - Other state agencies, such as the state Environmental Protection Agency and state law enforcement.
 - GIS.
 - Utilities (for building GIS databases).
 - Water management districts.
 - Precision agriculture.
 - Machine-controlled construction companies.
 - Private survey companies.
 - Golf course maintenance.
- Minnesota—About 50 user types that fall into three basic categories:
 - **Agriculture:** Farmers and dealers. Precision agriculture makes up the largest and most rapidly growing group of users in Minnesota and other Midwestern states.
 - **Public:** City, county, state and federal agencies.
 - **Private:** Engineering, surveying, railroads and GIS companies.
- New York user groups:
 - DOT Surveying Office.

- Consulting.
- Contracting.
- GIS data collection.
- Academia.
- Agriculture.
- Utilities.
- Municipalities.
- Oregon—More than 400 users in six categories:
 - Private (more than half of the users).
 - Oregon DOT.
 - Other government agencies.
 - Academia.
 - Automated machine control.
 - Precision agriculture (the fastest-growing segment).
- Washington—Three key user categories:
 - **Asset mapping and surveying** (the largest industries). Each segment makes up about 30 percent of users.
 - **Construction and agriculture.** Combined, these segments comprise most of the remaining 40 percent of users.
 - **Scientific research.** Although this segment has a small number of users, it consumes a large amount of data.
- Wisconsin user groups:
 - Engineering.
 - Surveying.
 - Road construction.
 - Agriculture.
 - GIS.
 - Environmental.
 - Navigation.
 - Maritime activities.
 - Signal timing.
 - Zero visibility snowplowing.
 - Atmospheric science.
 - Utilities.

System Access

End users typically access an RTN through an Internet website (Florida, Minnesota, New York and Wisconsin); an NTRIP caster (Minnesota) or a mobile rover (Oregon). Wisconsin users complete a registration form available on the RTN's Web server; a network administrator then issues a username and password within three working days.

Access to an RTN					
State	Internet/ Website	NTRIP Caster	Mobile Rover	Other	Notes
Florida	X				
Minnesota	X	X			Most users access through NTRIP caster.
New York	X				NTRIP software required. Password-protected accounts.
Oregon	X		X	GPS receiver	<ul style="list-style-type: none"> • Website login: Rinex files. • GPS receiver login: NTRIP software.
Washington	X				Access through cellular or Internet data connection. Password-protected accounts.
Wisconsin	X				Network administrator issues username and password.

Available Data Products

A variety of data products are available to end users, typically including both single-station and multi-station (network) real-time GPS corrections, and archived GPS/GNSS measurement data for post processing work. All respondents offer the real-time correction products in open-source formats (RTCM 2.x, RTCM 3.x and CMR+), although RTCM 3.x is currently the most common format used. All respondents provide archived data in Rinex format. Three respondents (Minnesota, Washington, and Wisconsin) provide archived data in proprietary Trimble formats as well.

State	Data Products	Formats	Notes
Florida	Single Baseline Network Correction	RTCM 2.3, RTCM 3.1, CMR+ MAX/iMAX: RTCM 2.3, RTCM 3.1, CMR+ VRS: RTCM 2.3, RTCM 3.1, CMR+ FKP: RTCM 2.3	Products list: www.dot.state.fl.us/surveyingandmapping/FPRNProducts.shtm .
	Post Processed Data	Rinex 2.1, 2.1, 3	
Minnesota	Single Baseline Network Correction	RTCM 2.3, RTCM 3.1, CMR+, CMRx VRS: RTCM 2.3, RTCM 3.1, CMR+, CMRx	Built-in functionality for downloading post-processing files available on the Trimble website. Most users download files in preferred format from an FTP server.
	Post Processed Data	Rinex 2.1, 2.1, 3, t01, t02, TGD, DAT	
New York	Single Baseline Network Correction	RTCM 2.3, RTCM 3.1, CMR+ MAX/iMAX: RTCM 2.3, RTCM 3.1, CMR+	Products list: cors.dot.ny.gov/spiderweb/frmindex.aspx (under the RTN Product Descriptions tab).
	Post Processed Data	Rinex 2.1, 2.1, 3	
Oregon	Single Baseline Network Correction	RTCM 2.3, RTCM 3.1, CMR+ MAX/iMAX: RTCM 2.3, RTCM 3.1, CMR+	Products list: www.oregon.gov/ODOT/HWY/theorgn/Pages/Products-Services.aspx .
	Post Processed Data	Rinex 2.1, 2.1, 3	
Washington	Single Baseline Network Correction	RTCM 2.3, RTCM 3.1, CMR+, CMRx MAX/iMAX: RTCM 2.3, RTCM 3.1, CMR+ VRS: CMR+, CMRx, RTCMx FKP: CMR+, RTCMx	Typically only users with old equipment use CMR+.
	Post Processed Data	Rinex 2.1, 2.1, 3, t01, t02, TGD, DAT	
Wisconsin	Single Baseline Network Correction	RTCM 2x, RTCM 3.1, CMR+, CMRx VRS: CMR+, CMRx, RTCM 3.1 MAX/iMAX: RTCM3.1	Wisconsin DOT's IT restricts storage space; older information can be retrieved from the NGS database.
	Post Processed Data	Rinex 2.1, 2.1, 3, t01, t02, TGD, DAT	

End User Charges

Currently five of the states—Florida, Minnesota, New York, Oregon and Wisconsin—do not charge a user fee, however Oregon reserves the right to institute charges in the future.

In Washington, station providers or subscribers can access the network. Subscriptions start at \$1,900 for a single account, with discounts at five, 10 or 20 accounts.

Supplemental Funding from Users

None of the respondents reported receiving any supplemental funding or donations from users, although some states have received in-kind support such as grant money to upgrade software.

- One Florida user offered to donate a base station and antenna, but the state didn't accept the station or hardware because of their age.
- In Minnesota, some counties and private companies that host sites provide in-kind support for network infrastructure.
- Washington's Department of Natural Resources and DOT have both used grant money to upgrade software to add stations and capacity.

7) Public/Private Relationships

None of the respondents have formed any type of partnership with private networks in their state. Some co-exist with private networks, but they do not have any formal connections.

RTNs in Operation when State RTN was Implemented

Except for several small-scale, private agricultural networks in Minnesota and Wisconsin, no other private RTNs were operating when the each state's system was implemented.

- Florida's network was one of the first in the nation when it was started about 13 years ago. The state currently has two private networks. Florida DOT used to share data with both networks, but the DOT's administration considered this data sharing unethical and about a year ago, stopped transmitting data to third-party firms that re-sell data.
- Oregon DOT explains that the mission of its network is to maintain horizontal and vertical geodetic control for all Oregon surveyors, which is a legitimate government function. The state RTN is the best way to provide that service.
- About a year after Washington started its network, Pierce County, WA, began its own separate network. While the county borrows a data stream from the statewide network, the two networks are separate and not compatible.
- Several private agricultural networks that were in place when Wisconsin created its RTN are still operating and are independent of WISCORS.

Funding of Public/Private Partnerships

Since none of the respondents have developed a network with a private partner, no information was available about funding and policy management in public/private partnerships.

8) Best Practices

Respondents recommended a diverse set of best practices for implementing an RTN:

- Train district liaisons to respond to local issues quickly.
 - Florida believes liaisons should be able to completely rebuild a site in the event of a catastrophe such as a lightning strike. Regional locations should also have enough equipment on hand to be able to replace equipment quickly.
- Seek federal grants to fund the network.
 - Florida recommends looking for grants through NOAA for height modernization, crustal motion corrections, and possibly replacing sites damaged by natural disasters.
- Partner with local agencies with the necessary infrastructure.
 - Minnesota suggests partnering with cities or counties that have the necessary infrastructure and building relationships with different equipment dealers.
 - Washington suggests partnering to reduce duplicated effort from multiple individual networks.
- Build relationships with equipment dealers.
- Maintain a strong wired network to ensure network reliability.
 - New York relies on good IT support and a wired network to keep servers running. The state's stations are rarely down, but if they do go down, the IT network can get them up and running within a day or two.
 - New York thinks twice before including partner stations. Partnerships can be a weak link since they are not on the wired network and they go down more frequently. In the past, the RTN included several Vermont stations to provide better coverage in the border area. However, these stations weren't stable and data was unreliable. The state also doesn't rely on Internet providers or communications companies to transmit data since they can create a weak link.
- Involve stakeholders from the beginning.
 - Oregon recommends working with the IT department and gathering stakeholder input before RTN startup. Oregon did a lot of work upfront to manage risk. For example, the network used a risk management assessment tool from the Oregon DOT IT department. Much of what was included in the tool had already been addressed, but it was useful to confirm that all bases were covered, and ORGN did identify a few points to address.
 - Wisconsin suggests thorough planning and research before making any decisions that will affect the network well into the future.
- Keep the network independent from the public sector IT.
 - Washington recommends hosting the servers separate from government agencies to avoid trying to work through the labyrinth of public sector IT. In one Washington case, a simple connection took 14 months to work out.

- Washington also recommends third-party hosting, particularly if multiple networks are brought together. Washington recommends talking to South Carolina DOT about IT issues with its RTN.
- The Washington network makes good use of hold-harmless agreements. Station owners are not liable for the actions of any one user, and vice versa.

RTN Impact on Safety

Respondents reported some safety improvements as a result of RTNs, particularly for surveyors and other highway workers. New York, Washington and Wisconsin said surveyor travel time to field locations is reduced, and exposure to traffic is limited for employees who must work within the highway right of way. Other examples of safety improvements follow:

- A vehicle automation summit in Florida will use the RTN as a control for automated vehicles. The RTN is improving accuracy from decimeters to centimeters.
- In addition to the safety improvements related to the University of Minnesota research on guided buses, and Minnesota's Geodetic Unit uses network data to determine if it is safe to recover and reuse monuments.
- New York projects are surveyed more quickly. The state currently uses the network to control laser scans and is starting to use mobile LiDAR, which the network will probably control.

Contacts

CTC contacted the individuals below to gather information for this investigation.

State Agencies

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Appendix A: Survey Questions

We conducted an email and telephone survey of a select group of state DOTs identified by Caltrans as having experience with a statewide real-time network. The survey addressed the following topic areas:

- Ownership of statewide RTNs.
- Funding.
- Operation and maintenance.
- Standards.
- Software and hardware.
- User information.
- Public/private relationships.
- Best practices.

The complete set of survey questions follows.

Ownership of Statewide RTNs

1. Is the real-time network (RTN) owned, operated and maintained by the department of transportation (DOT) (or other state agency), or is the system administration and management contracted out?
2. Are the physical continuous GPS (CGPS) stations owned by the RTN operator? If not, how is the RTN provider working with the station owner(s) to ensure service reliability to the users?
3. Who owns the computer hardware and software needed for the RTN operations?
4. Who owns the communications hardware?
5. Are the stations on public or private lands, and are there associated, periodic permitting costs that need to be funded?
6. How does the RTN provider protect itself legally from liability exposure from end users? How was this legal disclaimer process developed and by whom? Has it been tested or challenged?

Funding

7. How are the RTNs funded in your state, including ongoing software and hardware maintenance, real-time communications, network expansion and upgrades, and all associated labor costs?
8. How is the funding for the CGPS station maintenance secured?
9. What are the annual costs of maintaining and operating a statewide RTN? (A per station breakdown will be useful for scalability purposes.)
10. What is the return on investment?
11. Is there a cost recovery mechanism in place, such as a subscription or annual fee imposed on end users?

Operation and Maintenance

12. Who is responsible for the day-to-day system administration? Please provide a breakdown on personnel classifications and associated labor cost estimates.
13. How is information technology (IT) support integrated into the system? How is it funded? How is it managed?
14. How does the system IT meet the security standards of the IT backbone to which they are attached?
15. Who performs the maintenance of the stations?
16. Does the DOT (or lead state agency) have partners in the operation of the network, such as in academia or at the local level?
17. If so, how is that partnership defined, including allocation of resources and cost sharing?
18. Are there ongoing efforts by the RTN operators to improve the system and determine how the system might integrate with, and support, emerging technologies such as intelligent transportation, early earthquake warning or unmanned aerial systems?

Standards

19. Are there minimum standards or specifications in place regarding the construction and stability of stations in the RTN?
20. Is the RTN aligned with the National Spatial Reference System? If so, by what process and procedure? If not, why not?
21. How is the integration with abutting states with RTN systems addressed?
22. Are there minimum standards in place to account for and address the positional degradation of the stations due to crustal motion or subsidence, such as regional subnets, requiring periodic updates?
23. If the system is broken into regions based on differential rates of crustal motion, how were the boundaries for those regions determined?

Software and Hardware

24. What requirements are there for the end user to access real-time data? For instance, is a static IP address needed?
25. What communication framework/technologies are used? Do the remote reference stations connect via cellular, wired network, point-to-point radio and/or other technologies?

User Information

26. Is the system open to all registered users or only to internal or state employees?
27. Who are the users of the system (e.g., land surveyors, GIS data collectors, researchers and the academic community, early earthquake warning system developers, asset managers, construction, contractors, navigation, agriculture, etc.)?
28. How do users access the system?
29. What data products are available to the end user?

30. How are the end users charged for the service (e.g., flat annual rate, per use, one-time registration fee)?
31. Have any of the users provided funding (donations, etc.) for the operation, maintenance and upgrade of the RTN beyond the standard user fee? If so, from what user sector(s)?

Public/Private Relationships

32. Were any private RTN providers in operation when the statewide system was implemented? If so, how was that handled? Have the service providers remained in operation?
33. If a public/private partnership was developed, how is it funded? How is policy managed under this partnership?

Best Practices

34. What best practices has your state established in any of the above areas that Caltrans should consider to establish its own statewide RTN, to fund or take over the operation of the (currently private) California Real Time Network, or to contribute to an RTN developed and operated in partnership with others?
35. Has the availability of the RTN improved the safety of employees and the public? If so, how?