ANALYZE BUSINESS MODELS FOR IMPLEMENTATION AND OPERATION OF A STATEWIDE GNSS RTN

FHWA/MT-22-004/9922-807

Final Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

October 2022

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Bozeman, MT

RESEARCH PROGRAMS

MONTANA
Department of Transportation

Analyze Business Models for Implementation and Operation of a Statewide GNSS-RTN

Final Report

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA/MT-22-004/9922-807	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle Analyze Business Models for Implementation and Operation of a Statewide GNSS-RTN	**5. Report Date** October 2022
	6. Performing Organization Code
7. Author(s) Ahmed Al-Kaisy, ORCID: 0000-0003-1198-0975 Rafael Teixeira, ORCID: 0000-0003-4314-0962 Sajid Raza, ORCID: 0000-0002-8223-1085 Benjamin Meyer, ORCID: 0000-0002-9447-0817	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Western Transportation Institute College of Engineering Montana State University Bozeman, MT 59717-4250	**10. Work Unit No.**
	11. Contract or Grant No. MDT Contract # 9922-807
12. Sponsoring Agency Name and Address Research Programs Montana Department of Transportation (SPR) 2701 Prospect Avenue PO Box 201001	**13. Type of Report and Period Covered** Final Report (December 2020 – October 2022)
	14. Sponsoring Agency Code 5401

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. This report can be found at https://www.mdt.mt.gov/research/projects/planning/gnss.aspx DOI: https://doi.org/10.21949/1518323

Recommended Citation:

Al-Kaisy, A., Teixeira, R., Raza, S., & Meyer, B. (2022). Analyze Business Models for Implementation and Operation of a Statewide GNSS-RTN (FHWA/MT-22-004/9922-807). Helena, MT: Montana Department of Transportation. https://doi.org/10.21949/1518323

16. Abstract

The Global Navigation Satellite System (GNSS), commonly known as the global positioning system, has become one of the fastest-growing emerging technologies delivering location services to various sectors. The applications of geospatial data span every sphere of modern-day science and industry where geographical positioning matters. The list includes navigation, agriculture, surveying, construction, transportation, forestry, mining, and many others. The accuracy and precision of geospatial data using the GNSS Real-Time Network (RTN) technology enable advanced applications in many fields where geospatial data is used; and open the doors for new applications such as the emerging autonomous systems in transportation, mining, and agriculture. This research project is intended to provide information that would help the state's efforts in the planning and implementation of the Montana GNSS-RTN system. Four major tasks were completed for this project, namely; state-of-the-art review, state-of-the-practice assessment, characterizing Montana existing GNSS-RTN infrastructure, and identifying and cataloging viable business models for statewide GNSS-RTN systems.

17. Key Words Geospatial data, Location data, Real time network, Global navigation satellite system, Global positioning system, GNSS-RTN, GPS, Reference stations, CORS, Location coordinates, Corrections.	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 140 pages	**22. Price**

DISCLAIMER STATEMENT

ALTERNATIVE FORMAT STATEMENT

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ACRONYMS AND ABRECIATIONS

Caltrans – California Department of Transportation

CMR – Compact Measurement Record

CORS – Continuously Operating Reference Station

CPC – Central Processing Center

DOP – Dilution of Precision

DOT – Department of Transportation

FA – Free Access

GAGE – Geodetic Facility for the Advancement of Geoscience

GPS – Global Positioning System

GNSS – Global Navigation Satellite System

IGS – International GNSS Service

MAC – Master Auxiliary Concept

MnCORS – Minnesota Continuously Operating Reference Station Network

MTSRN – Montana State Reference Network

NAVD 88 – North American Vertical Datum of 1988

NAVSTAR – Navigation Satellite Timing & Ranging

NCN – NOAA CORS Network

NGS – National Geodetic Survey

NMEA – National Marine Electronics Association

NOAA – National Oceanic and Atmospheric Administration

NSRS – National Spatial Reference System

OPUS – Online Positioning User Service

NAD 83 – North American Datum of 1983

NTRIP – Networked Transport of RTCM via Internet Protocol

ORGN – Oregon Real-Time GPS Network

PPP – Precise Point Positioning

RINEX – Receiver Independent Exchange Format

RTK – Real-Time Kinematic

RTN – Real-Time Network

SPU – Seattle Public Utilities

SSI – Signal Strength Indicator

UC – User Charges

UNAVCO – University NAVSTAR Consortium

VRN – Virtual Reference Network

WSRN – Washington State Reference Network

EXECUTIVE SUMMARY

The Global Navigation Satellite System (GNSS), commonly known as the global positioning system (GPS), has become one of the fastest-growing emerging technologies delivering location services to various sectors. The applications of geospatial data span every sphere of modern-day science and industry where geographical positioning matters. The list includes navigation, agriculture, surveying, construction, transportation, forestry, mining, and many others.

The GNSS Real-Time Network (RTN) is a satellite-based positioning system using a network of ground receivers (also called base stations, reference stations, or continuously operating reference stations (CORSs)) to improve the accuracy of corrections in positioning data. The network of reference stations extenuates the atmospheric and satellite orbit biases and improves the accuracy and precision of geospatial positioning through real-time corrections sent from a central processing center to a rover. The utilization of ground sensors enables systems to have a range of 1 to 5 centimeters accuracy in positioning data.

Although statewide GNSS-RTN systems have not been around for long, the benefits of this new technology have been proven in the states where it was implemented. Recognizing the significant role and potential benefits this technology brings to the state economy and citizens, the state of Montana is interested in establishing a statewide GNSS-RTN system where accurate and reliable location data is made available throughout the state. To that end, this research project is intended to provide information that would help the state's efforts in the planning and implementation of the Montana GNSS-RTN system. Specifically, multiple tasks were successfully completed to gather the required information on all aspects of the GNSS-RTN system design, implementation, and operations.

A literature review was carried out first where information on GNSS-RTN technology, system design, applications and business models were reviewed and summarized. This task used research articles, government publications, research reports, agency websites, and industry magazine articles to collect and compile information.

The following task in the project aimed at screening the state of practice to collect information on the GNSS-RTN practices across the country. An online survey was designed and distributed to the owners/operators of the statewide GNSS-RTN systems in the country. Thirty states, represented by thirty-eight respondents, contributed by submitting the survey. Further, a phone interview was conducted targeting major vendors/manufacturers that provide GNSS-RTN products and services in the US. The survey and interviews collected valuable information on the current state of practice regarding statewide GNSS-RTN systems including network ownership, system attributes and technologies, associated costs, and business models.

The next task involved the assessment of all existing GNSS-RTN infrastructure in Montana and identifying aspects such as CORS ownership, sampling rate, current network, station coordinates, and mounting type. This task used data from governmental databases as well as data provided by the Montana Department of Transportation (MDT). It was found that a total of sixty-nine stations were then installed in Montana, with fifty-seven out of the total being publicly owned.

The final task aimed at cataloging business models that are used in the current GNSS-RTN practice for providing geospatial location data nationally and internationally. The task provided an overview and identified the advantages and disadvantages of each business model using information collected in the previous project tasks. The information gathered was then used to discuss the conceptual elements of any business model and to provide a high-level assessment of all models identified in this task.

This report discusses in detail the work performed on all project tasks and culminates with a summary of findings and recommendations.

1. INTRODUCTION

The Global Navigation Satellite System, commonly known as the global positioning system, has become one of the fastest-growing emerging technologies delivering location services to various sectors. The applications of geospatial data span every sphere of modern-day science and industry where geographical positioning matters. The list includes navigation, agriculture, surveying, construction, transportation, forestry, mining, and many others.

The accuracy and precision of geospatial data using the GNSS-RTN technology enable advanced applications in many fields where geospatial data is used; and open the doors for new applications such as the emerging autonomous systems in transportation, mining, and agriculture.

The satellite-based position system, GNSS-RTN, consists of a network of continuously operating reference stations that communicate in real time with a Central Processing Center (CPC). The network receives satellite locational signals that are sent to the CPC where coordinates are corrected and sent to the end user in different formats. Over the years, many public and private entities in Montana established limited networks or individual CORSs seeking access to more accurate geospatial data. Realizing the significant role and potential benefits this technology brings to the state economy and citizens, the state of Montana is interested in establishing a statewide GNSS-RTN system where accurate and reliable location data is made available throughout the state.

This research project is intended to provide information that would help the state's efforts in the planning and implementation of the Montana GNSS-RTN system.

Four major tasks were completed for this project. These tasks are: The chapters are:

1. Literature Review,
2. State-of-the-Practice Assessment,
3. Characterize Montana Existing GNSS-RTN Infrastructure, and
4. Identify and Catalog Viable Business Models for Statewide GNSS-RTN

The final report consists of six chapters, one chapter for each of the four project tasks listed above, one chapter for the introduction, and another chapter for the major conclusions and recommendations.

2. LITERATURE REVIEW

With the emergence of the Global Positioning System (GPS) Real-Time Kinematic (RTK) technology in the early 1990s, the use of GPS-RTK has become vital in various applications which require highly accurate positioning in real-time. However, the performance and accuracy of the traditional GPS-RTK are limited due to the distance between a reference station (also called base station or CORS), and a roving receiver (user device). The accuracy and reliability of the measurements degrade with the increase in baseline length (i.e., base-to-rover distance) due to distance-dependent errors such as ionospheric refraction, tropospheric refraction, and to some level, orbit errors. To achieve reliable and accurate results, specifically centimeter-level accuracy in positioning, from the GPS-RTK technique, it is required that the roving receiver (rover) is located within the restricted range (typically in the order of 10 km) of the reference station (1). To overcome the limitation of the baseline length of the traditional GPS-RTK technique and due to advancements in GNSS technology, GNSS Real-Time Network (RTN) concepts were introduced in the mid-1990s (2). GNSS-RTN is a satellite-based positioning system using a network of ground receivers (also called base stations, reference stations, or CORS). The network of reference stations extenuates and alleviates the spatially correlated atmospheric and satellite orbit biases (3) and improves the precision of geospatial positioning through real-time corrections sent from a central processing center to a rover. GNSS-RTN has been increasingly used in the U.S. and around the world for many benefits and applications where high-precision geospatial location data is needed. A GNSS-RTN benefits multiple public and private entities that utilize GPS survey and GIS mapping services. Geographic information system (GIS) mapping, survey-grade applications, precision agriculture, emergency management, construction engineering projects, infrastructure asset management, environmental studies, municipal infrastructure, and navigation are only some of the important applications of the GNSS-RTN system. As the accuracy and precision of positioning data continue to enhance with developments in technology and such data or services become more accessible to the users, more applications can utilize the positioning data that these methods and systems can produce. Geographical data are not only used in measuring ground distances and mapping topography (4), but they have become vital in various fields such as safety and sustainability with uses including structural health monitoring, natural disaster management and prevention (5), and precise localization and accurate navigation of autonomous vehicles (6).

These innovative and diverse applications drive the technological advancement towards precise and accurate measurements that the RTN system would produce.

This chapter presents the results of the literature review project task which aims at screening the state of knowledge regarding the GNSS-RTN technology nationally and internationally. This chapter discusses various aspects regarding GNSS-RTN systems such as technology, technological improvements, applications, business models for implementation and operations, and system design. Those aspects are discussed in the following sections of this chapter.

2.1 TECHNOLOGY

With the evolution of technology and advancement in satellite systems, the use of GNSS-RTN technology for the correction of positioning data has developed into commercially viable systems available today. The advent of GNSS-RTN made it possible to achieve highly accurate positioning over a distance of 70-100 km (7) (reference station spacing should generally not exceed 70-100 km) from the base station.

Continuously operating reference stations (CORS) were long used as a source of differential GPS (DGPS) and RTK corrections, mainly for surveying and mapping applications. New applications for these reference stations have recently emerged; Utah's TurnGPS and the North Carolina Geodetic Survey have considered CORS as a source for weather monitoring, while Japan and Washington have used CORS to study plate tectonics and provide early warning of earthquakes (8).

Schrock acknowledged that, although the RTN technology was reasonably new, it had already had a significant impact on many fields and showed a tremendous increase in popularity. In the U.S., there were 18 systems at the beginning of 2005 and 40 in 2006 (9). RTN is a satellite-based positioning system that uses ground sensors such as CORS to improve the precision of corrections. One of the most significant issues with satellite-based positioning systems is calibration. Without ground sensors, signal ambiguities can sometimes deny satellite-based positioning systems a precise measurement. Ground sensors provide more reference stations to the system, allowing the system to overcome the ambiguities and generate corrections in real-time for any location and provide higher precision. The utilization of ground sensors will enable systems to have a range of

1 to 5 centimeters in accuracy, compared to a range of 1 to 10 meters when sensors are not utilized (9).

The US Department of the Interior Bureau of Reclamation provided an overview of how data flows in an RTN (10). Data starts flowing when the rover connects to a virtual reference network (VRN) and sends a National Marine Electronics Association (NMEA) GGA string to a centralized server. The string has information about the location of the rover and the accuracy of the data being sent. The server uses nearby reference stations to compute corrections to send back to the rover. Finally, the rover receives the corrections and uses them in real-time as shown in **Figure 1**. The benefits and limitations of an RTN system were also discussed. Benefits included eliminating the need to establish a base station, integrity self-checking by the RTN, and a common reference coordinate system. Limitations included the high cost to establish and maintain such a system and accuracy being limited by the quality of the cellular phone connection (10).

Rydlund and Densmore discussed the use of Global Navigation Satellite Systems (GNSS) technology by the U.S. Geological Survey in applications such as monitoring natural hazards, ensuring geospatial control for climate and land-use change, and gathering information necessary for investigative studies on water, the environment, energy, and ecosystems (11). The GNSS technology essentially provides three-dimensional positioning as a function of the North American Datum of 1983 ellipsoid. A GNSS survey is approachable in two different ways: post-processed positioning for static observations or real-time corrections. Field equipment can consist of one or multiple receivers that create a network. In the post-processed approach, the data is processed through the Online Positioning User Service (OPUS) – a universally accepted utility maintained by the National Geodetic Survey (NGS). The real-time approach can be described as a roving receiver augmented by a single-base station receiver, or a single-base real-time (RT) survey. The real-time network (RTN) method is more efficient: CORSs are used instead of a single-base receiver (11).

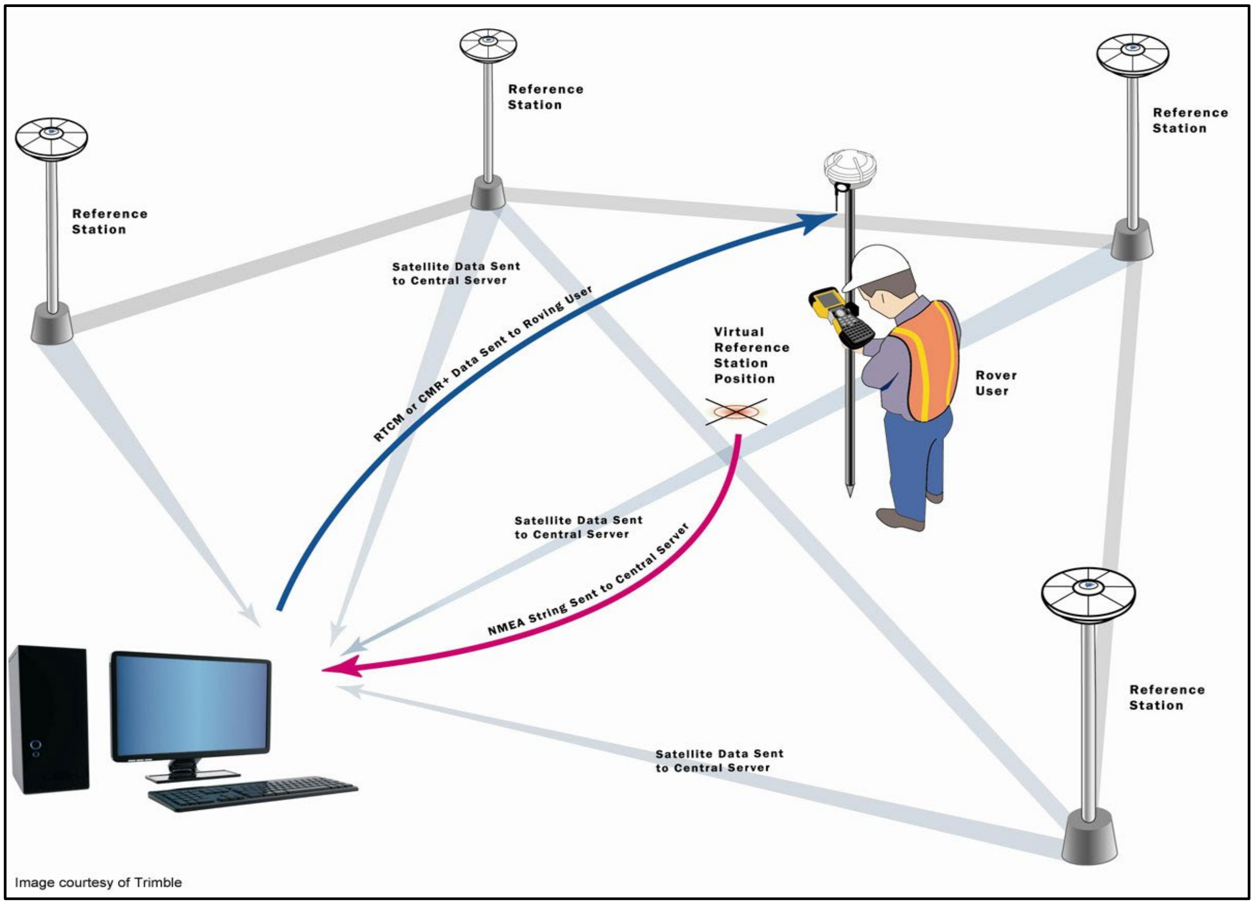


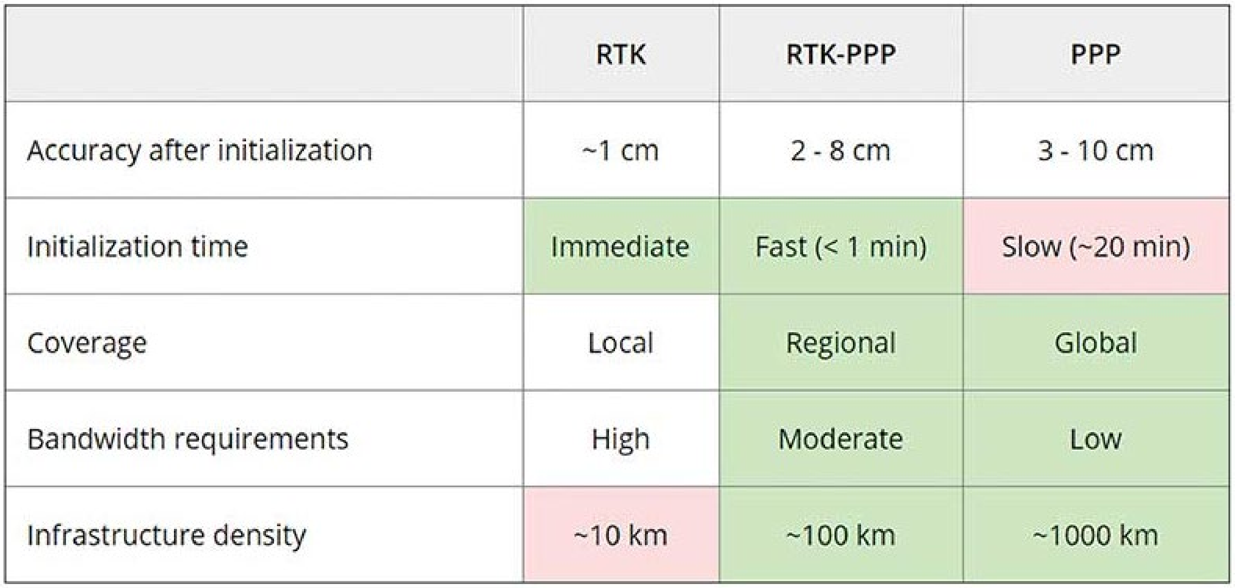
Figure 1. Data Flow in RTN and Configuration of a VRN (image courtesy of Trimble)

Henning discussed reasons to use network RTK (N-RTK) (12). Reasons included not needing reconnaissance and recovery of passive control, no time lost setting up and breaking down a base station, reduced labor cost, regional inter-GIS compatibility, continual accuracy and integrity monitoring, and no distance correlated error. A description of NGS's role in supporting network RTK is also presented, such as providing real-time uncorrected data streams (a process for officially recognizing RTNs as being compliant with the National Spatial Reference System (NSRS) within 2 centimeters horizontal and 4 centimeters vertical) and assessing site conditions for current or potential station sites to ensure optimal performance (12).

In a recent article, Luccio provided an overview of the recent developments in the GNSS positioning systems (8). In search for a centimeter-level positioning, the automotive industry, smart consumer devices, and other forms of automation were behind the recent boom in correction services. Two established methods are analyzed: RTK and precise point positioning (PPP). In

RTK, a receiver obtains correction data from a single base station or a reference network. In PPP, the data is accessible worldwide, but initialization can take up to 30 minutes. Some PPP correction services only provide corrections for satellite clock and orbit errors, which lowers the accuracy in measurements. A third hybrid method is presented: combining PPP's global access with the accuracy and quick initialization times of near-RTK. A network of reference stations, located within 150 kilometers of each other, collect data and calculate both satellite and atmospheric corrections. Results from the analysis of these methods are shown in **Table 1** provided by GPS World magazine (8).

Table 1. Differences of Various Correction Methods



	RTK	RTK-PPP	PPP
Accuracy after initialization	~1 cm	2 - 8 cm	3 - 10 cm
Initialization time	Immediate	Fast (< 1 min)	Slow (~20 min)
Coverage	Local	Regional	Global
Bandwidth requirements	High	Moderate	Low
Infrastructure density	~10 km	~100 km	~1000 km

Note: Adapted from *GPS World Magazine,* (8)

Richter provided a brief introduction to the development of PPP (13). Compared to RTK and RTN, PPP allows for accurate geolocations from remote regions, dismissing the need for established reference stations and networks. This is different from RTK where users need to manage their own reference stations and stay within the radio range of control points. RTN, on the other hand, eliminates the need for individual reference stations and allows for larger coverage, but users are still limited to the extent of the network. PPP allows for much larger coverage with precision to the centimeter level, but the time to access the data is not favorable (13).

2.2 RECENT ADVANCEMENTS IN POSITION DATA CORRECTIONS

Since the 1990s, positioning technology has vastly improved. Whether that be with new constellations, new methods, or better hardware, GNSS and RTN improvements mean that the technology can provide positions more accurately than they were 25 years ago. New constellations increase the number of available satellites at any given time (38), new methods can account for error correction to yield more reliable results, and better hardware can increase accessibility to the system by decreasing the cost of entry.

Karaim discussed the most serious sources of errors affecting GNSS signals (14). These errors differ in many ways and are grouped based on their similarities. Clock errors are related to differences between the receiver and satellite clocks while signal propagation errors are related to the shift between the satellite and the receiver's location caused by the rotation of the earth. Examples of signal propagation errors include the Sagnac effect (errors caused by the earth's rotation during signal propagation time between the satellite and the receiver), ionospheric errors (errors caused by the propagation time delay when the signal passes through the ionosphere), tropospheric errors (errors caused by the signal passing through the dry gases and water vapor of the troposphere), and multipath errors (errors caused when the signal reaches the receiver's antenna via more than one path). System errors are the result of the nature of the system: examples include satellite orbital errors and receiver noise. Errors that are imposed by the service provider are called intentional error sources. These include selective availability, signal jamming, and signal spoofing. While not a source of error, the dilution of precision (DOP) factor (a factor related to the geometry of visible satellites) can affect the accuracy of the final results (14).

Allahyari et al. evaluated the accuracy of shorter-duration RTN observations by analyzing data collection from two National Geodetic Survey (NGS) surveys in South Carolina and Oregon. The study explored the horizontal and vertical accuracy of real-time observations as a function of observation duration, examined the influence of the inclusion of Globalnaya Navigazionnaya Sputnikovaya Sistema (GLONASS) observables, compared results from real-time kinematic (RTK) positioning using a single-base station versus a network of base stations, and assessed the effect of baseline length on accuracy (15). An observational study was conducted in thirty-eight passive marks using RTN over a varying observation time range of 5 – 15s. The study found the range 180 – 300s to be the optimal real-time observation duration. The data from the network of stations showed to be more accurate and precise. The inclusion of GLONASS observables was beneficial in obtaining more fixed solutions at longer baseline lengths (15).

De Angelis et al. considered the issue of acquiring high-accuracy locations in urban scenarios and proposed the use of GNSS and mobile cellular networks to overcome the issue (16). The study suggests the combination of the time-difference-of-arrival (TDOA) technique measurements gathered from the cellular network with GNSS measurements. The data is integrated with the extended Kalman filter algorithm. Real measurements were used to simulate the results. The study showed an increase in location accuracy when the number of visible satellites is not adequate (16).

NGS discussed efforts to build a tool – dubbed the "RTN Alignment Service" (RAS) – to provide checks to RTN users on how well the RTN is aligned to the National Spatial Reference System (NSRS) (17). Previously, RTN operators reported coordinates within the NSRS datums NAD 83 or NAVD 88. However, there was no way offered by NGS to check if any biases existed between the NSRS and RTN-based data. Such a system would work in two parts: the first part would align RTN base stations to the NSRS, while the second part would align the rover to the NSRS. The second part requires further study, and thus such a system is still under development (17).

Jackson et al. evaluated the use of low-cost GNSS receivers within an RTN to investigate claims of centimeter-level accuracy (18). The study was done to predict future demand on the Minnesota Continuously Operating Reference Station (MnCORS) RTN. Five low-cost receivers ($540 or lower) were tested in rural, suburban, and urban environments using static and dynamic applications. The study found that the receivers could perform well in static applications in rural areas depending on equipment expectations, but the receivers performed below expectations in the other environments and the dynamic applications. Multifrequency receivers were recommended for future study in dynamic applications as they have better continuity and availability for fixed-integer solutions (18).

2.3 APPLICATIONS

Besides the primary application of RTN to enable accurate positioning relative to the National Spatial Reference System (NSRS), RTN has played a pivotal role in advancing multidisciplinary investigations including in earth sciences and atmospheric sciences. The scope of applications of

RTN is multifaceted and growing with time. The GNSS technology and RTN are increasingly being utilized for a wide range of applications such as transportation, agriculture, construction, and surveying, by providing users with instant and highly accurate position information over distances of several tens of kilometers. According to a report on the CORS network in Vermont by NOAA/NGS (19), the VECTOR (Vermont Enhanced CORS and Transmission Of Real-time corrections) network of Vermont is used by land surveyors, engineering firms, GIS professionals, foresters, state and non-state agencies such as the agency of Natural resources and department of agriculture, University of Vermont, Maine, and New Hampshire, Lyndon and Johnson State Colleges, army corps of engineers, National weather service and other federal and international agencies, etc. In addition, several COR stations along the western border of Vermont stream data to the New York Department of Transportation (NY DOT) which includes it in the New York CORS network NYSNET. The data of VECTOR is also streamed to a private RTN with correction and made available to users in Vermont for a subscription. Other vendors have also shown interest to acquire and include real-time VT data in their networks (19).

In the following sections, a brief description is provided for some of the applications in major fields where RTN data is used.

2.3.1 Transportation

The application of RTN in transportation is perhaps one of the most obvious of all the major applications of GNSS-RTN. It can assist in accurate positioning of land transportation and provide accurate information to sea and aerial transportation for navigation.

Specht et al. investigated the use of GNSS data to reproduce the trajectory of a railway geometric layout (20). The study used different methods of measurements in a comparative analysis. Measurements were made using tachometry, mobile satellite measurements, and satellite measurements using a measurement trolley (continuous RTK). An algorithm was used to enable the assessment of the compliance of satellite measurements with tachometer measurements. The continuous RTK method presented a mean value of residuals at a 5mm level. The GNSS measurements were found to be an efficient alternative to tachometer measurements (20).

Liu et al. investigated problems with multisensory system integration implemented in land-vehicle navigation (LVN) and studied the use of new smoothing algorithms to integrate systems and improve the accuracy of LVN (21). The Kalman Filter (KF) is frequently used in LVN multisensory configuration as a base for the integration of the Inertial Navigation System and Global Positioning System (INS/GPS). The study presented a method to solve issues with GPS signal loss in urban centers and - when INS is used in a stand-alone mode - inertial navigation errors are amplified with rapid-time. This method involves the use of secondary smoothing algorithms such as the Rauch-Tung-Striebel (RTS) smoother as part of a two-filter smoothing (TFS) algorithm. The performance of the RTS smoother compared and the TFS algorithm was validated using two different LVN INS/GPS datasets (21).

Toledo-Moreo et al. investigated challenges for navigation systems such as lane-level positioning and map matching (22). For more beneficial results, the study strives for a navigation system in which lane-level positioning is achievable and its quality can be monitored with integrity parameters. Measurements from a GNSS receiver, an odometer, and a gyroscope are combined in the proposed system. Data from enhanced digital maps, capable of storing road information, is also used. The feasibility of the proposed system was provided through a set of experiments that took place in France and Germany which showed good results in terms of positioning, map matching, and integrity (22).

Maaref et al. investigated the use of LiDAR data combined with pseudoranges drawn from unknown cellular towers to overcome GNSS-challenged environments (23). The study considered a vehicle-mounted LiDAR sensor that enters an environment where GNSS signals are of no use. An extended Kalman filter is used to fuse the pseudoranges produced by the receiver equipped in the vehicle to cellular towers, aid the LiDAR odometry, and estimate the vehicle's 3-D position. The errors are corrected simultaneously through the difference between the positions of the cellular towers and the vehicle. Simulated and experimental results found a 68% reduction in the 2-D root-mean-square error over solely LiDAR odometry (23).

2.3.2 Agriculture

Giannaros et al. introduced the assimilation of GNSS zenith tropospheric delay (ZTD), derived from more than 48 stations of the Hellenic GNSS network, into the operational numerical weather predictions (NWPs) of the National Observatory of Athens, Greece (24). The study used the Weather Research and Forecasting (WRF) model to collect data over the dry and wet season of 2018; seven high-impact precipitation events occurred over that period. The use of ZTD along with the WRF model showed a positive impact. The results were more accurate especially during heavy rainfall events and improved the simulation of precipitation in the dry season (24).

Due to the lack of a precipitable water vapor (PWV) dataset, Zhao et al. focused on generating an hourly PWV dataset for China using GNSS observations from the Crustal Movement Observations Networks of China (25). The study combined zenith total delay parameters (estimated by GAMIT/GLOBK software and validated with an average root-mean-square error of 4-5 millimeters), the zenith hydrostatic delay, and a weighted average temperature of atmospheric water vapor (calculated at the GNSS stations using the improved global pressure and temperature 2 wet (IGPT2w) model with an average root-mean-square error of 3.32 K). Between 2011 and 2017, the average root-mean-square error values of the generated PWV dataset were found to be less than 3 millimeters in China, which was validated using the corresponding AERONET and radiosonde data at specific stations (25).

Yan et al. investigated the feasibility of the usage of the Signal Strength Indicator (SSI) recorded using data from GNSS receivers to estimate soil moisture (26). The study compared the in-situ soil moisture and an estimated SSI phase. A relationship was determined and used to estimate 36 days of soil moisture data. A correlation coefficient of approximately 0.7 between the SSI phase and the in-situ soil moisture was found, and a root-mean-square estimation error of soil moisture lower than 9.9%. The results showed that the use of SSI data is feasible for estimating soil moisture (26).

2.3.3 Construction

Burak and Lysko studied the use of RTN technology to provide additional control over marking works and to develop practical recommendations to measure the axes of main buildings (27). Theoretical and experimental studies were performed to ensure accuracy. The studies measured the axes from two basis lines taken by the GNSS receiver in a way that coincides with the x- and y-axes of the object's general plan. The investigation was made on the inherent basis, 10 kilometers from the permanent station, to minimize sporadic errors. The study found that the required accuracy is provided when the main axes of construction netting coincide with the fixing baseline with a dual-frequency GNSS receiver (27).

Another study by Burak and Lysko investigated the accuracy of measuring relatively short distances for performing survey, planning, and engineering geodesy work with dual-frequency GNSS receivers by performing seven experiments at varying locations (28). The investigation took place in the city of Ivano-Frankivsk, Ukraine, and was made on the inherent basis to minimize sporadic errors. The hypothesis claims the general dispersion of two normally distributed groups that receive an optimum quantity of necessary measurements when building lines are less than 200 meters to be equal. The results showed a range of accuracy depending on the location of network points and defined the designation of building vectors to be more accurate with GNSS receivers under different conditions of observations (28).

Chang et al. (29) laid out a plan for the implementation of intelligent compaction (IC). IC is a technology that uses vibratory rollers outfitted with RTK receivers, measurement systems, and feedback systems to compact aggregates more uniformly. In hot mix asphalt (HMA), nonuniform compaction can result in a shorter pavement life or premature pavement failure. IC technology can identify and correct for substandard patches of pavement, resulting in a long-lasting and more consistent pavement. RTK is required for IC technology and is recommended to have a fixed position that equates to a precision of 1-3 centimeters. An RTN can send corrections to a rover for use with IC (29).

2.3.4 Surveying

Krzyzek used RTN measurements, along with other methods, to determine the cartesian coordinates of buildings (30). During tests, the alternative of using RTN surveys to determine the location of a building was presented to surveying contractors. The HMM algorithm was used to harmonize various surveying methods used in the study. The study resulted in the determination of X, Y coordinates at the level of 0.03 meters, with the building corner's mean location errors at the 0.02-meter level (30).

Continuously operating reference stations (CORS) have long been used as a source of differential GPS (DGPS) and RTK corrections, mainly for surveying and mapping applications. New applications for these reference stations have recently emerged; Utah's TurnGPS and the North Carolina Geodetic Survey have considered CORS as a source for weather monitoring, while Japan and Washington have used CORS to study plate tectonics and provide early warning of earthquakes (8).

U.S. Geological Survey used GNSS technology in various applications such as monitoring natural hazards, ensuring geospatial control for climate and land-use change, and gathering information necessary for investigative studies on water, the environment, energy, and ecosystems (11).

Gabara and Sawicki investigated the accuracy of an unmanned aerial vehicle (UAV) for photogrammetry using an RTN (31). Eight hundred and fifty-one photos were used to generate a digital site model using a bundle block adjustment (BBA). The coordinates of control points noted during the flight were compared to coordinates generated from the BBA and error was calculated based on the differences between these coordinates and US and Polish technical accuracy requirements. Planimetric (XY) coordinates fell within the accepted 0.10-meter root mean squared (RMS), while vertical (Z) coordinates fell within the accepted 0.05-meter RMS (31).

Yu et al. compared the use of N-RTK to the use of RTK and an accelerometer for monitoring dynamic displacement in bridges (32). An experiment was conducted at a local bridge where three sensors were set up: an RTK receiver, N-RTK receiver, and accelerometer. The results showed that N-RTK is a valid alternative to RTK; N-RTK was able to provide millimeter-level accuracy and successfully identify the frequency of the bridge. Additionally, in general, N-RTK had a lower standard deviation and a higher correlation coefficient with the accelerometer than RTK did. Furthermore, it was observed that the N-RTK measurements generally had less noise. The authors noted that the use of N-RTK was also beneficial in reducing the cost of monitoring by 80 percent while still providing a high level of robustness and reliability (32).

2.4 GNSS-RTN BUSINESS MODELS

An RTN can be an excellent investment, but its success largely depends on the business plan to ensure implementation and sustainable system operation while meeting the needs of all users and stakeholders. In the following section, best practices for different aspects of a business plan are summarized. Overviews of existing business or operations plans of existing RTN are also highlighted.

Goodliss et al. performed a cost-benefit analysis on high-accuracy location (HALO) services (33). The analysis was performed by placing dollar values on various levels of injuries and predicting how many injuries could be prevented with the implementation of different technologies requiring HALO services such as curve speed warning, forward collision warning, and intersection collision warning. Certain mobility benefits were estimated as well. It was estimated that between \$160 billion and \$320 billion in benefits could come from HALO services over a horizon time of 22 years, with over 90 percent of those being safety benefits. These benefits were compared against the cost of infrastructure for an N-RTK system. By interviewing N-RTK operators, the authors were able to estimate a 22-year horizon cost per base station ranging between \$220 thousand and \$615 thousand (\$570 thousand to \$1.6 million with annual contingency costs included). Costs such as hardware, software, maintenance, and rent were included. If such a system were to cover the entire U.S., system implementation would cost between \$1.6 billion and \$4.4 billion (33).

Hale et al. examined the development of a management model for CORS networks within Australia (34). A successful model will ensure national consistency among other CORS networks, consider professions beyond surveying, and remove legal barriers to using these networks for cadastral surveys. A potential model is shown in **Figure 2**. The data service providers and value-added resellers would buy the raw data at wholesale rates and sell the data to users. Value is added either through providing access to many different networks under one roof or by building other services to be used with the data. Such a system would require a nationally consistent coordinate system. This model would also help navigate legal barriers by supporting legal certification of the National Measurement Act and providing guidance to cadastral surveyors on best practices. Additional benefits include streamlining agreements with site hosts and GNSS suppliers, managing human connections (which ensures system continuity), and accounting for IT systems (34).

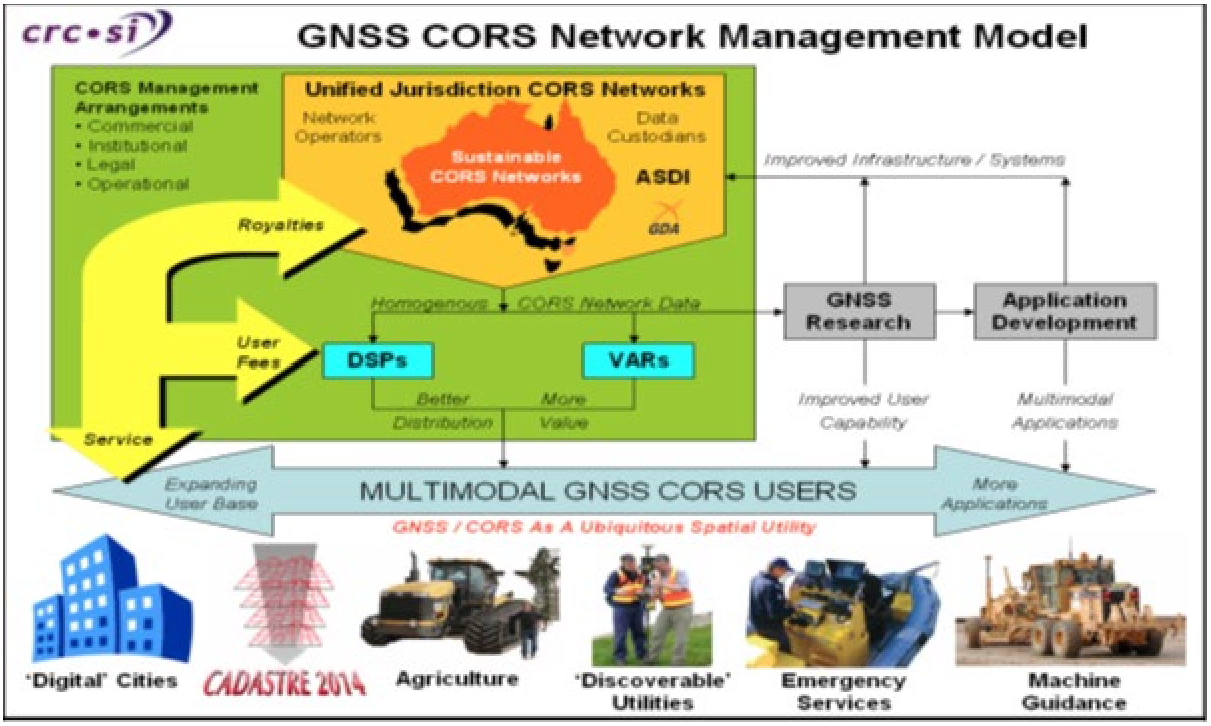


Figure 2. GNSS CORS Network Management Model

Note: Adapted from "Validating a model for CORS network management", (34)

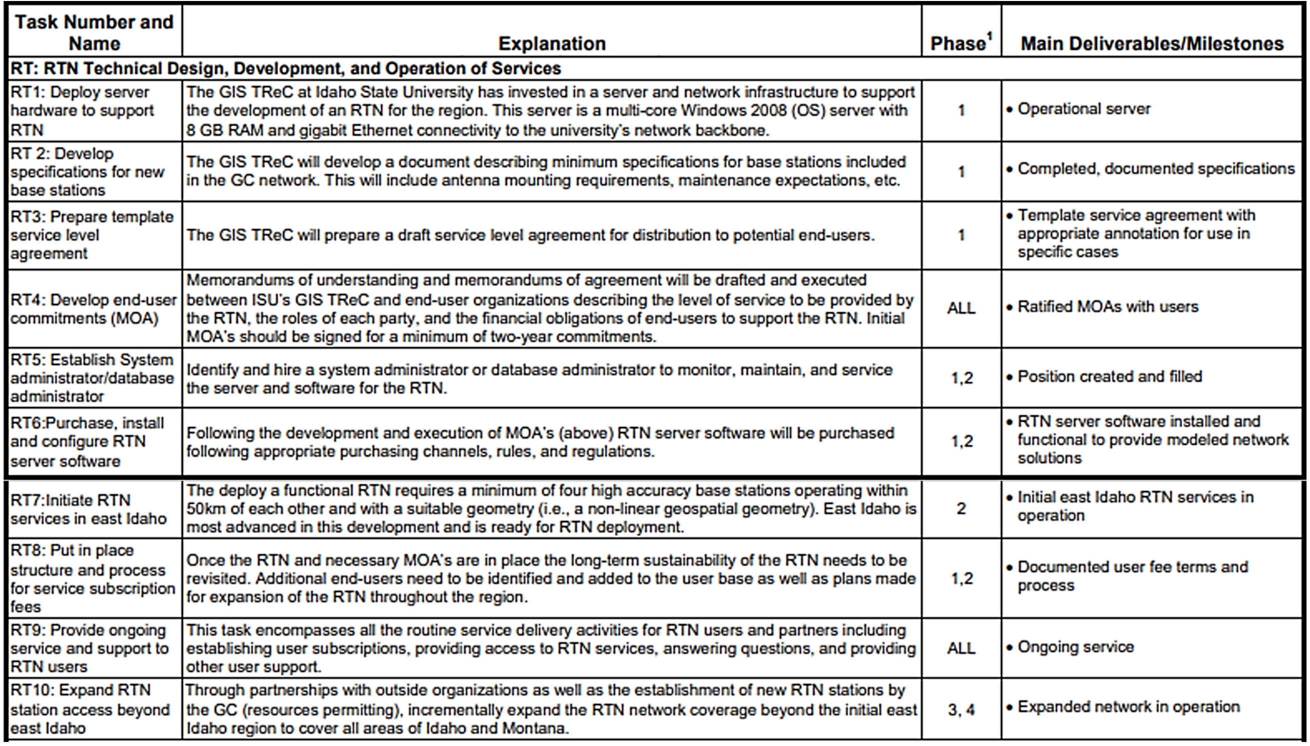
Rizos and Van Cranenbroeck considered a business model for an RTK provider that broadcasts full corrected coordinates to the user, not just corrections (35). The authors suggest that some providers do not charge for services because they cannot guarantee reliable coordinates. If providers can broadcast coordinates computed within the required reference frame, they can guarantee accurate results and justify charging a fee for services. If providers simply broadcast corrections and leave it to the user to compute the coordinates, they cannot justify a fee because the accuracy of the coordinates cannot be guaranteed by the provider. For this to work, the network needs not only geodesy specialists but also IT specialists. The added value could also be provided by a separate entity using raw data licensed for use by the provider. However, such a service requires bi-directional communications between the rover and central server (35).

Martin undertook a review of six existing statewide RTN systems in areas including ownership, funding, system operations and maintenance, and system design (36). In most cases, the RTN was owned by the state department of transportation (DOT) with station ownership varying between the public and private sectors. Software is typically owned by the state while hardware ownership varies between private entities and the state. Most stations are located on public land. Most operating costs are funded from the state, and while return on investment was not formally investigated in most states, Florida did calculate $964,360 in annual savings for its DOT. Most networks do not charge for access. System operations typically come from either the DOT or a separate state IT department, and generally required between 1.3 to 2 full-time equivalent (FTE) employees. Responsibility for station maintenance is typically that of the station owner, which varies between network partners and the state. Station construction standards are typically consistent with those set forth by NGS, although there is some variance. All networks surveyed are aligned with the NSRS and typically bring stations from other states into the network. For access to corrections, each network requires an internet connection as a basic requirement. Stations are connected to the network via either wired or wireless connection. No network engaged in a public-private partnership. Recommendations from states included seeking federal grants, partnering with local agencies that may have needed infrastructure, involving stakeholders in network implementation, and keeping the network separate from public sector IT. One network unique in terms of its ownership and system operations is the Washington State Reference Network (WSRN) (36).

Washington State Reference Network (WSRN) outlined its ownership and operations structure on its website (37). The WSRN is a cooperative of about 80 different partners spanning the public and private sectors. The network is owned by the cooperative; joining the cooperative requires contributing a station to the network. Access to static files is free, while access to real-time corrections requires being either a partner or a subscriber, which requires an annual fee to help cover operations costs. Seattle Public Utilities hosts the central processing center for the network, provides stations to the network, and serves as a point of contact for WSRN matters. Central Washington University is also an important partner in providing infrastructure, expertise, and the backup central processing center (37).

Weber et al. outlined a business plan for a potential geo-positioning cooperative between Idaho and Montana (38). Organizational structures, service priorities, and administrative needs, among other topics, were discussed. A mission of providing high-quality GNSS data to as broad of a user base as possible was established. An initial, informal partnership structure was proposed to be followed by a permanent structure that is legally and administratively simple and contains a dedicated management office. The most important service priority was determined to be the operation of a multi-state control point database, followed by RTN set-up and operations and assisting the user community in using the system. Administratively, it was determined that manager, administrative support, and technical personnel roles would need to be filled, with potential options ranging from using host organization resources to student interns to volunteers. Tasks for RTN development and operations were also established; **Table 2** below shows all the steps identified. Furthermore, preliminary budgets were also generated; over five fiscal years, $1,146,500 was estimated to be needed for the cooperative. Risk management tactics were also discussed; detailed work plans, effective project monitoring, competent personnel, being ready for delays, and formal commitments were identified as ways of reducing risk (38).

Table 2. Identified Tasks for RTN Development and Operations



Task Number and Name	Explanation	Phase[1]	Main Deliverables/Milestones
RT: RTN Technical Design, Development, and Operation of Services			
RT1: Deploy server hardware to support RTN	The GIS TReC at Idaho State University has invested in a server and network infrastructure to support the development of an RTN for the region. This server is a multi-core Windows 2008 (OS) server with 8 GB RAM and gigabit Ethernet connectivity to the university's network backbone.	1	• Operational server
RT 2: Develop specifications for new base stations	The GIS TReC will develop a document describing minimum specifications for base stations included in the GC network. This will include antenna mounting requirements, maintenance expectations, etc.	1	• Completed, documented specifications
RT3: Prepare template service level agreement	The GIS TReC will prepare a draft service level agreement for distribution to potential end-users.	1	• Template service agreement with appropriate annotation for use in specific cases
RT4: Develop end-user commitments (MOA)	Memorandums of understanding and memorandums of agreement will be drafted and executed between ISU's GIS TReC and end-user organizations describing the level of service to be provided by the RTN, the roles of each party, and the financial obligations of end-users to support the RTN. Initial MOA's should be signed for a minimum of two-year commitments.	ALL	• Ratified MOAs with users
RT5: Establish System administrator/database administrator	Identify and hire a system administrator or database administrator to monitor, maintain, and service the server and software for the RTN.	1,2	• Position created and filled
RT6:Purchase, install and configure RTN server software	Following the development and execution of MOA's (above) RTN server software will be purchased following appropriate purchasing channels, rules, and regulations.	1,2	• RTN server software installed and functional to provide modeled network solutions
RT7:Initiate RTN services in east Idaho	The deploy a functional RTN requires a minimum of four high accuracy base stations operating within 50km of each other and with a suitable geometry (i.e., a non-linear geospatial geometry). East Idaho is most advanced in this development and is ready for RTN deployment.	2	• Initial east Idaho RTN services in operation
RT8: Put in place structure and process for service subscription fees	Once the RTN and necessary MOA's are in place the long-term sustainability of the RTN needs to be revisited. Additional end-users need to be identified and added to the user base as well as plans made for expansion of the RTN throughout the region.	1,2	• Documented user fee terms and process
RT9: Provide ongoing service and support to RTN users	This task encompasses all the routine service delivery activities for RTN users and partners including establishing user subscriptions, providing access to RTN services, answering questions, and providing other user support.	ALL	• Ongoing service
RT10: Expand RTN station access beyond east Idaho	Through partnerships with outside organizations as well as the establishment of new RTN stations by the GC (resources permitting), incrementally expand the RTN network coverage beyond the initial east Idaho region to cover all areas of Idaho and Montana.	3, 4	• Expanded network in operation

Note: Adapted from "Business Plan for Development of Regional Geopositioning Cooperative for Idaho and Montana", (38)

Ojigi discussed an implementation plan for a GNSS-CORS system in Nigeria to provide RTK corrections services (39). A central data processing facility is proposed in the capital with regional and backup servers in six other cities. Three reference stations are proposed for each of the 36 states and capital territory to provide a total of 111 stations. The estimated cost for this system was ₦740 billion (equivalent to $3.70 billion in 2015 dollars).

Furthermore, two possibilities for revenue were investigated: charging a fee for access to the system or treating the system as a utility and providing access for free. Charging a fee for access to the system would require client-server-based corrections in order to provide value to the product. The value comes from the provider controlling the results, whereas simply delivering corrections to the user provides no added value to the services because hardware and software errors may be present in the results. The provider can also free the users from having to learn complicated techniques or software (39).

Jenssen et al. presented an overview of CORSnet-NSW, an RTN owned by the Government of New South Wales in Australia (40). At the time of writing, 75% of the state was within the maximum range of a base station. CORSnet-NSW also engages in data-sharing agreements with neighboring states to provide adequate coverage. The Government owns the equipment and conducts all the maintenance and operations. Three FTE staff work on the network within the surveying unit while other staff within the surveying unit provide 1.5 FTE for surveying, research, and management. Raw data is sold to three companies, while CORSnet-NSW subscriptions are sold through 16 authorized providers. Raw data is also made available to various positioning efforts including the Asia-Pacific Reference Frame (40).

Bakici et al. (41) reviewed the business plan for the Turkish National Permanent GNSS Network – Active (CORS-TR). The CORS-TR system consists of 146 stations spread around Turkey and Northern Cyprus. The system is jointly operated by the General Directorate of Land Registry and Cadastre (GDLRC) and General Command Mapping (GCM); the terms of their partnership are outlined in a formal agreement and an executive board was established to make technical and administrative decisions. The executive board holds the power to determine access fees; principles of access for educational institutions; principles of maintaining and marketing the system; and plans for investment, research, and development. System setup costs $6.6 million, while operating costs can vary. Operating costs are covered by service fees; **Table 3** shows a schedule of these fees. In 2016, revenue totaled $1.5 million, while operating costs totaled $270,000. Most users (63.96% of the 8455 total users as of February 2017) are from the private sector (41).

Table 3. Schedule of CORS-TR Service Fees

TYPE OF SERVICE	DATA TYPE	FEES	EXPLANATION
Registration Fee	-	\$42.00	One-Off
RTK Fees	Web-RTK	\$28.00	Monthly
RTK Fees	Web-RTK	\$210.00	Annual
RTK Fees	Web-DGPS	\$14.00	Monthly
RTK Fees	Web-DGPS	\$105.00	Annual
Static Data	RINEX 1 sec.	\$0.14	Station/Hour
Static Data	RINEX 30 sec.	Free	Station/Day

Note: Adapted from "Business Model of CORS-TR (TUSAGA-AKTIF)", (41)

The North Carolina Geodetic Survey (NCGS) gave an overview of the economic benefits of the North Carolina Continuously Operating Reference Stations (NC CORS) network compared to its costs (42). Using data on industry spending patterns from IMPLAN in 2015, NCGS estimated that the system provided \$360 million in annual economic benefits to North Carolina. This is compared to the annual operating cost of \$625,000 per year. Furthermore, using data from the North Carolina Office of State Budget and Management, NCGS estimated the system to generate \$3.5 million in state taxes annually, making the system self-sustaining in a sense. Access to the real-time network requires \$500 for the first two ports followed by \$250 for each additional port (42).

Laaksonen (43) undertook a design of a business model for the FinnRef system operated by the National Land Survey of Finland (NLS). At the time of the study, there were two companies operating positioning services in Finland. The study considered the effects of NLS allowing the public to access data from its CORS facilities. The study concluded that allowing access to the data for a fee and access to an NLS-operated positioning service for free would provide the greatest value by making the barrier of entry for other positioning services lower while increasing competition in that sector. The proliferation of new positioning services would serve to drive down the costs of such services, thereby benefiting the consumer (43).

2.5 SYSTEM DESIGN

The RTN system design is just as important as the business plan. The system design will ultimately dictate system establishment and operating costs, operating principles, and quality of service provided. While the best way to design the system is to get potential stakeholders involved early in the process, there are common practices that can be referenced. This section provides an overview of these practices as well as summaries of designs of existing networks.

Henning et al. (44) detailed guidelines for the design of a GNSS real-time network (RTN). Topics covered included station construction and system planning and design. Stations should be constructed with an uninterruptible power supply and with physical disturbances such as high winds in mind. When mounted on buildings, antenna placement should be prioritized over receiver placement. Ground mounts are generally more expensive but more flexible with location. When designing the system, it is important to identify goals by involving stakeholders in the design process. With spacing, general guidelines call for 50 - 70-kilometer baselines, although this can change based on cost or usage. Some stations should be submitted for acceptance into the national CORS program; this ensures that the system is consistent with the NSRS. If using existing infrastructure, priorities of the station owner should be identified to make sure they line up with the goals and priorities of the network. Stations should be designed with multiple forms of communication to provide redundancy. When designing the central processing center (CPC), it is important to get IT involved as they will ultimately set policies regarding security and system access. It is also important to establish a mirror CPC to ensure service and to possibly offset load from the main CPC. The integrity of the RTN needs to be monitored to ensure proper precision and accuracy of corrections (44).

Denys et al. (45) examined certain aspects of an N-RTK system that must be considered during system design. One critical aspect is communications services; available methods include wired and wireless connections. Wired connections are typically used to connect stations to the central server and are preferred over wireless connections. Wireless connections, such as through mobile networks, are typically used to connect users to stations. However, cell coverage may be limited or nonexistent in certain areas, and increased latency can lead to decreased solution accuracy. Stations should be placed between 50 and 70 kilometers away from each other. The network should be aiming for a precision much greater than that required by the user to reduce error propagation.

Furthermore, current day coordinates should be used rather than a set reference frame to account for regional motion differences. The goal is to provide corrections or a spatial model in near-real-time with biases modeled (45).

Schrock (46) went over best practices for real-time GNSS networks. Communications from the station to the central processing center (CPC) should have low latency (less than 2-second latency), the bandwidth to handle multiple data streams, the ability to handle remote operation and maintenance, and the ability to receive static observations after outages. Communication methods should be contracted under guaranteed service agreements. The number of stations communicating via satellite should be limited due to latency issues. The CPC should consist of quality hardware and software capable of accepting station observations, processing observations in real-time and statically, tracking system health and accuracy, and administering accounts for system access. Access to the network from rovers should be provided through Standard for Networked Transport of RTCM via Internet Protocol (NTRIP) casters which can serve hundreds of users at a time while maintaining system security. RTNs should, at a minimum, be able to provide corrections via the Virtual Reference Station (VRS) method in either RTCM Version 3 or CMR+ formats, single-base corrections, network integrity monitoring, NTRIP casters and account management for system access, ionospheric condition monitoring, tropospheric condition monitoring, field results monitoring, static-post files for postprocessing, a static file request system, and a web portal. The network should provide corrections based on the official national or global reference frame but have the capability to provide corrections in other reference frames. Receivers should be specifically designed for CORS use and antennas should be labeled as geodetic-grade (46).

Janssen (47) compared two different N-RTK methods and their required bandwidths. In the VRS concept, the rover sends its position to the server, which treats the coordinates as a virtual base station. The server then calculates corrections and sends them to the rover. The baseline between the rover and the virtual base station is short, so the rover can use the corrections and apply single-base RTK algorithms to obtain a position. This method has the advantage of requiring less bandwidth because the server models atmospheric effects but has the downsides of requiring two-way communication and issues with legal traceability (47). There is also the Master Auxiliary Concept (MAC) - as Leica Geosystems (2005) explains, a reference station acts as a master station that sends its corrections and coordinates to the rover, while auxiliary stations transmit corrections and coordinate differences based on the master station (48). From there, the rover can perform calculations to get a final position. The MAC allows for one-way communication and legal traceability but has the downside of offloading calculations to the rover. Janssen went on to measure the bandwidth required of each concept. While the MAC required more bandwidth, common radios can support the bandwidth requirements. Janssen concludes by recommending the MAC from the perspective of a CORS operator since the user is supplied with raw data and surveys can be legally traced back to a physical reference station (48).

Prescott et al. (49) outlined an operations plan for a network of GPS reference stations to study earthquake hazards. The stations were designed to operate continuously and with high precision. As part of the operations plan, guidelines for site selection and station construction were drafted. Sites should have an adequate view of the sky; be secure from theft or vandalism; be on firm, natural ground; and have sufficient power and communications equipment available nearby. An adequate view of the sky is one where there are no obstructions above 45-degree elevation, nothing above the expected antenna location that is within 3 meters of the expected antenna location, no power lines within 100 meters, and away from flat, reflective surfaces that may serve as sources of multipath. Five years of tree growth should be accounted for when considering unacceptable obstructions. At each site, the contractor was to install a metal box with 2 110-volt AC outlets and a plug for radio link and metal conduit containing power, phone, and cable from the antenna to the receiver (49).

Lapine and Wellslager (50) discussed part of the process that went into designing the real-time network for the South Carolina Geodetic Survey (SCGS). GNSS receivers can receive data from both GPS and GLONASS satellites. Station spacing was desired to be 70 kilometers to provide centimeter-level accuracy on a 24-hour basis even if other stations in the network were offline. Antenna mounts are generally built to NGS standards. Additionally, mounts near the coast were designed to withstand category 3 hurricanes. Sites for stations were based on Internet access, building construction materials, and backup power access. For these reasons, most stations ended up on South Carolina Department of Transportation property. Where building construction materials were not to NGS standards, special steel towers were constructed to mount the stations to (50).

Yildirim et al. (51) discussed the planning and infrastructure for the TUSAGA-Aktif (CORS-TR) network. An initial prototype system covering an area of 300 x 150 kilometers was set up to test different techniques, hardware, and software. From the test, system planners determined that optimal station locations would be in city centers, on stable ground, easily accessible, close to the energy and communications sources, and less than 100 kilometers apart from each other. Stations mounted on roofs were set on galvanized steel, while stations mounted on the ground were set on concrete pillars. The master control station carries out functions such as computing reference station coordinates, modeling errors, storing data, and providing Web services. See **Figure 3** for a schematic setup of the master control station. The system can broadcast corrections using either the VRS, MAC, or Flächen-Korrektur Parameter (FKP) methods. Reference stations are connected to the control stations via a duplex ADSL connection along with a GPRS/EDGE connection. Each reference station sends about 700 bytes of data per second to the control stations (51).

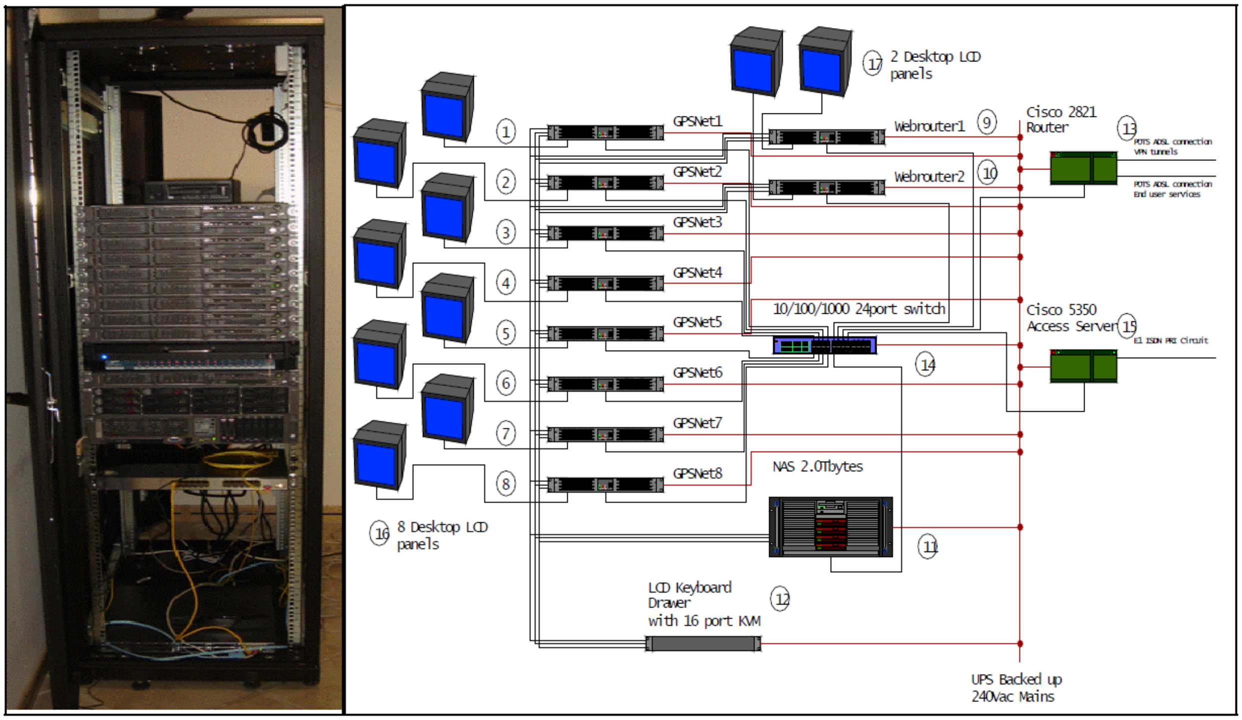


Figure 3. Schematic Diagram of the Master Control Station

Note: Adapted from "The Turkish CORS Network (TUSAGA-Aktif)", (51)

Wisconsin Department of Transportation (WisDOT) provided an overview of the design and technology of the Wisconsin Continuously Operating Reference Stations (WISCORS) Network

(52). A hundred stations are set approximately 50 kilometers apart from each other. Most stations are capable of utilizing the GPS, GLONASS, and Galileo constellations. Along with providing real-time corrections, station data is collected, stored, and made available via a web server for post-processing. Access to the webserver is password-protected, but users can register through the webserver. Each station consists of a mounting system (concrete pillar or building mount), GNSS receiver and antenna, coaxial cable, lightning suppressor, plastic conduit to carry the coaxial cable from the antenna to the lightning suppressor, enclosure for equipment, and backup battery (52).

2.6 SUMMARY

This chapter presented the results from the literature review project task. The review offered a brief overview of the technology behind a GNSS-RTN and how users may utilize the system. While the main focus of the review was examining methods for implementing a business plan; other aspects of the systems in relation to technology, applications, and system design were also considered in this review.

The review is divided into five parts: technology, recent advancements in GNSS data corrections, applications, GNSS-RTN business plans, and system design. Technology, advancement in GNSS data correction, and applications are briefly discussed to provide familiarity with the system and its potential uses. GNSS-RTN business plans are summarized, and best practices and guidelines are presented. Finally, system design considerations are reviewed by examining characteristics of existing systems and reviewing available guidance.

3. STATE-OF-THE-PRACTICE ASSESSMENT

A state-of-practice screening has been conducted as part of the project "Analyze Business Models for Implementation and Operation of a Statewide GNSS-RTN." This screening involved a practice survey that was sent to all statewide GNSS-RTN system owners/operators as well as interviews with major GNSS-RTN vendors/manufacturers. First, the online survey was conducted targeting owners/operators of the GNSS-RTN systems in the United States to evaluate various aspects of the statewide RTN system, RTN ownership and business model, system attributes including CORS types and spacing, the precision of location data, etc. Second, the vendors/manufacturers which provide products and services for developing, operating, and maintaining statewide GNSS-RTN systems were interviewed to gain more precise information about the costs and technologies involved in system development and gather more information about the different ways these vendors provide services to different GNSS-RTN system operators. This chapter is organized into two parts. The first part discusses the methodology, results, and findings from the online survey which aimed to examine the state of practice concerning establishing, operating, managing, and maintaining the statewide GNSS-RTN systems in different states. The second part of the chapter discusses the information gathered from the interviews with major technology vendors/manufacturers. A summary of the findings is presented at the end of the chapter.

3.1 GNSS-RTN OWNERS/OPERATORS SURVEY

To better understand the current practice in establishing and operating the GNSS-RTN systems at the national level, a questionnaire survey was developed and sent to the GNSS-RTN system owners/ operators at different states across the U.S. The survey consisted of 23 questions divided into two sections: i) System general information, and ii) System operation. The questionnaire survey was created and administered using Qualtrics survey software. Thirty-eight respondents submitted the survey representing 30 states (4 states with two responses and 4 states with no GNSS-RTN system). The duplicate responses were removed and the response from the manager of GNSS-RTN was considered. Only five responses were incomplete, however, they provided answers for the majority of survey questions, thus included in the analysis. Out of the 30 respondents from the 30 different states, as shown in **Figure 4**, twenty-seven responses were from public agencies and only three responses were from private entities. The following section of this chapter discusses the results of the questionnaire. A copy of the questionnaire is provided in **APPENDIX A**.

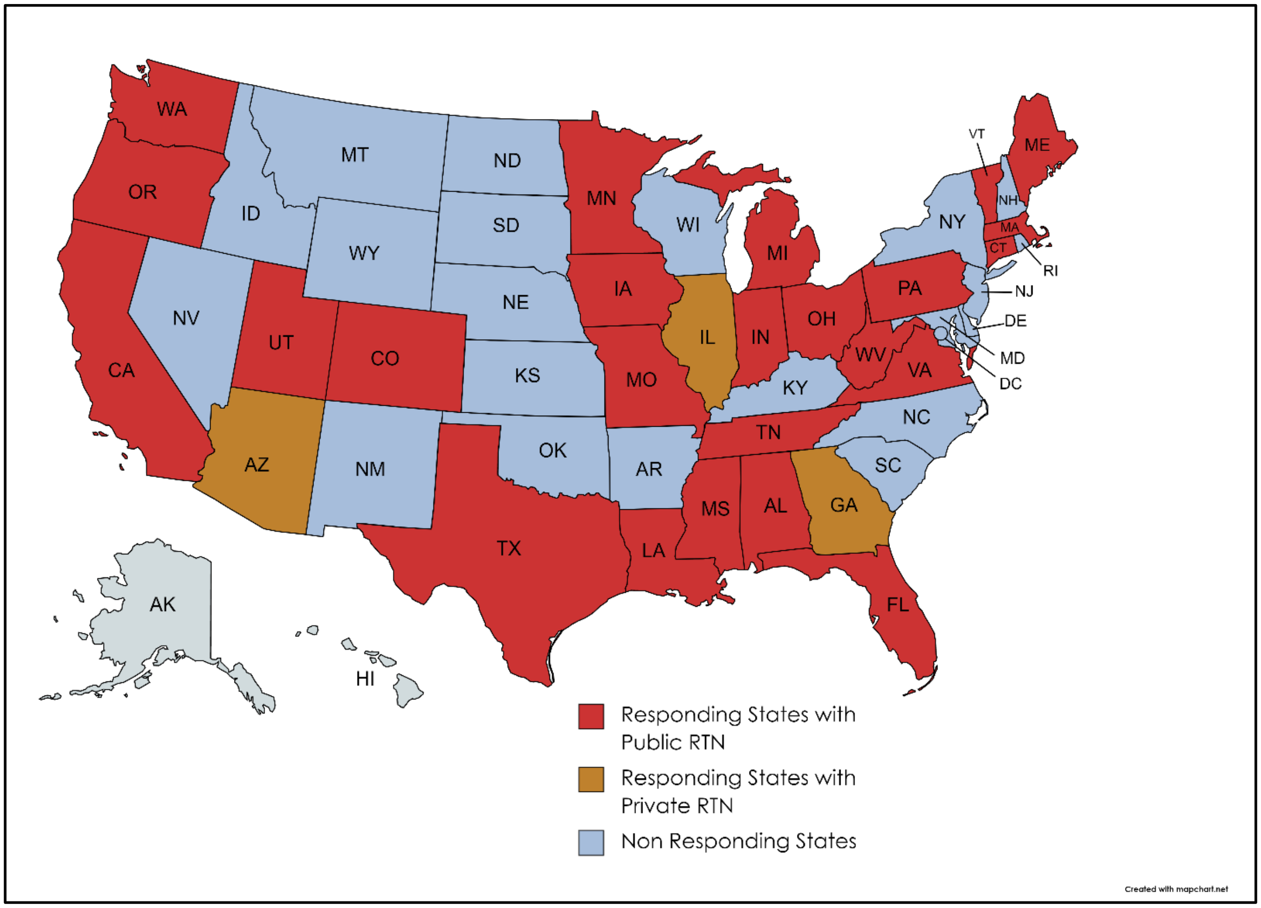


Figure 4. U.S. Survey Respondents Map (Map Source: mapchart.net)

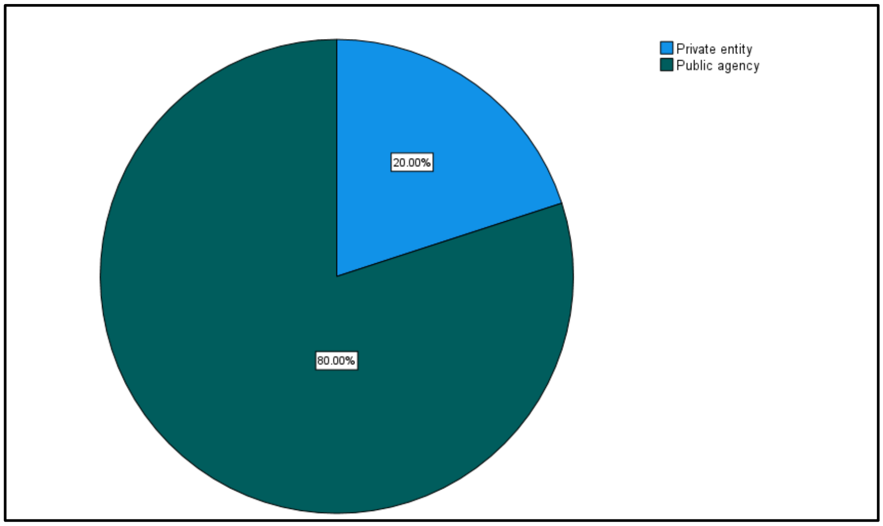
3.1.1 Survey Results

This section discusses the results of the questionnaire survey and is divided into two sections, one for the system general information and one for system operations and services.

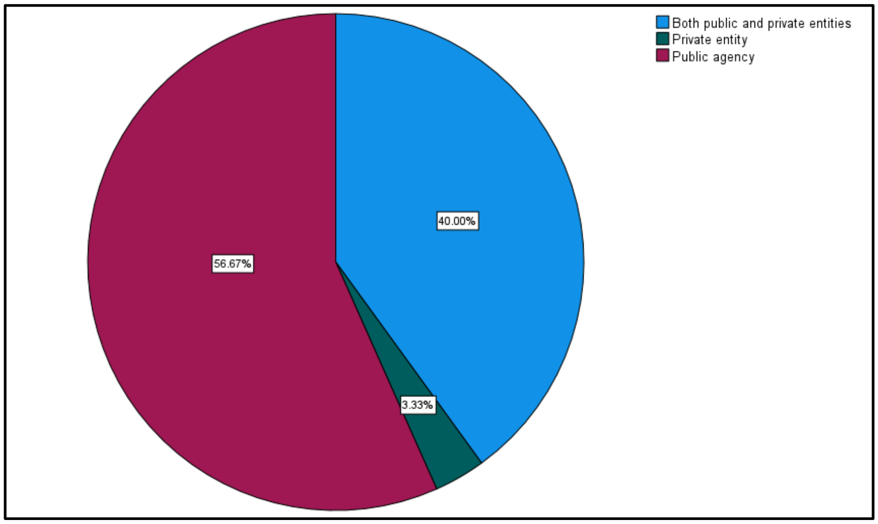
3.1.1.1 GNSS-RTN System General Information

The results presented in this section summarize the information gathered from all 30 responses from the thirty different States.

It is imperative to know about the ownership of the GNSS-RTN system and its components. When asked about the ownership of the RTN central facility and the CORSs, 80% of respondents mentioned the central facility is owned by the public agencies in the corresponding states. Regarding the ownership of CORSs in respective states, 40% of respondents indicated that the CORSs are owned by both public and private entities, while around 57% of respondents indicated that the CORSs are owned solely by the public agency. Most of the state Departments of Transportation (DOT) own the central facility and operate the statewide RTN system. They also own most but not all of the CORSs within their respective networks. The results for system ownership are shown in **Figure 5a** and **5b**.



(a)



(b)

Figure 5. Ownership of RTN (a) Central Facility; (b) CORSs in the Networks

To obtain information on the vendors/suppliers of the GNSS-RTN products and services acquired for RTN systems in different states, questions were asked about the companies which supplied hardware for CORSs, hardware for the central processing facility, and the software for the RTN system. The complete response options were: *Trimble, Leica, NavCon, TopCon, and Others (where respondents can write in text)*. It was allowed to select multiple options if more than one company has provided products or services to the statewide RTN system. Based on the responses from RTN operators, the top three companies that provided hardware for CORSs in the U.S. are Trimble, Leica, and TopCon as shown in **Figure 6**. The same three companies were the major suppliers of software and hardware for the central facility of the GNSS-RTN systems. Few DOTs are using their data servers to host the central facility data processing and storage.

It is essential to know about the current practices of both the coverage area of the RTN system in each state and the inter-CORS spacing which is an important determinant of the accuracy of the spatial data. When asked "*Total number of CORSs that are part of statewide GNSS-RTN system (including CORSs owned by entities other than the GNSS-RTN system owner/operator)*, respondents reported numbers which varied between 10 stations in Connecticut and 240 stations in Texas.

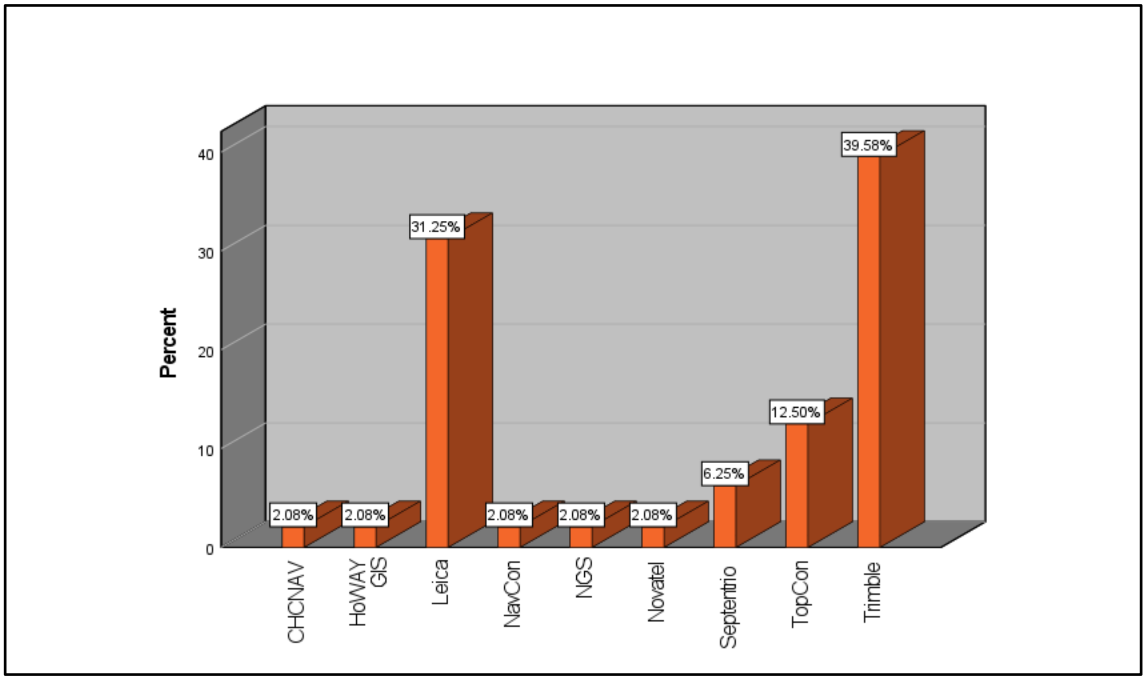


Figure 6. Companies Providing Hardware for CORSs in the U.S.

These results, shown in **Figure 7**, clearly show that larger states have a higher number of CORSs in their systems which is anticipated. Moreover, the survey question "*Your GNSS-RTN system provides coverage in the whole State or part of the State?*" yielded results of '*whole State coverage'* in approximately 86% of responses, and '*part of the State coverage'* in 14% of responses as illustrated in **Figure 8**.

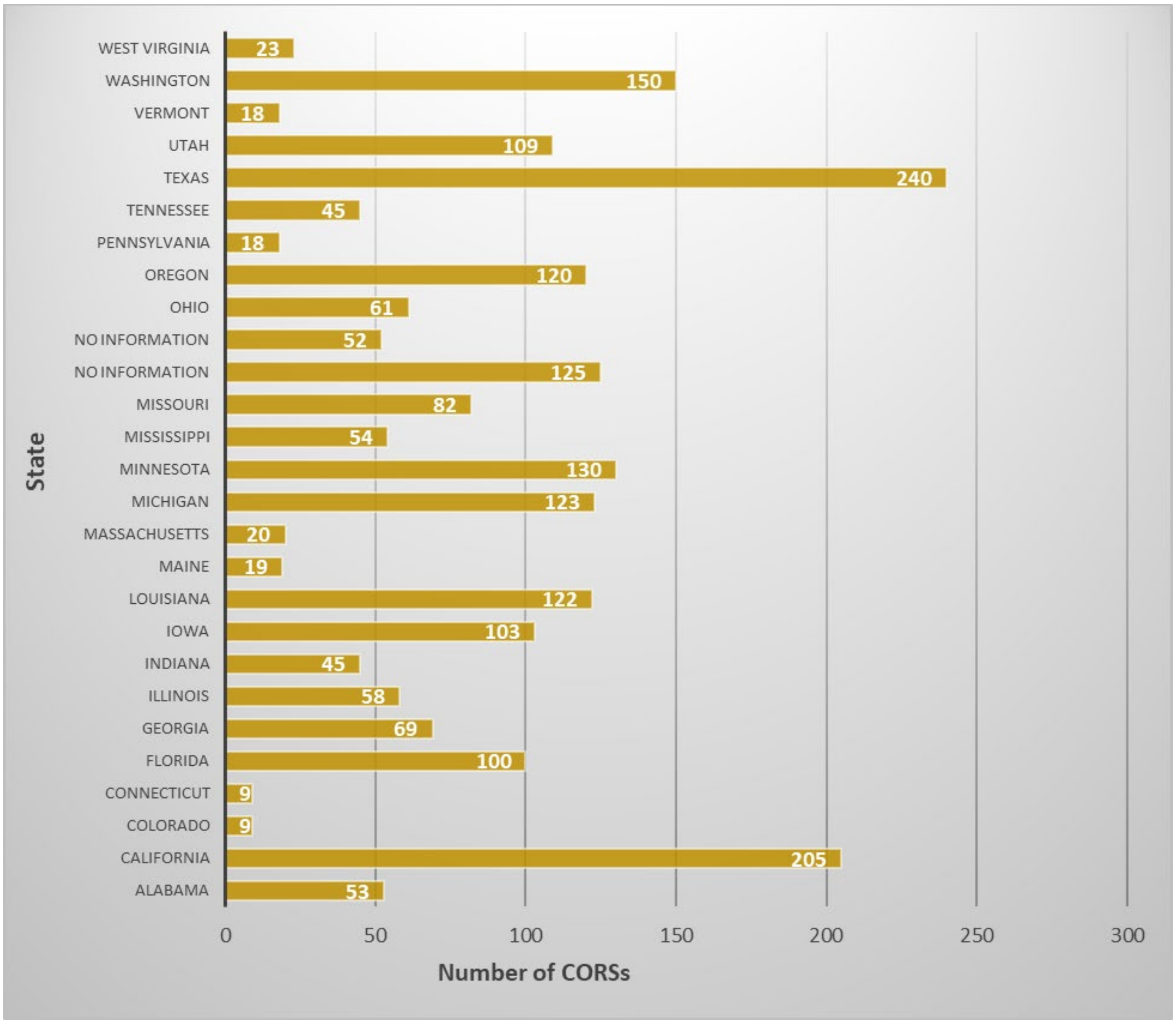


Figure 7. Number of CORSs in Each State

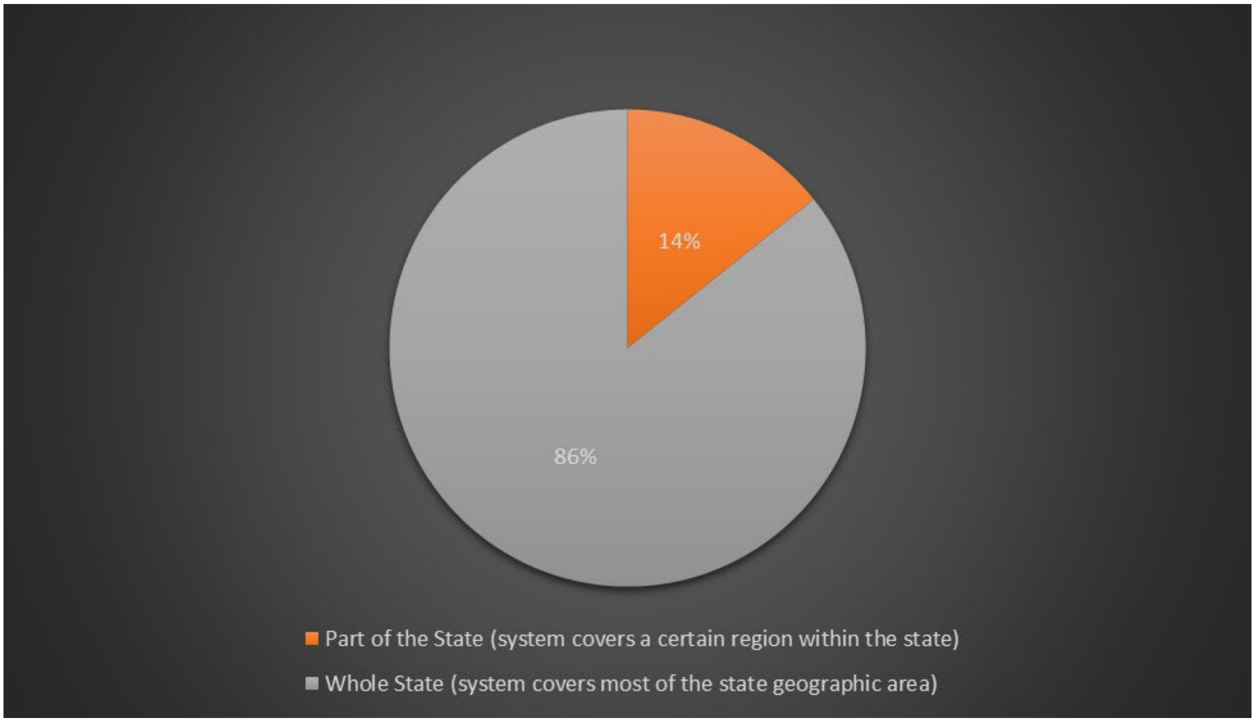


Figure 8. GNSS-RTN Coverage in the State

One of the important factors influencing the economic feasibility and the accuracy of the statewide GNSS-RTN system is the spacing between the CORSs. The lower the spacing between CORSs, the higher the accuracy of the spatial data and the higher the cost of the GNSS-RTN system. The current owners/operators of GNSS-RTN systems were asked about the average spacing between CORSs in their respective RTN systems, and the results of their responses are summarized in **Figure 9**. The results show that approximately 90% of statewide GNSS-RTN systems in the U.S use CORSs with a spacing of less than 70 km.

The GNSS-RTN system owners/operators were asked about the accuracy of the statewide RTN systems, and the results are summarized in **Figure 10**. Four options were provided which are accuracy of *2-4 cm; 4-6 cm; 6-8 cm; and more than 8 cm*. Twenty-seven out of 30 respondents indicated that their statewide RTN system provides an accuracy of 2-4 cm. Two respondents reported accuracy of 4-6 cm, and one respondent skipped this question. This high percentage of responses (90%) for high accuracy in location data (i.e., 2-4 cm) is consistent with the fact that the majority of the statewide GNSS-RTN systems have CORS spacing lower than 70 km as discussed earlier.

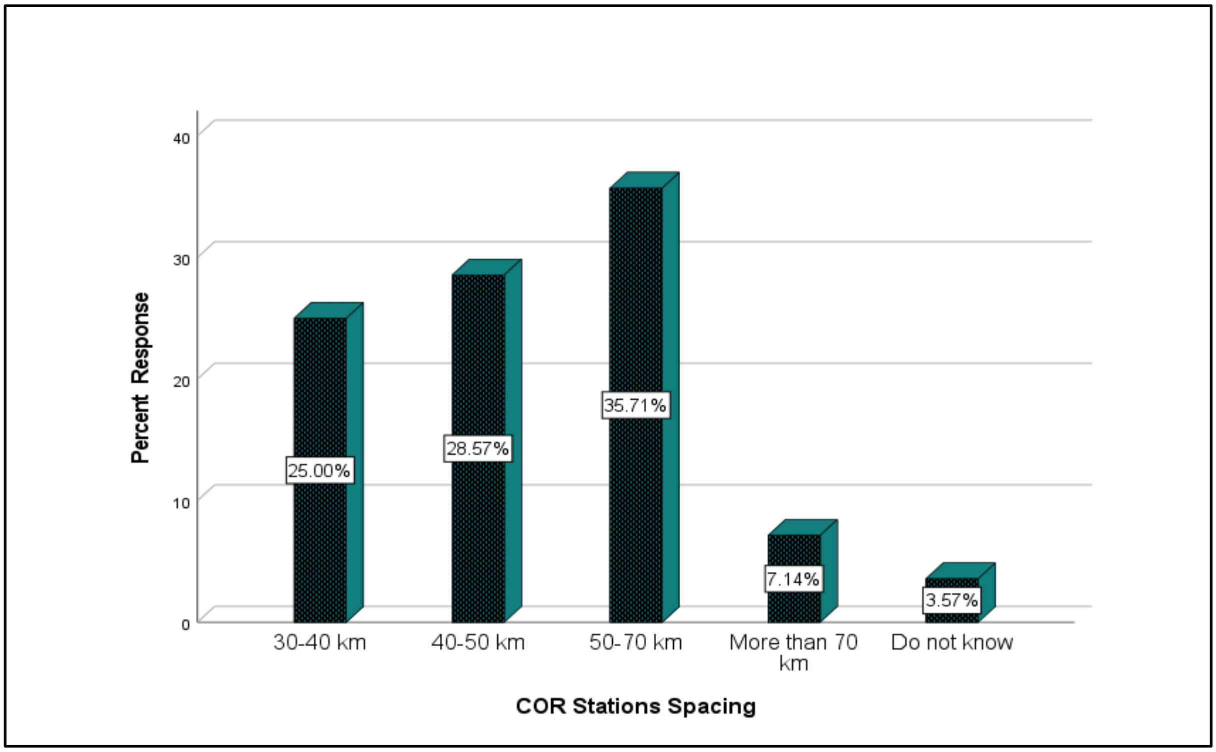


Figure 9. Percent RTN Systems based on CORSs Spacing

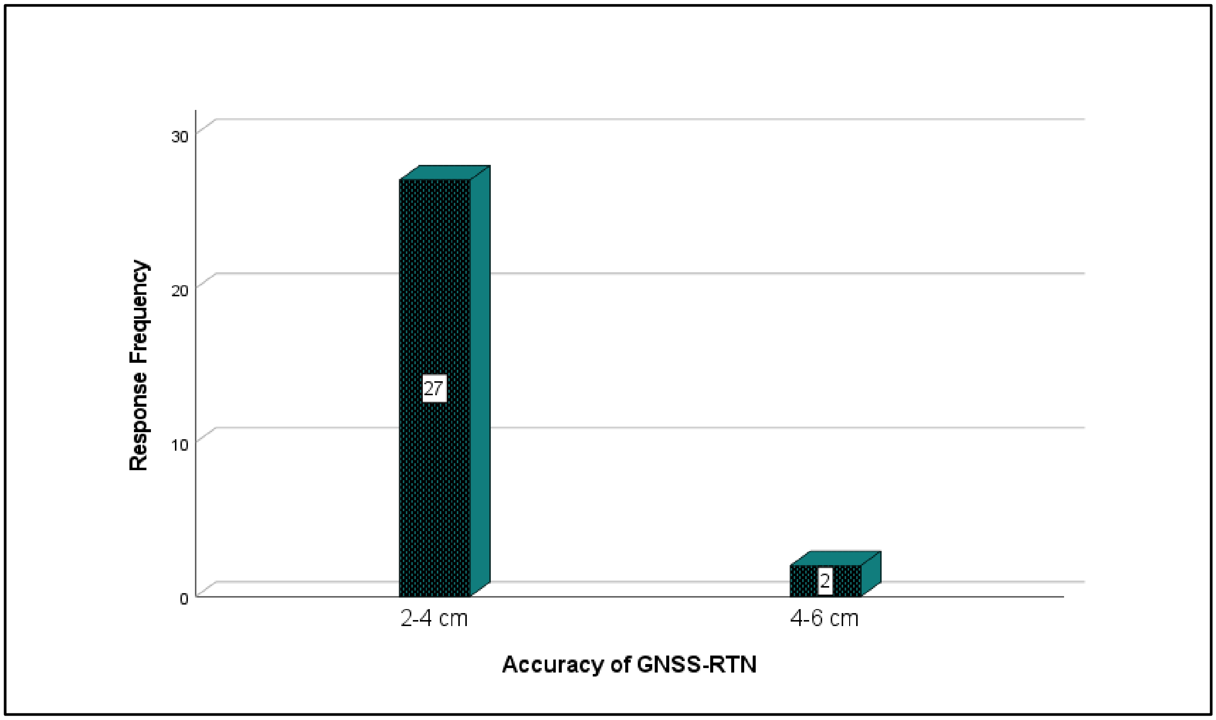


Figure 10. Accuracy of Statewide GNSS-RTN System

3.1.1.2 System Operations and Services

As CORSs need to communicate with the central processing facility for data correction, different communication means or methods can be used to connect the CORSs with the central facility. When asked about the *"Communication methods currently in place to connect CORSs to central facility/server,"* the respondents were provided with the following response options: *mobile cellular network, internet-based communication, radio signal-based, and Others (where respondents can write in text)*. Based on the responses of the operators/owners of current statewide GNSS-RTN systems in the U.S., most of the networks use the internet or both internet and mobile cellular network for communication between CORSs and the central processing facility. Few states also use radio signals for communication as shown in **Figure 11.**

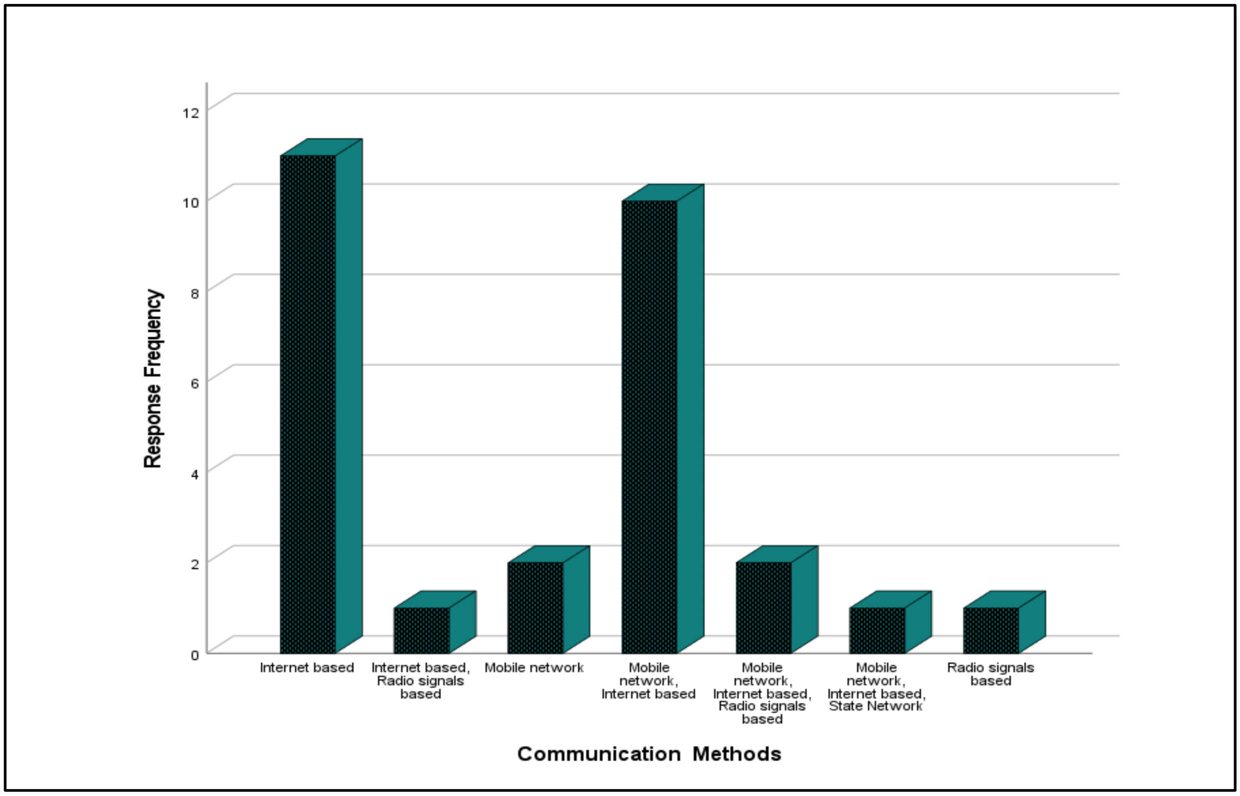


Figure 11. Methods Used for Communication between CORSs and Central Facility

To gather information on products/services provided by the statewide RTN systems to the users, the survey question "*Does your GNSS-RTN system provide the following products to users [check all that apply]:*" was asked with options of *corrected coordinates (Real-time), network corrections (Real-time), post-processed data (Static), and Others (where respondents can write in text)*. The results of the responses to this question are summarized in **Figure 12**. The results indicate that approximately 66% of the statewide RTN systems provide corrected coordinates (Real-time), network corrections (Real-time), and post-processed data (Static), whereas approximately 17% of the statewide RTN systems provide only network corrections (Real-time), and post-processed data (Static). Moreover, some statewide RTN systems also provide the following products (responses as Other):

- Virtual Rinex
- User statistics
- Real-time & Historical Tracking of rovers for clients
- Online post-processing solutions
- Observation streams for science and industry

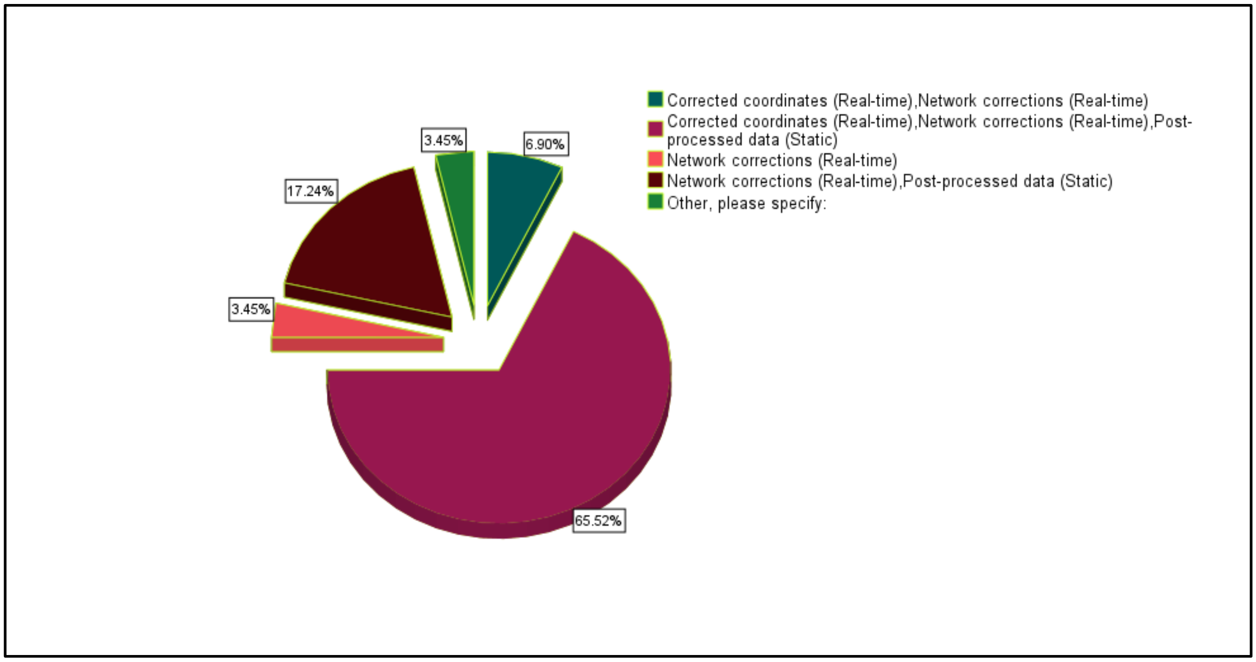


Figure 12. Products of GNSS-RTN Available to Users

To obtain information about the users who benefit from the statewide RTN, a question was asked to "*Provide the average number of users of your GNSS-RTN system:*" separately as total system users; annual subscriptions; less-than-a-year subscriptions; and others. Responses are summarized in **APPENDIX B**. which shows that Colorado state's RTN system had the highest number of total users, an average of 10,000 total users. The number of users of statewide RTN in Ohio, Florida, Michigan, and Minnesota varied in a range from approximately 5,000 to 7,700. A few states reported equal numbers of total users and annual subscriptions as shown in **Figure 13**, indicating that they only offer annual subscriptions to access the network.

The statewide GNSS-RTN system provides highly accurate location services to public and private users. To know about the rules and charges of accessing the RTN system, respondents were asked: "*Users of your GNSS-RTN access the system [check all that apply]*" with the following options: *free of cost; annual subscription fee; less-than-a-year subscriptions fee; charges based on access duration; charges based on data-size download; and others (where respondents can write in text)*. The current statewide RTNs differ in their access rules, however, most of the state DOTs offer free access to the networks. Approximately 60% of statewide GNSS-RTN systems' access is entirely free of cost for both public and private users. **Table 4** summarizes the details of charges/rules for accessing the GNSS-RTN systems in responding states. In California, direct access is only available to Municipalities. Public departments can access data from state-owned stations via the partner California Real-Time Network (CRTN). Colorado DOT offers free access to the public departments and private users pay an annual subscription fee through private vendors. Similarly, the RTN system in Pennsylvania is only accessible for DOT and private users can access private RTN based on the subscription fee. The Utah Reference Network GPS (TURN GPS) requires annual subscriptions to access TURN GPS for location services. The respondents from Washington state reported that users access the network based on annual subscriptions, however, the majority of the users are cooperative partners in the statewide network.

As the RTN system is comprised of CORSs and central facility, the CORSs can be managed and maintained by the owner of the central facility or CORSs, or both, while the central facility of the GNSS-RTN system can be managed and maintained by the owner of the statewide GNSS-RTN system or partner with any other entities. To identify the current practices regarding the party responsible for maintenance, IT services, etc., the following question was asked: *"Who is responsible for the cost of: user and IT support; communication between central facility and CORSs; maintenance of the central facility; and maintenance of CORSs."* The options provided were: *central facility owner, CORSs owner, and others (where respondents can write in text)*. The results of the responses to these questions are summarized in **Figure 14**.

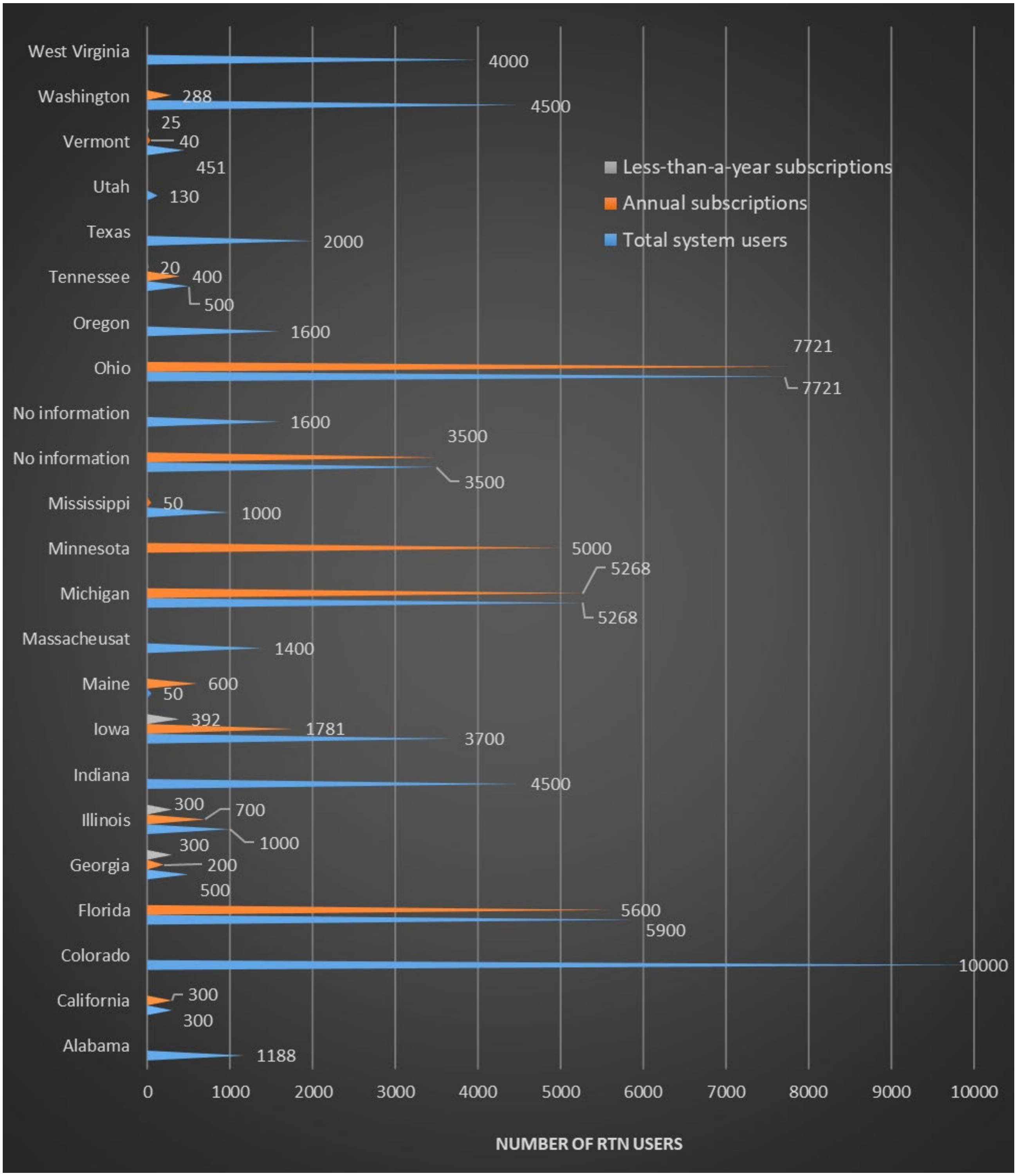


Figure 13. Number of Users of Statewide GNSS-RTN System

Table 4. Rules/Charges for Accessing GNSS-RTN System

Charges to Access RTN	Response Frequency	Percent
Annual subscription fee	1	3.6
Annual subscription fee, Less-than-a-year subscriptions fee, Charges based on access duration	1	3.6
Annual subscription fee, Less-than-a-year subscriptions fee	1	3.6
Annual subscription fee, Other, please specify:	2	7.1
Free of cost	17	60.7
Free of cost, Annual subscription fee	1	3.6
Free of cost, Annual subscription fee, Less-than-a-year subscriptions fee	1	3.6
Free of cost, Annual subscription fee, Less-than-a-year subscriptions fee, Charges based on access duration, Other, please specify:	1	3.6
Free of cost, Annual subscription fee, Other, please specify:	1	3.6
Other, please specify:	2	7.1

For user and IT support service costs, the owners of central facilities are responsible for approximately 64% of all the statewide RTN systems. In a few states such as California, Massachusetts, Texas, and Vermont, the state DOTs are operating statewide RTN system with private partners (who own some CORSs), hence, CORSs owners are also sharing the responsibility of the cost of user and IT support services.

The central facility and CORSs are connected and communicate primarily via the internet or cellular network or both. These services cost a fair share of the operation costs. In most of the responding states, central facility owners are responsible for the cost of communication services between the central facility and CORSs, however, approximately 22% of respondents reported that CORSs' owners also share the responsibility of the cost of communication with central facility owners. In a few states including Utah and West Virginia, only CORS owners are responsible for the cost of communication between central facility and CORSs.

The GNSS-RTN system needs regular maintenance of the central facility and CORSs. The results of the survey indicate that approximately 85% of central facility owners are responsible for the maintenance costs of the central facility. In Texas, both the central facility's owner and CORSs' owners share the responsibility of the cost of maintenance of the central facility. Whereas in Vermont, the central facility owner and the state agency of Digital Services are responsible for the maintenance of the central facility. Furthermore, the maintenance of CORSs is also a responsibility of central facility owners in most of the states (53.6% of total responses). However, CORS owners are also responsible in several states (28.6% of total responses) such as Colorado, Maine, Massachusetts, West Virginia, and Mississippi. In five states including California, Oregon, Texas, Vermont, and Washington, the central facility owners and CORSs' owners are responsible for the maintenance costs of their own CORSs.

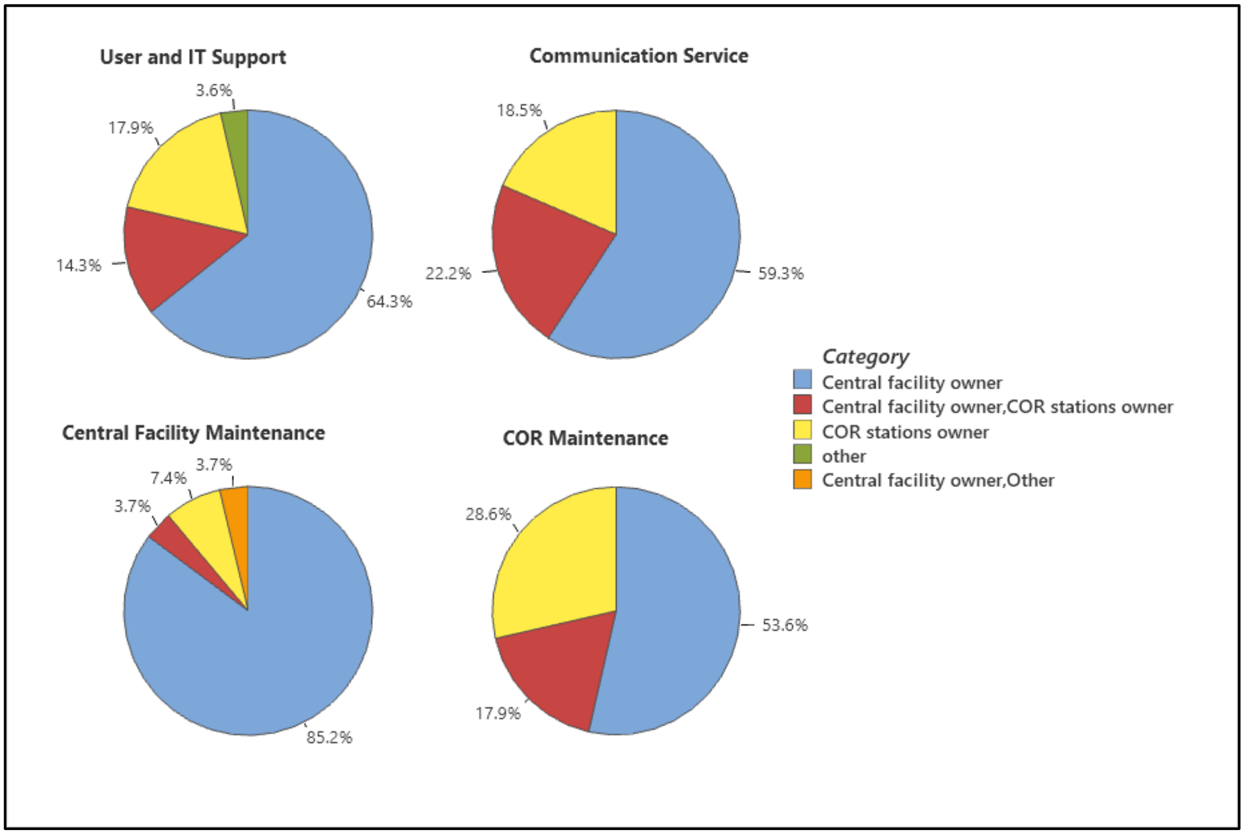


Figure 14. Entity Responsible for Various Costs of RTN System

To better understand the business model for RTN systems included in this survey, the respondents were asked about the revenues of the RTN system from any users' fees or subscription charges. A more meaningful way to know about the revenues of the system is to ask in terms of the total system operation costs covered by users' fees. When asked "*How much revenues are collected from user fees/charges in terms of total system operation costs,*" the respondents provided information that is quite surprising as presented in **Figure 15**. Most of the state agencies (17 out 26 respondents) reported revenues generated from users' fees of "*0% of total system operation cost*" which indicates that these states provide access to the RTN system free of charge for all users. Two states, Tennessee, and Mississippi earn "*1% to 20% of total operation cost*" of the RTN system from users' fees. The RTN system in Arizona, Illinois, and Georgia are privately owned networks (AZGPS, AZ; Kara Co. Inc, IL; eGPS Solution Inc, GA) and reported that users' subscription charges make "60% to 80% of total operation cost", "80% to 99% of total operation cost", and "total cost of system operation", respectively. Furthermore, the revenues obtained from the user fees in the states of Louisiana, Utah, and Washington cover the total cost of RTN system operation.

Significant resources are required for establishing, operating, and maintaining the GNSS-RTN system. To get information on funding sources of current statewide GNSS-RTN systems in the United States, questions were asked to specify the funding sources for the establishment of the GNSS-RTN system, its operations, and maintenance, with options provided: *Federal funds, State funds, Users/subscription fee, and Others (where respondents can write in text)*. Many of the GNSS-RTN systems in responding states were established using state funds (11 out of 27 responses), however, 8 RTN systems also received federal funds along with state funds as shown in **Figure 16**. Only two statewide RTN systems were built on federal funds. Tennessee state RTN system was established using state funds and users' fees. The Washington state RTN was funded by an initial investment of Seattle Public Utilities, partners' contributions, and users' subscription fees. "*Other*" funding source reported by a respondent (owner of private network) from Georgia is "private business ownership for profit".

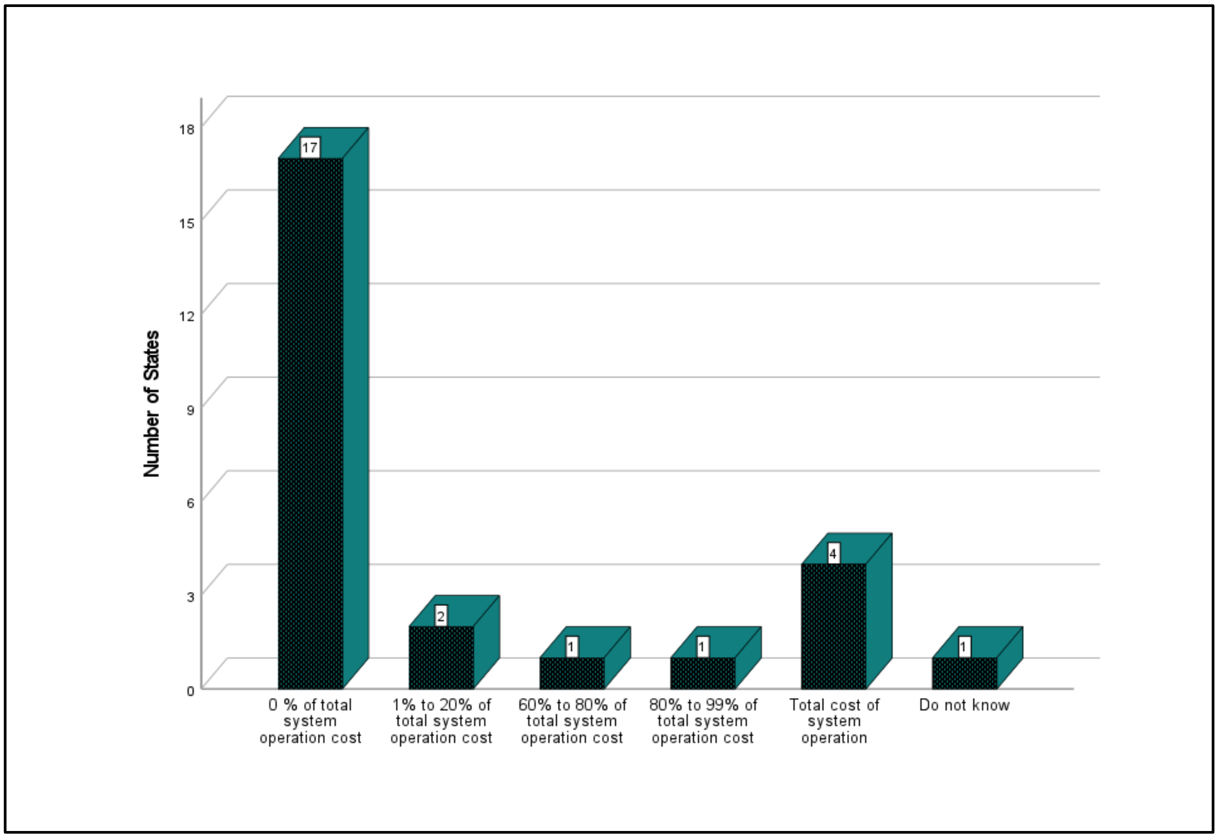


Figure 15. Revenues of RTN System from User Fees/Charges

Regarding funding sources for the operation of the GNSS-RTN system, somewhat similar responses were received. The operating costs of approximately 50% of statewide RTNs were entirely funded by the respective states. Furthermore, 5 out 27 RTN systems (approximately 20%) also received federal funds along with state funds for regular operations. Only the Tennessee state's RTN system operating cost was funded by the state funds and users' subscription fees. The operations of statewide RTN systems in Illinois (a private network), Louisiana, Utah, and Arizona (a private network) were fully funded by users' charges. The respondent from Washington state reported that the operating cost of the RTN system is mainly funded by users' fees, however, some partners contribute for software upgrades and other miscellaneous costs. These findings are summarized in **Figure 16**.

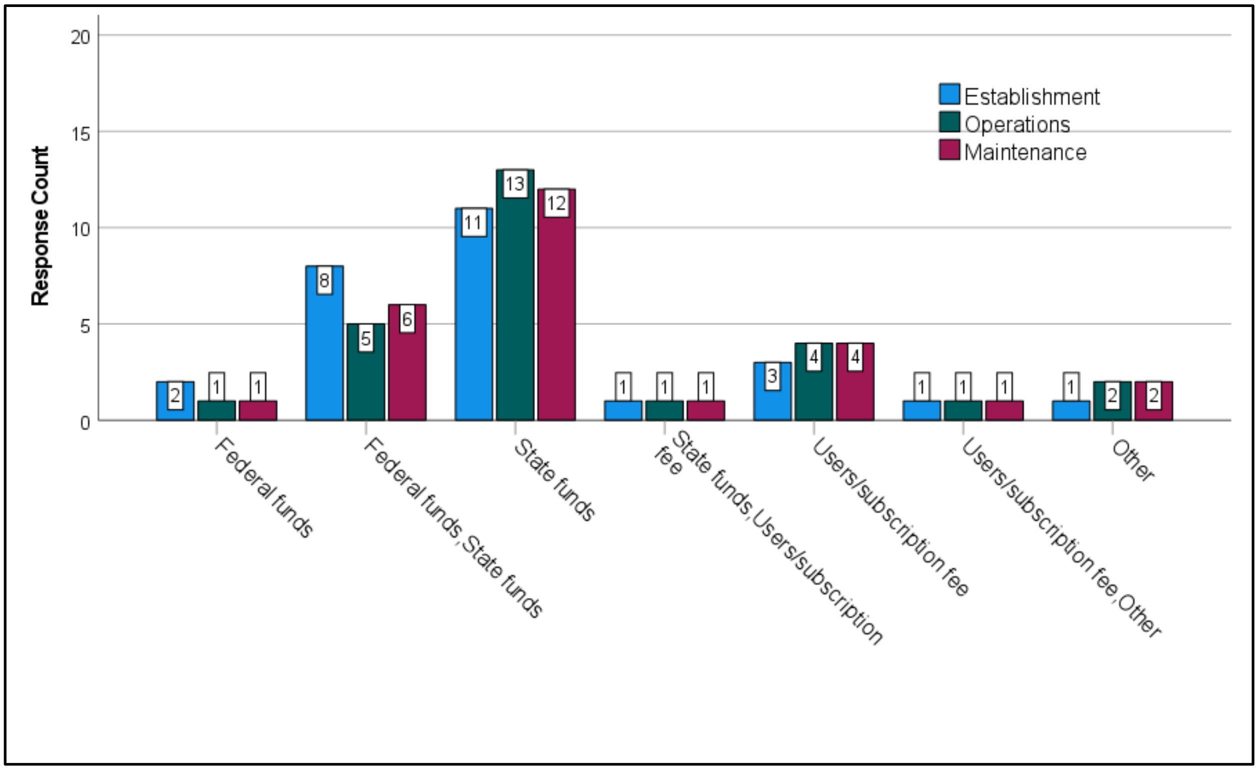


Figure 16. Sources of Funds for RTN Systems

The GNSS-RTN system requires regular maintenance of CORSs and the central facility. When asked about the funding sources for maintenance purposes, the respondents provided somewhat similar responses as those for the funding source of operation costs. The results are shown in **Figure 16**.

Most of the statewide GNSS-RTN systems are managed and operated in-house by state agencies. This requires assigning resources and staff to oversee the daily operations of the RTN system. It is essential to know the resources and staff (in terms of full-time equivalent - FTE) required for the in-house GNSS-RTN system operation. Therefore, operators of the current statewide RTN systems in various states were asked about the number of FTE staff assigned to the daily operations of the RTN system. The responses indicated that the number of FTE staff assigned for operating the RTN system varied between 0.75 FTE and 5 FTE, however, 34% of responses indicated 1 FTE, 21% reported 2 FTE, and 25% reported 3 FTE. A summary of the responses to this question is illustrated in **Figure 17**.

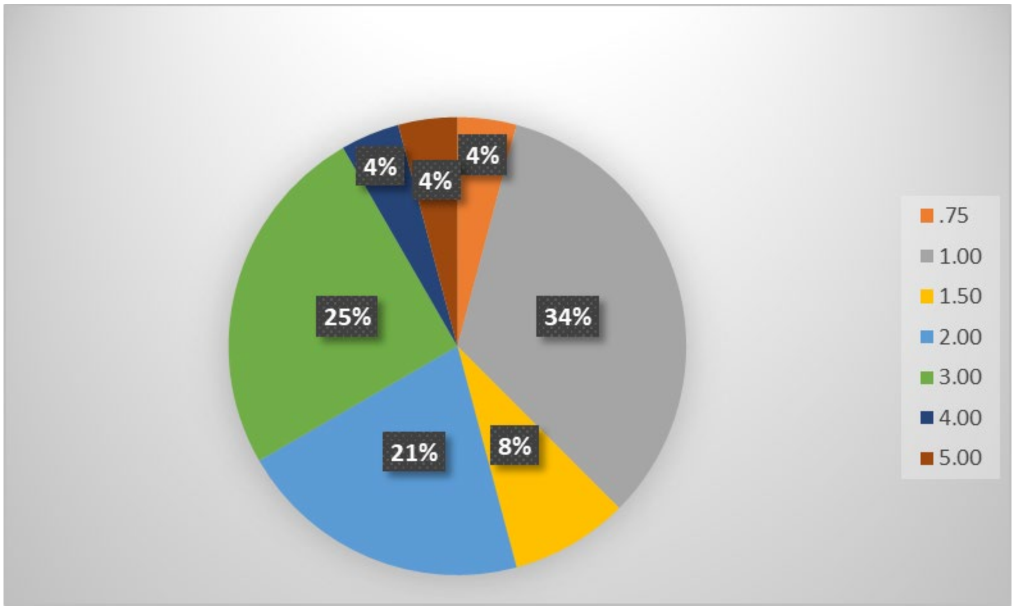


Figure 17. Staff Assigned to RTN System for Daily Operations (In terms of FTE)

Before establishing a larger statewide GNSS-RTN system, some states have a number of existing CORSs owned by different entities such as private consultants, research institutes, municipalities etc. To reduce the initial cost of developing a statewide GNSS-RTN system, it is logical to consider the incorporation of existing CORSs. To gather information on the integration and inclusion of existing CORSs in the statewide GNSS-RTN system surveyed, the respondents were asked if they included existing CORSs in establishing their statewide GNSS-RTN systems. The responses are summarized in **Figure 18**, illustrating that 14 out of 25 (56%) states have incorporated existing CORSs, 8 out 25 (32%) have not incorporated existing CORSs, 2 respondents (8%) reported that there were no existing CORSs in their states, and one respondent selected ‘Other’ option and reported ‘adjacent states and municipal’.

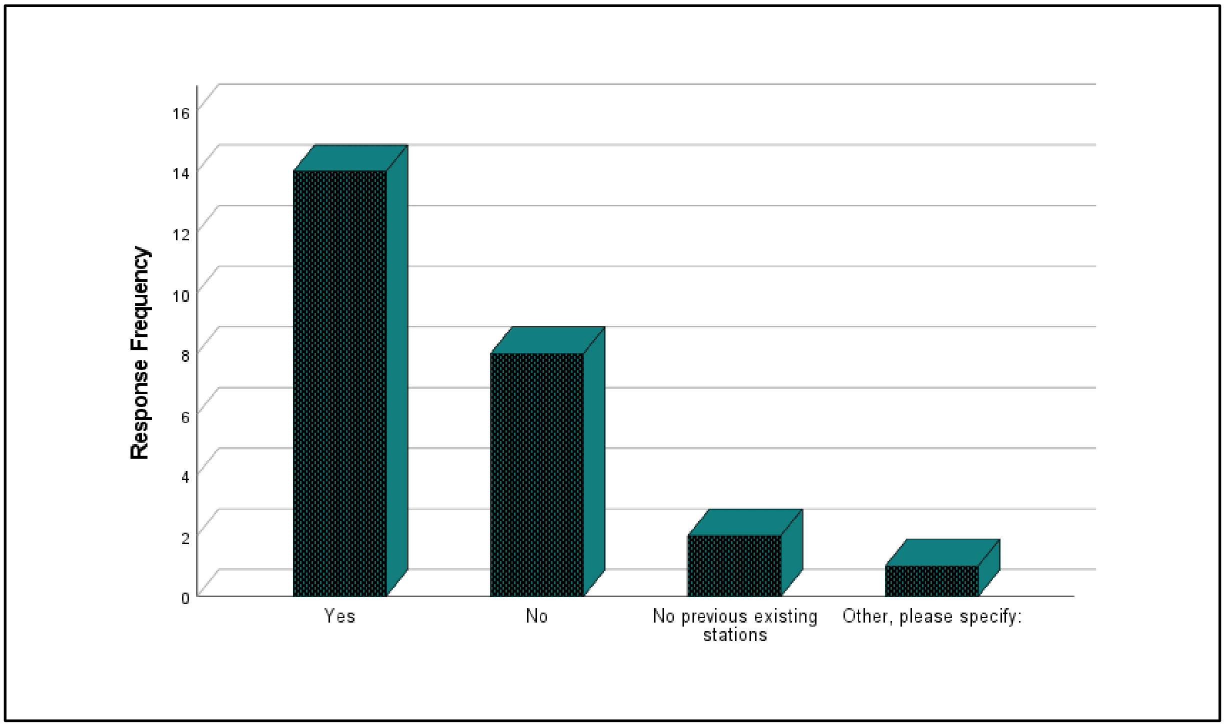


Figure 18. Incorporation of Existing CORSs in Statewide RTN Systems

To gather further information on the inclusion of CORSs and incentives provided to the owners of those already existing (private) CORSs, the operators/owners of the 15 statewide GNSS-RTNs that incorporated the existing CORSs were asked if they had been providing any incentives to the owners of the CORSs. Most of the respondents (73%) reported that they did not provide any incentives to the owners of existing CORSs as presented in **Figure 19**. Some states reported providing incentives to the owners of private CORSs in various forms such as unlimited access to data, access to value-added services, one free subscription per CORS, educational opportunities for schools that host CORSs, and reduced subscription charges.

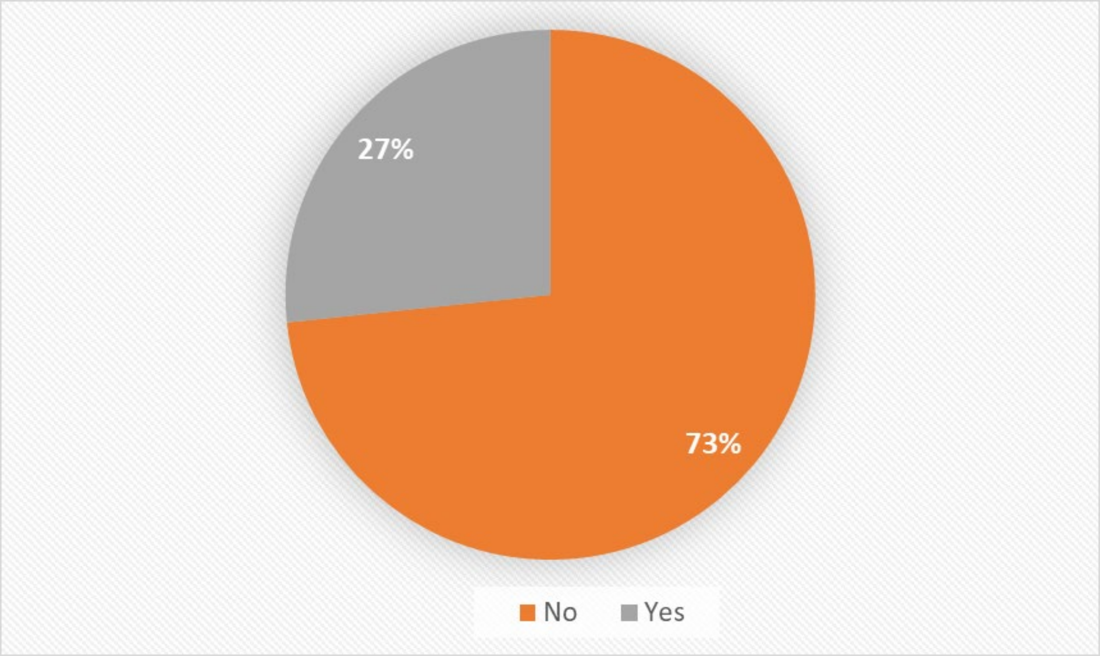


Figure 19. Incentives to Owners of Private CORSs

3.1.2 SUMMARY OF RTN OWNERS/OPERATORS SURVEY

A state of practice survey was conducted to learn about the current practices of operating and managing the GNSS-RTN systems and providing accurate location services in different states around the U.S. The survey was sent to the public and private GNSS-RTN owners/operators throughout the 50 States. Thirty-eight respondents submitted the survey representing 30 states (four states with duplicate responses and another four with no RTN system). This chapter presented and discussed the results of the survey of which the major findings are summarized below.

- Most of the statewide GNSS-RTN systems surveyed are owned by the state Departments of Transportation (DOTs). The DOTs also own most of the CORSs within their respective network.
- Based on the responses from GNSS-RTN operators, the top three companies that provide GNSS-RTN hardware and services in the U.S. are Trimble, Leica, and TopCon.
- Most of the statewide GNSS-RTN systems provide coverage throughout the whole state.
- Approximately 90% of statewide GNSS-RTN systems in the U.S. are based on CORSs

with an average spacing of less than 70 km.

- The accuracy of position data offered by 90% of statewide GNSS-RTN systems is 2-4 cm.
- Most of the statewide GNSS-RTN systems use either the internet or both internet and mobile cellular network for communication between CORSs and the central processing facility.
- The statewide GNSS-RTN systems often provide corrected coordinates (Real- time), network corrections (Real-time), post-processed data (Static), and occasionally they may provide virtual Rinex.
- Approximately 60% of statewide GNSS-RTN systems offer entirely free access to both public and private users. However, several statewide GNSS-RTN systems charge annual subscription fees.
- The owners of central facilities are responsible for user and IT support service costs in approximately 64% of all the statewide GNSS-RTN systems. In addition, the central facility owners are responsible for the cost of communication services between the central facility and CORSs and for the cost of maintenance of the central facility in most of the GNSS-RTN systems surveyed.
- Most of the state agencies (17 out 26 respondents) reported that they do not generate revenues from users' fees.
- The funding sources for the establishment of most of the statewide GNSS-RTN systems are either only state funds or some federal funds along with state funds. However, the funding sources for the daily operation of GNSS-RTN systems are state funds and users' fees.
- To manage and operate an in-house statewide GNSS-RTN system, 1 to 3 FTE staff are required.
- Approximately 50% of the statewide GNSS-RTN systems did incorporate the already existing CORSs in their networks. Some states provide incentives to the owners of private CORSs in various forms such as unlimited access to data, access to value-added

services, one free subscription per CORS, educational opportunities for schools that host CORSs, and reduced subscription charges.

3.2 VENDORS/MANUFACTURERS INTERVIEWS

After screening current practices of the statewide GNSS-RTN system, the researchers conducted in-depth interviews with representatives of major GNSS-RTN manufacturers and suppliers to obtain more precise information about the costs, technologies, and services provided by these companies. Based on the survey responses of operators/owners of current statewide GNSS-RTN systems, the top three manufacturers and suppliers were selected including Trimble, Leica, and TopCon. The researchers contacted more than six (06) officials at Trimble office including Trimble Public Relation (PR), and Trimble Sales and Support office via email and phone several times but did not receive any response. The researchers were able to arrange interviews with representatives from the other two manufacturers TopCon and Leica. The interview questions and topics were shared with TopCon Sale’s executive and Leica's Executive officer before the interviews which were conducted via web conferencing. The following subsections discuss in detail the responses of the company representatives to the interview questions. It should be noted that the cost information provided by the representatives during the interviews is only tentative and may be different from the actual cost solicited through a bidding process. The complete set of interview questions is available in **APPENDIX C**.

3.2.1 TopCon

3.2.1.1 Products and Services

The researchers began the survey by asking the TopCon representative about the various product and services along with the costs and other attributes. When asked about the hardware kit for CORSs, hardware for a central facility, and software for the central facility, the respondent reported that the TopCon offers two types of antennas and two types of receivers for CORSs. The cost of a complete kit of hardware for a CORS is approximately $8,500.

The central facility hardware consists of data servers and computers for the processing and storage of data. The respondent reported that the central facility can be established using in-house servers or a hosted environment. The cost differential is based on different factors such as short- term and long-term hosting and in-house vs. hosted environment. For in-house central facility establishment, the reported approximate initial cost of servers ranges from $25,000 to $35,000. When asked about the cost of software for central facility servers and processing, the respondent reported that the cost of RTN software depends on the features and functionalities you wish to provide to the customers. For in-house private network establishment, the approximate cost of TopNET PLUS Server software is $54,000 plus $3,200 per CORS in the network (reported by the representative from TopCon). This software has additional charges of $6,000 per year for the annual maintenance of the software.

Before establishing the statewide RTN system, the system is designed by professionals based on standards and the required attributes and functionalities such as ubiquity, reliability, and accuracy of location services. System design includes the number of CORSs required to achieve specific accuracy, number of servers, and processing power/CPU required for maximum efficiency. The representative was asked if the company offers design services for the RTN system, the respondent reported different options. TopCon does not offer stand-alone design consulting services, however, it offers online subscription services for the design and positioning of CORSs within the complete network. In addition, TopCon offers training and consulting services for the GNSS-RTN systems solely built by the company. The approximate cost for training client's employees and setting up software is in the order of $2500 per day on-site for a minimum of 3 days or $250/h for remote services.

When asked about building and/or establishing the components of the RTN system including CORSs and central processing facility, the respondent reported that TopCon provides building RTN components as part of building a complete statewide RTN system, in conjunction with hardware/software procurement, and/or in conjunction with system operation contract as well.

To gain further information about the network operation services of statewide RTN, a question was asked "*Does your company operate GNSS-RTN systems?*" with options: operates as stand-alone service, or only for systems designed and built by your company. The respondent mentioned that TopCon does not operate statewide publicly owned networks, however, it operates TopNET Live which is a private network of Topcon. **Figure 20** shows the coverage of TopNET Live North

America. TopNET Live Global has over 5000 reference stations in the Americas, Europe, Asia, China, and Russia. Topcon incorporates privately owned (third party) CORSs in TopNET Live and provides free subscriptions to the private owners of CORSs. TopNET Live has globally 250 private partners. Moreover, the respondent reported that the subscription fee for the entire west coast is $1300 per year.

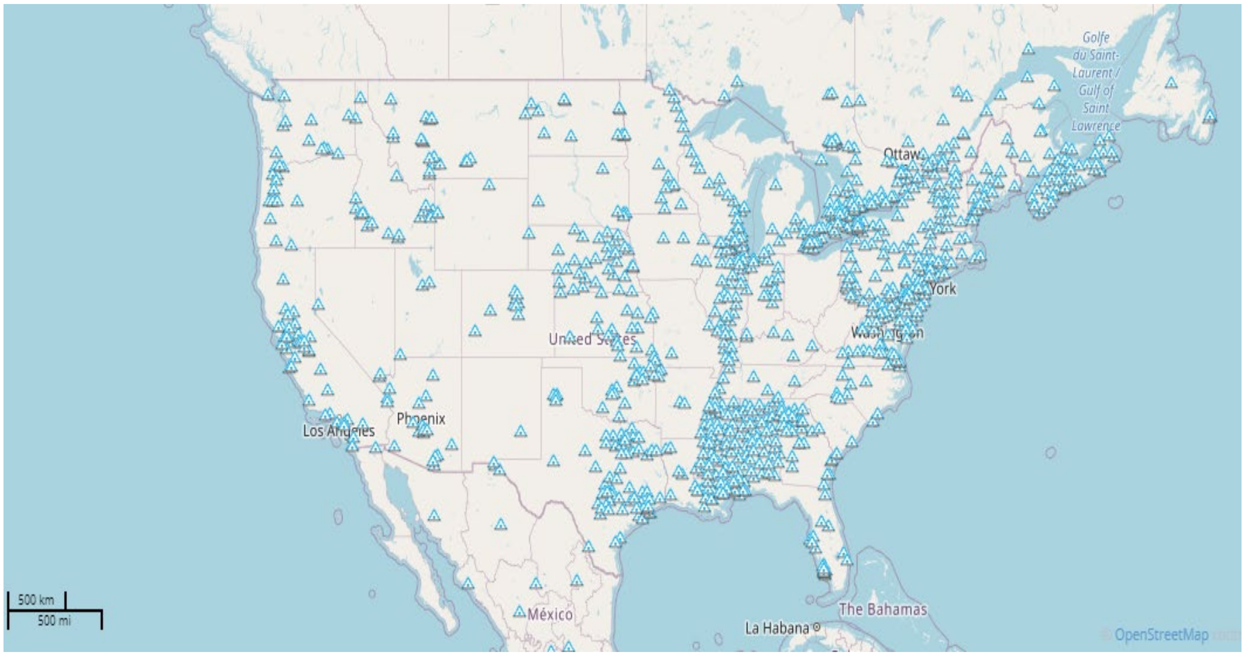


Figure 20. Coverage of TopNET Live in North America (Courtesy of TopCon)

Apart from this information, TopCon has designed a plan of CORSs for the state of Montana as shown in **Figure 21**. Based on the TopCon estimate, 120 CORSs would be needed for full coverage in the state of Montana. In this figure, CORSs are spaced no more than 70 km which is the required spacing between CORSs for higher accuracy (2-4 cm). The radius of each coverage circle around each CORS is 35 km. Blue CORSs (25 stations) are existing CORSs that are part of the TopNET live, whereas the green CORSs (95 stations) are proposed new stations for the statewide GNSS-RTN system. The representative from TopCon communicated that if the state of Montana wants to be a part of TopNET live, the following incentives would be offered to the state agency (owner of CORSs):

i. TopCon will be responsible for hosting Montana CORS and providing real-time location services, which means the state does not need:

    a. To pay for the software of the central facility.
    b. In-house server development and expenses.
    c. To spend on maintenance of the central facility.

ii. TopCon would offer two full-time free subscriptions per CORS.

iii. The state agency would be able to purchase annual subscriptions for entire west coast coverage at a discounted rate and sell it to private customers.

It is reported that the already existing CORSs can be incorporated into the larger statewide network.

The respondent was asked about the subscription charges to access the network. He reported a $1,300 per year subscription charge that would offer full access to the entire west coast data including the state of Montana. An in-house GNSS-RTN system requires regular maintenance of the central facility and CORSs. TopCon provides maintenance services to the RTN system designed and built by TopCon. It offers depot repair services for CORSs. Besides, the respondent reported that warranty and extended warranties are also available for the hardware of CORSs. For maintenance of the central facility, an annual maintenance contract is required which costs $6,000 per year (primarily software upgrades).

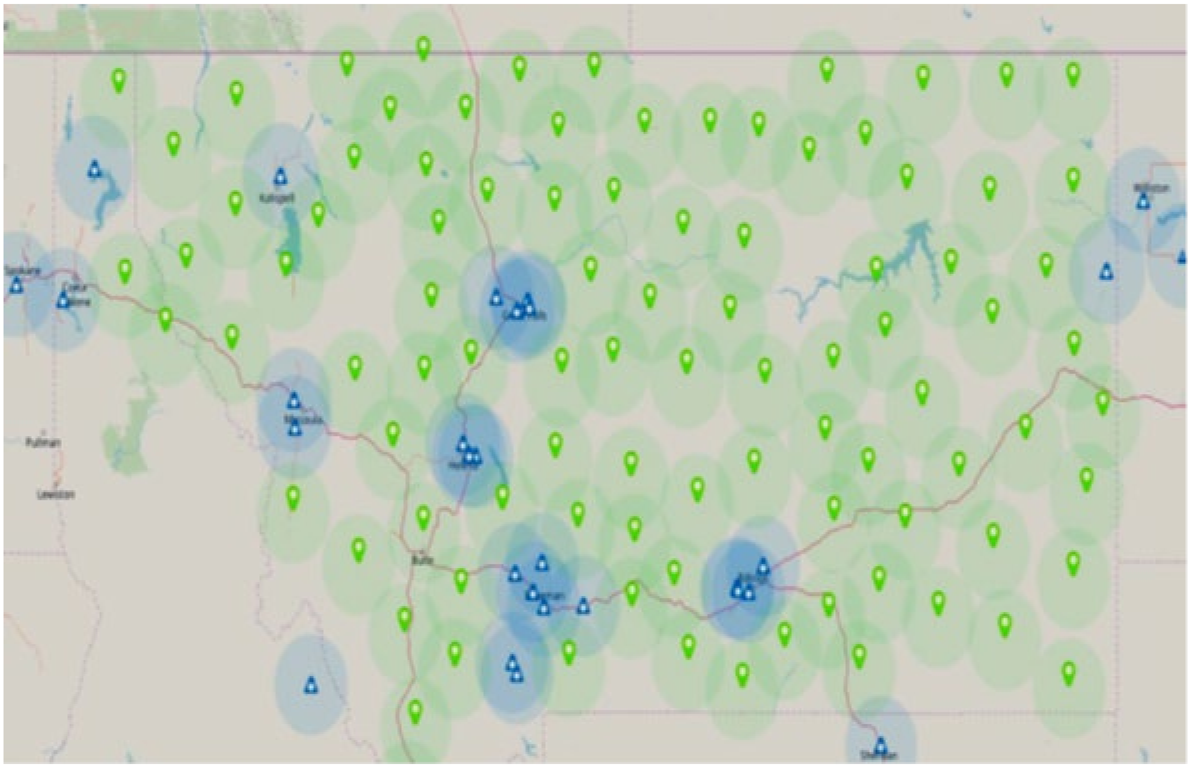


Figure 21. Plan of CORSs in Montana

3.2.1.2 Current and Past Clients

To gather information on TopCon's expertise and their market share of the GNSS-RTN industry, the representative of TopCon was asked about current clients of the company. The respondent reported that Topcon has several ongoing business relationships with key network clients such as the Geographical Survey Institute (GSI), an affiliate of the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) in Japan. Topcon will provide a total of 450 receivers for the GPS Earth Observation Network System (GEONET) operated by the GSI. Topcon will also provide GPS observation/control software as well as a database management system exclusively designed for the GEONET. Since GEONET is an ever-changing and expanding network, Topcon is pleased to be a part of this important relationship.

Further, TopCon was also selected to supply GNSS receivers for the Crustal Movement Observation Network of China (CMONOC). TopCon supplied 132 campaign-mode (portable) GNSS COR receivers and GNSS choke ring antennas for CMONOC. The CMONOC project was established by the China Earthquake Administration (CEA) of the People’s Republic of China, to monitor crustal deformation and to predict earthquakes using GNSS technology.

Moreover, in the United States, Topcon has been the GNSS-RTN provider for the Tennessee Department of Transportation (TDOT) for over ten years. TDOT owns and maintains a dense network of Reference Stations to provide statewide RTK coverage for highway projects carried out by TDOT staff and its consulting engineering and survey firms.

3.2.2 Leica

The researchers had an online interview with the representative of Leica, a major GNSS-RTN services and hardware provider in the United States. The questionnaire was shared well in advance with the interviewee.

3.2.2.1 Products and Services

The researchers started the interview with questions about the central facility, CORSs, and establishing of the GNSS-RTN system. The respondent reported that Leica offers four types of antennas and two types of receivers for CORSs. The cost of the receiver ranges from approximately \$15,500 to \$ 18,000, and the cost of the antenna ranges from approximately \$1400 to \$10,500 (depending on features and functionalities). The representative of Leica was asked if they provide GNSS-RTN system design services, he stated that Leica is an open platform and can offer an in-depth design of GNSS-RTN system as a stand-alone service, in conjunction with hardware or software procurement, and also for GNSS-RTN systems solely built by Leica. According to the respondent, the design of the network is part of the business partnership for developing the network. Leica does not charge for the design service as the establishment of the RTN system is a partnership and requires a team effort to include Information Technology (IT), management, and manufacturer. The respondent stated that very few manufacturers have the skill set and staff to facilitate network design from start to finish, including planning, implementation, management, and monitoring the network. He mentioned that Leica can provide the network adjustment to the National Spatial Reference Frame as well, however, it has a per-site fee.

When asked about building and/or establishing the components of the RTN system including CORSs and central processing facility, the respondent stated that Leica establishes the CORSs and central facility as a stand-alone service, in conjunction with hardware/software procurement, and as part of building a complete GNSS-RTN system. He reported that Leica is a full-service manufacturer from start to finish of the GNSS-RTN system. All of the RTN components can be done, from installation to network adjustment, from design to management. Leica operates their own GNSS-RTN network and provides a total solution inside of SmartNET. SmartNET is a global network of Leica, including CORSs across the United States, which provides real-time location services. The coverage of SmartNET in the United States is shown in **Figure 22**. Furthermore, the respondent reported three major options for developing, operating, and managing the GNSS-RTN system which is discussed in the following sections.

Option - I

Leica provides hardware for CORSs and software for the central facility and the state agency is responsible for all charges. The agency is responsible for the installation of COR infrastructure and operating the facility. Regarding the central facility, the interviewee reported that blade servers can be set up to deploy an in-house central facility processing system or host it on cloud-based servers such as Azure environment or Hyland cloud. Hosting the system on Azure/Hyland would discharge the agency from upgrading the servers every two years and the maintenance cost of servers, etc. He suggested that approximately 6 servers and 4 CPUs would be needed for 120 CORSs.

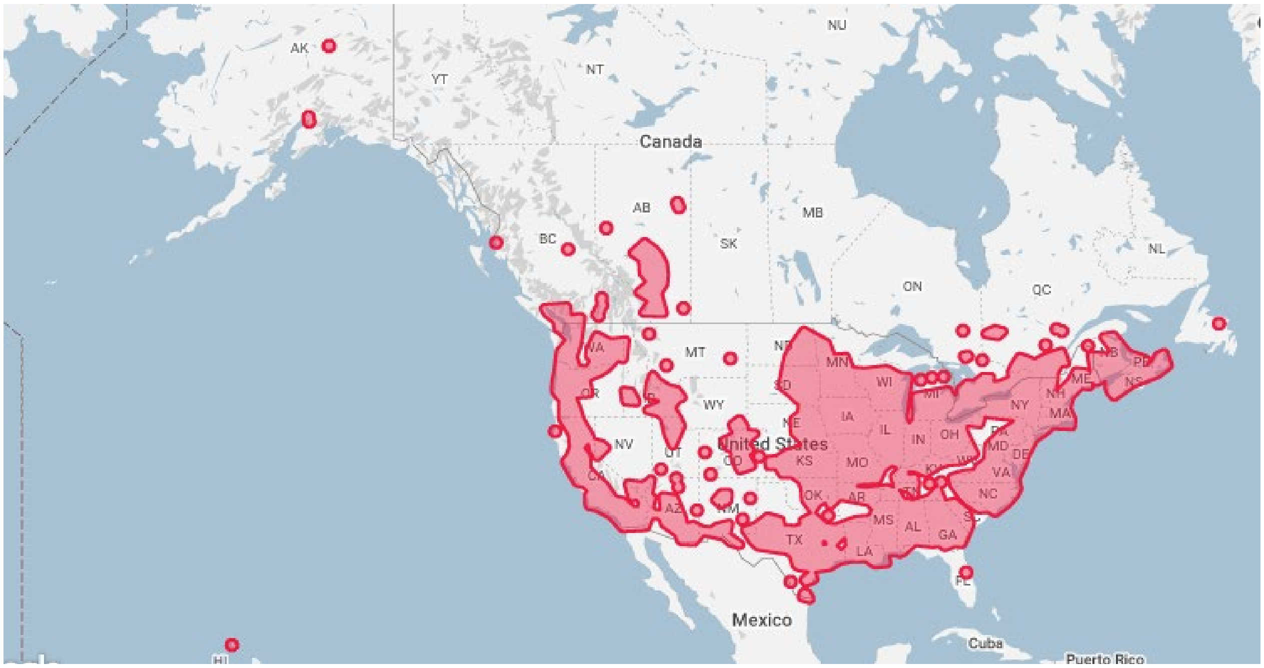


Figure 22. SmartNet Network Coverage in the U.S. (Courtesy of Smartnetna.com)

The cost of cloud-based servers for the GNSS-RTN system would be approximately $32,000 per year. If the agency wants to set up in-house servers, the server's life would be 2-3 years and would cost the agency approximately $30,000 to $40,000 every 2-3 years. The respondent reported that the cloud-based servers are very reliable and secure and have a fast backup service, in case, data servers crash. Whereas the inhouse servers may take up to a week on the backup process after a server crash. When asked about the software for the central facility, the Leica representative reported that Spider is a modular and scalable solution offered by Leica that can be upgraded anytime for additional sites (stations) inclusion and functionality. The respondent reported that the cost of Spider depends on the features required by the customer.

The respondent also tried to estimate an approximate cost for developing a GNSS- RTN system in Montana comprising 120 CORSs. In the estimation process, the following assumptions/selections were made:

- The AR10 GNSS Antenna (cost $2750.00) was selected including a longer antenna cable,
- Ability to use the different GNSS constellations GPS, Baidu, Galileo, and GLONASS,

- The functionality of monitoring the positions of CORSs at any moment over time,
- The functionality of billing the contractors and private users and performing analytics,
- The functionality to allow download of RINEX data for post-processing,
- The functionality to locate users of the GNSS-RTN system on a map when they are connected to the network,
- Communication between CORSs and the central facility is mainly based on the internet, but it would include an option of cellular from two networks to fall back on the cellular if internet access stops working,
- Costs of ground mounts or building mounts are included.

Using the above assumptions and functionalities, the total cost of a GNSS-RTN system including CORS, central processing center, software, etc. was estimated at around \$5 million. Leica representative reported that if the project goes for competitive bidding, the price may drop to half of the approximate cost. He mentioned that they usually offer significant discounts on the list price during the bidding process and this may bring the cost down to around \$2.6 million for the GNSS-RTN system. This cost includes the price of hardware for CORSs, software for the central facility, mounts (ground monument of 8 ft tall), cables, first-year regular maintenance, and network adjustments. The system would be operated by the agency. The annual maintenance (checkup of the hardware) includes visiting every CORS site, checking every cable connection, power supply, ethernet connection, among other services. The annual maintenance cost is approximately 20% of the total cost of hardware of CORSs. The cost of installation of CORSs (construction cost) and the cost of servers are not included in this total cost estimate.

In the case of adopting option-I (i.e., in-house GNSS-RTN system development), the agency would be able to provide free access to other public agencies and can sell subscriptions to private users. They can manage this through “Spider Business Center”, a software toolbox by Leica. The cost of it depends on the number of stations in the network and software functionalities the agency needs such as a function of billing the end-users for subscriptions, and data analytics of private user’s utilization. Furthermore, there is an inherent additional cost that one needs to take into consideration when the agency manages the GNSS-RTN network in-house. The network can have issues, a station can be down anytime, and other similar problems. To fix such randomly occurring problems in the network, at least two staff members are required to carry out the routine operations.

Option - II

In option-II, the agency establishes the complete GNSS-RTN system and Leica host the software and system on their own infrastructure. However, the agency staff operates and manages the system online through Leica system infrastructure. The CORSs of such GNSS-RTN system are only part of that specific network and not connected or incorporated into Leica's private network (i.e., SmartNET Live). Leica would not have any access to the network either. This would be based on a term of 3 years contract and quarterly/annual payment of an operational fee to Leica. The approximate annual operational cost to pay to Leica would be around $1.2 million. This price can fluctuate based on what Leica would provide and what the agency would be responsible for. Moreover, if the agency wants to manage and operate the GNSS-RTN system in-house on their own infrastructure, Leica can offer support and service contract that helps in managing and maintaining the network, in addition to the annual maintenance.

Option - III

In this option, Leica would plan and design the network and system requirements for the agency to establish a GNSS-RTN CORS network. After establishing the statewide GNSS-RTN CORS network, Leica would incorporate and host the proposed Montana CORS network in the SmartNet North America network based on 3 years contract. The renewal/continuation of the contract after three years depends on the choice of the agency. The agency would pay for the communication service and the annual maintenance cost of CORSs. Leica would take care of all the operations and maintenance of the system including the network adjustments, maintaining all the hardware and software of the central facility, and operating the network. In response to the network establishment, the agency would receive free full access to real-time data, and access to RINEX data for post-processing. The annual subscription charges to SmartNet Live North America are $2,500. Leica would set up an enterprise license for a number of employees of the agency. The number of free subscriptions depends on the type of use such as an agency surveying crew usage of the network, private contractors who are working for the agency, etc. However, the agency would be responsible for the block of 100-200 licenses and keep track of who is using this license.

When asked about the number of free subscriptions/licenses provided to the agency, the respondent replied that it is, usually, one free license per one CORS, but it can be discussed and negotiated in the contract. He also mentioned that the private users would need to buy subscriptions from Leica to access the network.

3.2.2.2 Current and Past Clients

To gain information on Leica's expertise and market share in the GNSS-RTN industry, the representative was asked about clients of the company. The respondent reported that Leica has established several statewide GNSS-RTN systems such as networks owned by Oklahoma DOT, New York DOT, Iowa DOT, and Michigan DOT. Regarding operation and contracts with the owner of the GNSS-RTN system, he mentioned that Iowa DOT purchased the hardware and established the statewide network; however, Leica managed and operated the network based on 5-year contract. The contract was continued for two consecutive terms. The 11th year Iowa DOT decided that they would manage and operate the statewide GNSS-RTN system in-house; however, they purchased a yearly-based maintenance service plan. In the following years, they signed a contract of support and services for various options with Leica. Further, he mentioned that another entity purchased all the hardware and software from Leica to establish the statewide network of CORSs, but made a contract with Leica to host the software of the GNSS-RTN system. In addition, one entity purchased all the hardware and software but had a contract of support and services with Leica to help the entity in managing and maintaining the network.

4. EXISTING INFRASTRUCTURE

This chapter aims to document all existing infrastructure used in providing GNSS-RTN geospatial location service in the state of Montana. Such documentation is deemed important as the existing infrastructure has the potential and is expected to contribute to the future Montana statewide GNSS-RTN system.

This chapter presents the current status of the CORSs infrastructure in Montana and provides much relevant information about those stations such as the current hosting arrangements, public and private networks that receive and correct data from CORSs, and station ownership, among other characteristics. Further, out-of-state CORSs currently used to improve location precision in areas near state boundaries are also discussed in this chapter.

4.1 MONTANA CORS INFRASTRUCTURE

This chapter identified a total of 69 CORSs within the geographic boundaries of the state of Montana. The stations vary in ownership, networks they contribute to, sampling rate, power source, and means of communication. **Figure 23** shows a map with Montana CORS locations. Further, location coordinates along with the mounting type for all CORSs in Montana are provided in **APPENDIX D** (53).

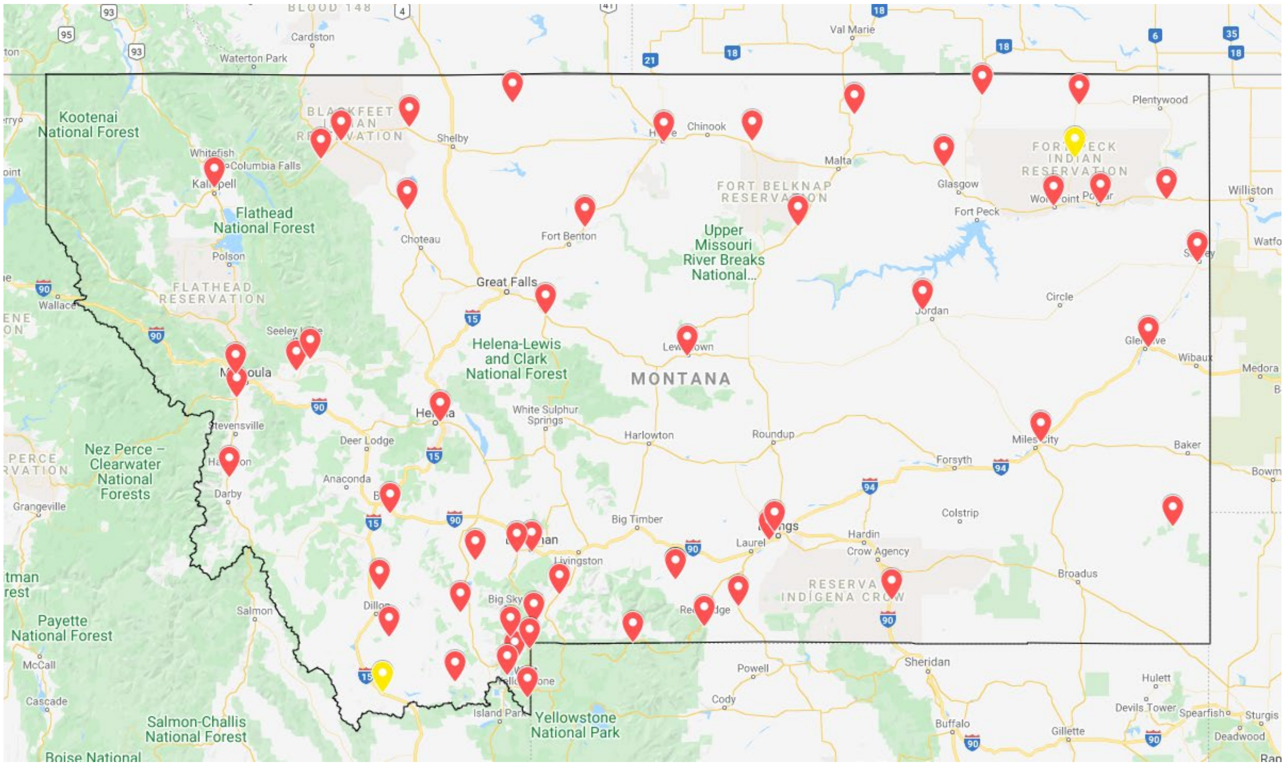


Figure 23. CORSs in the State of Montana

4.1.1 Montana CORSs by Network

Montana CORSs are part of different networks, both public and private, providing GNSS location services in Montana. Stations are not limited to being a part of a single network, as many CORSs contribute to multiple networks. Maps of the major GNSS networks along with a list of the contributing CORSs for each respective network are provided in **APPENDIX E**.

The Montana State Reference Network (MTSRN) is a Pilot network currently hosted by the Washington State Reference Network (WSRN). The MTSRN is the largest public network in Montana; currently consisting of 54 CORSs covering different parts of the state – other 7 CORS are to be added to the network in the spring of 2022. All the raw geospatial data collected by the CORSs in the MTSRN are sent to the WSRN central processing facility, where the data is corrected and sent back to the MTSRN users. The users of this public network have access to static files of any station in the network as well as real-time correction services (37).

The post-processed data or static files are available for any user to download at no expense. Real-time kinematics (RTK) corrected data, both single base and network, are available for authorized users and possible partners interested in joining the network. Authorized users have access to RTK single base corrections from any station in the network and to RTK network corrections for areas in which subnetworks are present, such as the Fort Peck and Blackfeet areas. Other public networks include the National Oceanic and Atmospheric Administration (NOAA) Continuously Operating Reference Stations (CORSs) Network (NCN), hosted by the NOAA/National Geodetic Survey (NGS) (54). Currently, NGS manages data from around 1900 CORSs located within the US and the UNAVCO network, provided by the Geodetic Facility for the Advancement of Geosciences (GAGE). Funded by the National Science Foundation and NASA, The UNAVCO network currently manages thousands of stations both within and outside the US (55). Post-processed data corrections are available for users of the NCN and the UNAVCO networks. Users of the latter network also have access to real-time GNSS data corrections.

Besides the public networks discussed above, private networks are also used to provide GNSS location services in Montana. Specifically, TopNet Live (56), SmartNet North America (57), and Trimble VRS network (58) are the major private networks providing location services in Montana. These networks are hosted by the manufacturers TopCon, Leica, and Trimble, respectively. The network provided by Trimble is the largest private network in Montana with a total of 47 CORSs (59). The services provided by these networks are subscription-based and network users usually have access to post-processed as well as real-time GNSS data corrections. **Table 5** includes all CORSs in Montana and the major networks they contribute to, namely: MTSRN, NGS, UNAVCO (60), and Trimble. For the TopCon Live and SmartNet North America, no information was available on Montana CORSs that are part of these networks, and therefore these networks were not included in **Table 5**. Further, **Table 5** also includes five stations in the MTSRN network that are located outside Montana (North Dakota, Wyoming, and Idaho) but contribute to the MTSRN network; and seven stations that will be added in the MTSRN in the spring of 2022.

4.1.2 Montana CORSs by Ownership

Currently, 57 CORSs are publicly owned in Montana, which constitute most CORSs in the state. For the vast majority of stations, the location was determined using accurate location coordinates. However, for a couple of stations, the location coordinates were not available and therefore the map location for those stations was estimated (shown in yellow in **Figure 23**). **Table 5** shows the names and ownership types (public or private) for Montana CORSs.

4.1.3 Montana CORSs by Sampling Rate

The sampling rate is another property that indicates the frequency with which the receiver is collecting data. Currently, most of the CORSs in Montana provide a sampling rate of 15 seconds or less; with a considerable number of stations providing a sampling rate of 1 second. **Table 6** lists the CORSs in Montana providing location name and sampling rate in seconds. Out of the 49 CORSs with known sampling rates in this table, 27 operate with a sampling rate of one second, 20 with a sampling rate of 15 seconds, and one station each with a sampling rate of 5 seconds and 30 seconds.

Figure 24 shows a map of Montana CORSs with known sampling rates. The CORSs are marked in light green, light blue, yellow, and orange for sampling rates of 1 second, 5 seconds, 15 seconds, and 30 seconds respectively.

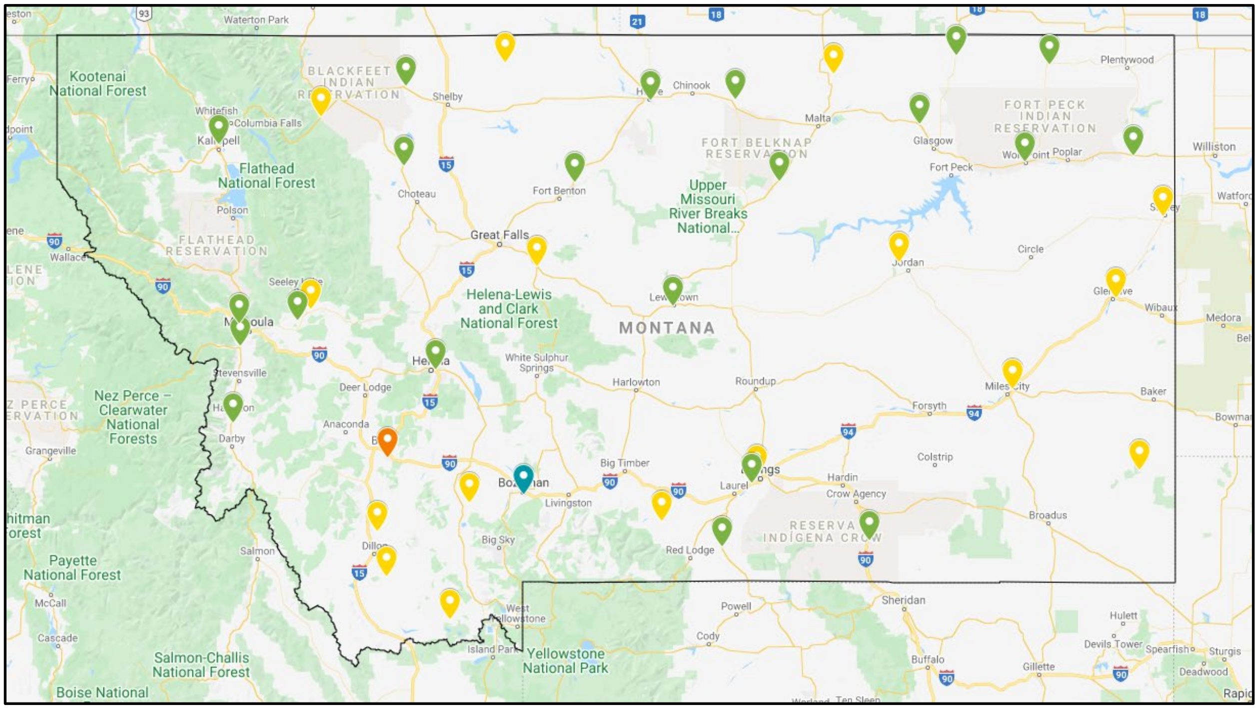


Figure 24. Montana CORSs with Known Sampling Rate

Table 5. CORSs by Network Affiliation

Station	Location	Network				Station	Location	Network			
		MTSRN	NGS	UNAVCO	Trimble			MTSRN	NGS	UNAVCO	Trimble
HAML	Hamilton, MT	•	•		•	**P046**	Clearwater Junct., MT	•	•	•	•
LOLO	Lolo, MT	•	•		•	**P047**	East Glacier, MT	•	•	•	•
MSOL	Missoula Airport, MT	•	•			**P048**	Four Corners, MT	•		•	•
MTBR	Bridger, MT	•	•		•	**P049**	Armington Junct., MT	•	•	•	•
MTCB	Culbertson, MT	•	•		•	**P050**	Sweat Grass Hills, MT	•	•	•	•
MTCU	Cut Bank, MT	•	•		•	**P051**	Billings Airport, MT	•	•	•	•
MTDT	Helena, MT	•	•		•	**P052**	Jordan, MT	•	•	•	•
MTEI	Billings, MT	•	•			**P053**	Whitewater, MT	•	•	•	•
MTFV	Flathead Valley CC, MT	•	•		•	**P054**	Ekalaka, MT		•	•	•
MTGW	Glasgow, MT	•	•		•	**P055**	Glendive, MT	•	•	•	•
MTHC	Butte, MT	•	•		•	**P456**	W. Yellowstone, MT			•	•
MTHM	Harlem, MT	•	•		•	**p457**	Big Sky, MT			•	•
MTLG	Lodge Grass, MT	•	•		•	**P458**	W. Yellowstone, MT			•	•
MTLO	Loma, MT	•	•		•	**P460**	Big Sky, MT	•		•	•
MTLW	Lewistown, MT	•	•		•	**P461**	Merriman, MT	•		•	•
MTMS	MSU N. Havre, MT	•	•		•	**P680**	W. Yellowstone, MT			•	•
MTOP	Opheim, MT	•	•		•	**P706**	Dillon, MT	•	•	•	•
MTPJ	Pendroy Junct., MT	•	•		•	**P707**	Red Rock Lakes, MT		•	•	•
MTRC	Sidney, MT	•	•		•	**P712**	W. Yellowstone, MT			•	•
MTSU	MSU Bozeman, MT	•	•			**P714**	Gardiner, MT			•	•

Private stations are underlined

Table 5. CORSs by Network Affiliation - Continued

Station	Location	Network				Station	Location	Network			
		MTSRN	NGS	UNAVCO	Trimble			MTSRN	NGS	UNAVCO	Trimble
MTSY	Scobey, MT	•	•		•	**P719**	Ennis, MT	•		•	•
MTUM	Sunset, MT	•	•			**P721**	Silver Gate, MT			•	•
MTWP	Wolf Point, MT	•	•		•	**P722**	Fishtail, MT		•	•	•
MTZM	Zoteman, MT	•	•		•	**P818**	Fishtail, MT			•	•
MTMI	Miles City, MT		•		•	**P819**	Fishtail, MT			•	•
NOMT	Norris, MT	•	•	•	•	**MAWY**	Mammoth, WY	•		•	
BKFB	Browning, MT	•				**RYA1**	East Hope, ID	•			
FTPP	Popular, MT	•				**NDGR**	Grenora, ND	•			
MTPO	Fort Peck RES., MT	•				**P024**	Sunset Peak, ID	•		•	
YBRA	Red lodge, MT			•		**P025**	Bonners Ferry, ID	•		•	
BUEH	Lima, MT			•		***STMY***	*St. Mary, MT*	•			
LCLN	Lincoln, MT	•				***CSCD***	*Cascade, MT*	•			
TWSD	Townsend, MT	•				***DUTN***	*Dutton, MT*	•			
DRLG	Deer Lodge, MT	•				***LBBY***	*Libby, MT*	•			
WTHL	Whitehall, MT	•				***PLSN***	*Polson, MT*	•			
EUKA	Eureka, MT	•				***SUPR***	*Superior, MT*	•			
P045	Dillon, MT	•	•	•	•	***BTMR***	*Big Timber, MT*	•			

Private stations are underlined
Stations to be added are presented in italic

4.1.4 Montana CORSs by Communication Type

The communication between CORSs and the central processing facility is often achieved using either the internet or mobile cellular networks depending on availability and cost in different areas of the state. This information is unavailable for many Montana CORSs and is only known for part of the MTSRN network stations. Specifically, this information is available for 28 out of the 54 CORSs comprising the MTSRN network. For the 28 CORSs with known communication type, 15 CORSs (around 54%) use mobile cellular networks while the remaining 13 CORSs use the internet as a means of communication with the central processing facility. **Figure 25** shows the breakdown of the MTSRN CORSs by communication type for stations with available information.

Table 6. Montana CORSs with Respective Sampling Rate

Station	Location	Sampling Rate	Station	Location	Sampling Rate
HAML	Hamilton, MT	1 sec	**P046**	Clearwater Junct., MT	15 sec
LOLO	Lolo, MT	1 sec	**P047**	East Glacier, MT	15 sec
MSOL	Missoula Airport, MT	1 sec	**P048**	Four Corners, MT	--
MTBR	Bridger, MT	1 sec	**P049**	Armington Junct., MT	15 sec
MTCB	Culbertson, MT	1 sec	**P050**	Sweat Grass Hills, MT	15 sec
MTCU	Cut Bank, MT	1 sec	**P051**	Billings Airport, MT	15 sec
MTDT	Helena, MT	1 sec	**P052**	Jordan, MT	15 sec
MTEI	Billings, MT	1 sec	**P053**	Whitewater, MT	15 sec
MTFV	Flathead Valley CC, MT	1 sec	**P054**	Ekalaka, MT	15 sec
MTGW	Glasgow, MT	1 sec	**P055**	Glendive, MT	15 sec
MTHC	Butte, MT	30 sec	**P456**	W. Yellowstone, MT	15 sec
MTHM	Harlem, MT	1 sec	**p457**	Big Sky, MT	--
MTLG	Lodge Grass, MT	1 sec	**P458**	W. Yellowstone, MT	15 sec
MTLO	Loma, MT	1 sec	**P460**	Big Sky, MT	--
MTLW	Lewistown, MT	1 sec	**P461**	Merriman, MT	--
MTMS	MSU N. Havre, MT	1 sec	**P680**	W. Yellowstone, MT	15 sec
MTOP	Opheim, MT	1 sec	**P706**	Dillon, MT	15 sec
MTPJ	Pendroy Junct., MT	1 sec	**P707**	Red Rock Lakes, MT	15 sec
MTRC	Sidney, MT	15 sec	**P712**	W. Yellowstone, MT	--
MTSU	MSU Bozeman, MT	5 sec	**P714**	Gardiner, MT	--
MTSY	Scobey, MT	1 sec	**P719**	Ennis, MT	--
MTUM	Sunset, MT	1 sec	**P721**	Silver Gate, MT	--
MTWP	Wolf Point, MT	1 sec	**P722**	Fishtail, MT	15 sec
MTZM	Zoteman, MT	1 sec	**P818**	Fishtail, MT	--
MTMI	Miles City, MT	15 sec	**P819**	Fishtail, MT	--
NOMT	Norris, MT	1 sec	**MAWY**	Mammoth, WY	--
BKFB	Browning, MT	--	**RYA1**	East Hope, ID	--
FTPP	Popular, MT	--	**NDGR**	Grenora, ND	--
MTPO	Fort Peck RES., MT	--	**P024**	Sunset Peak, ID	--
YBRA	Red lodge, MT	15 sec	**P025**	Bonners Ferry, ID	--
BUEH	Lima, MT	15 sec	***STMY***	*St. Mary, MT*	1 sec
LCLN	Lincoln, MT	1 sec	***CSCD***	*Cascade, MT*	1 sec
TWSD	Townsend, MT	1 sec	***DUTN***	*Dutton, MT*	1 sec
DRLG	Deer Lodge, MT	1 sec	***LBBY***	*Libby, MT*	1 sec
WTHL	Whitehall, MT	1 sec	***PLSN***	*Polson, MT*	1 sec
EUKA	Eureka, MT	1 sec	***SUPR***	*Superior, MT*	1 sec
P045	Dillon, MT	15 sec	***BTMR***	*Big Timber, MT*	1 sec

"--" Information unavailable

Stations to be added are presented in italic

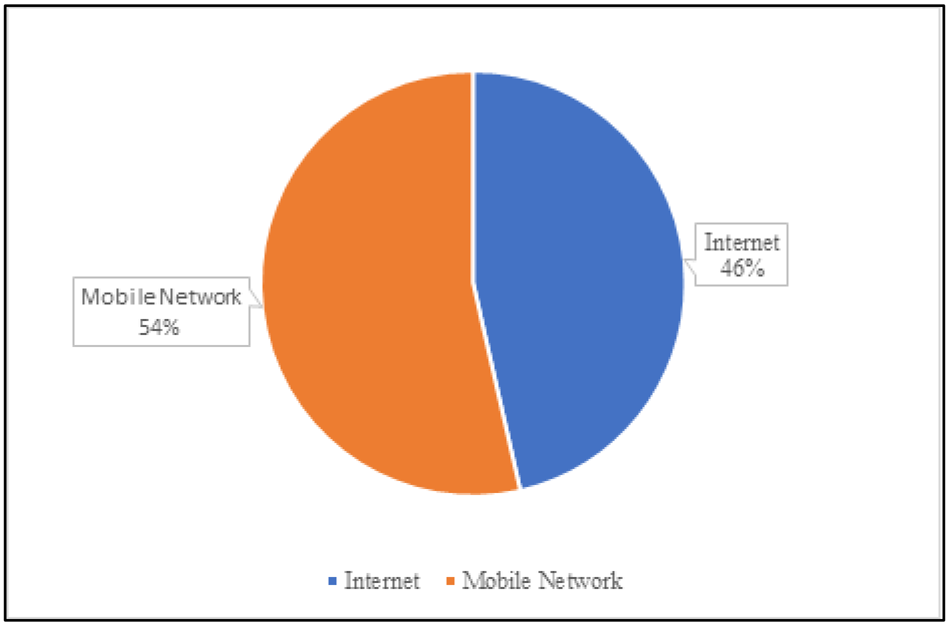


Figure 25. Type of Communication for Stations with Known Information in the MTSRN

4.2 SUMMARY

This chapter discussed the current CORSs infrastructure in the state of Montana. This infrastructure is very important for planning the future statewide GNSS-RTN system in the state. Specifically, many of the existing CORSs have the potential of being incorporated in the statewide RTN network thus reducing the capital investment required for establishing the system. Overall, this chapter identified a total of 69 CORSs in Montana owned by both public and private entities. This chapter discussed the different RTN networks, both public and private, that Montana CORSs contribute to. Further, this chapter also summarized other important aspects of CORS operation such as CORS ownership, sampling rate, and type of communication.

5. IDENTIFY AND CATALOG VIABLE BUSINESS MODELS FOR STATEWIDE GNSS-RTN

This chapter aims at cataloging business models that are used in the current domestic or international practice for providing GNSS-RTN geospatial location, and providing an overview of the merits and demerits of the different business models. The chapter is organized into three parts. The first part provides an overview of the most important business models that were identified in the literature review, the practice survey, or the manufacturers' interviews discussed in chapters 2 and 3 of this report. The second part of the chapter discusses in more detail the conceptual elements of any business model, i.e., system ownership, costs, and user access charges. The last part of the chapter provides a high-level assessment of the various business models identified in this task.

5.1 EXISTING GNSS-RTN BUSINESS MODELS

This section summarizes the most important business models identified in previous project tasks, specifically the literature review and the practice screening. The models are numbered in sequence without necessarily following a specific order.

5.1.1 Business Model 1

In this model, the state owns the GNSS-RTN system and is responsible for all the costs associated with building and operating the system. In a survey conducted by the California Department of Transportation (Caltrans), it was reported that the Minnesota GNSS-RTIN network follows this business model (61). Specifically, the Minnesota Continuously Operating Reference Station (CORS) Network (MnCORS) is primarily composed CORSs and a Central Processing Center (CPC) that are owned and operated by the state DOT. However, several stations that are part of the network in Wisconsin and Iowa are owned by private companies or counties in neighboring states. At the time of the study, the users of the network had free access to all products provided by the MnCORS network.

The main advantage of this business model is that the state has full control over the system (the state has almost full ownership of the system). However, the state is responsible for all costs associated with building, operating, and maintaining the system. This model has the potential to improve user engagement by providing end users with free access to all data and system products. The study conducted by Caltrans and published in 2015 estimated this model to have a total annual cost equivalent to roughly $580,000, and an annual benefit equivalent to roughly $38.5M (61).

5.1.2 Business Model 2

In this model, the state owns the CPC facility and part of the CORSs within the state while other CORSs are owned by other state partners including private entities. Operation and maintenance costs are borne by the owners of system components, i.e., the state is responsible for operating and maintaining the CPC and state-owned CORSs, while other partners are responsible for maintaining their CORSs. In a study conducted by Caltrans (61), it was reported that the GNSS-RTN system in the state of Oregon follows this model. Specifically, the study reported that the Oregon Real-Time GPS Network (ORGN) is operated and controlled by the Oregon DOT's Geometronics Unit. Around 30% of CORSs in this network are owned and maintained by the agency while the remaining 70% CORSs are owned and maintained by ORGN partners. The state DOT monitors all stations and notifies ORGN partners when their stations malfunction or go down. ORGN partners are responsible for the maintenance of their CORSs while the state DOT is responsible for the state-owned CORSs and the CPC's operation and maintenance costs. At the time of the study, the users of the network had free access to all products provided by the system.

In this model, the state still owns the majority of the infrastructure for the network, i.e., the CPC and a part of the CORSs network, which allows the state to have good control over the network. This model involves a public-private partnership in which private entities own, operate, and maintain the remaining CORSs needed to complete the statewide network. The public-private partnership requires agreements in place between the state agency and all other system partners. Similar to the first model, this model provides access to all system users free of charge, which can potentially increase the number of end users.

5.1.3 Business Model 3

This business model shares a great deal of similarity with business model 2 except that the public agency which owns and operates the CPC does not necessarily own any notable portion of the CORSs network. In the same study conducted by Caltrans (61), it was found that the GNSS-RTN system in the state of Washington follows this model. The state CORS network, called the Washington State Reference Network (WSRN), is owned by a cooperative of more than 80 partners (cities, counties, utilities, state agencies, and private partners). The Seattle Public Utilities (SPU), one of the partners in the cooperative, owns the CPC and is responsible for its operation and maintenance costs. Operation and Maintenance costs for each CORS are the responsibility of that station's owner. The WSRN provides free real-time services to partners in the cooperative, while other users have access to real-time services for a subscription fee.

This business model proposes a network that is owned and operated by a cooperative. Although public agencies are some of the partners of the cooperative, the network is controlled by all partners, not only the state. In this model, an entity can be a partner of the cooperative by providing, operating, and maintaining one or more CORSs. Similar to the previous two models, a state agency is responsible for addressing any technology-related cost of the network and to implement, operate, and maintain the CPC. This model also requires agreements between all partners of the network and the operating agency. The strategy used to deliver data in this model differs from the first two models by requiring an annual subscription fee to all non-partner end users. The revenues generated by the paid subscriptions are used to cover some of the operating costs of the network. The level of control the state has over the system is still reasonable (but less than the previous two models) given that a state agency is operating and maintaining the CPC.

5.1.4 Business Model 4

In this business model, the state agency has full ownership of the system, i.e., the CORSs network and the CPC, however, the system is operated using a private company/corporate. All costs associated with operating and maintaining the system are the responsibility of the state agency. This was one of the business models proposed by GNSS-RTN manufacturers/vendors to the state of Iowa as part of planning the statewide GNSS-RTN system (62). Specifically, Iowa DOT required that the CORSs and the CPC facility are owned by the state but managed by a private vendor. Operation and maintenance costs for CORSs and the CPC are paid by the state. The state DOT also requested that all users have access to the system services and products free of charge. This model is very similar to business model 1, except that the state would use a private vendor for operating and maintaining the system.

Similar to business model 1, this model involves a considerable initial and annual costs borne by the state. As the system is completely owned by the state, the state maintains a high level of control over the system. Contracts and/or agreements between the vendor and the state agency are required. User engagement is estimated to be high with this model, as users have access to system products free of charge.

5.1.5 Business Model 5

The University of New South Wales, Australia, and Leica Geosystems worked together in the analysis of GNSS-RTK network business models. One of the models examined in the study recognized the existence of 90 CORSs that were owned by public entities and suggested that Leica would install 40 more CORSs (63). In this business model, the CPC is owned and operated by the vendor. The study suggested a partnership between public and private entities to address the operation and maintenance costs of the CORSs. All costs related to the CPC are the responsibility of the vendor. This model also considers a subscription fee as a source of revenue to the vendor.

Rizos (63) reported that the model was adopted by the U.K.'s Ordnance Survey, who have licensed the CORS data to Leica Geosystems and Trimble. Leica has undertaken to install more than 40 additional GNSS CORS receivers.

This model suggests a strong public-private partnership with a vendor, in which the vendor installs all remaining CORSs needed to complete the network and utilizes its own CPC to process and deliver location data to end users. In this model, it's the vendor's responsibility to cover all costs the CPC and vendor-owned CORSs may require, leaving only operating and maintenance costs of other CORSs as the responsibility of the state. In another effort to lower state costs, a partnership with private entities was proposed to help cover costs to operate and maintain the CORSs. In this system, data is delivered to the end user for an annual subscription fee. The revenues generated from subscription fees are used to help support the operation and maintenance costs of the CORSs. While this dynamic requires negligible initial investment and annual costs by the state, it also provides the state with lower control over the network.

5.1.6 Business Model 6

This business model is based on public-private partnership and was discussed as part of the interviews with the technology vendors/manufacturers' representatives conducted in Task 3 of this project (model discussed with both Leica and TopCon representatives) (64). In this model, the state would establish the CORSs network (alone or with partners) while the private vendor would host and manage the network using their infrastructure. The state network in this model would contribute to the private vendor network, and in return, the vendor would provide the state agency with access to the network data and services in the form of an agreed-upon number of network subscriptions. The agency in this model has the freedom to use those subscriptions in any way they see fit including selling some subscriptions to private users. One variation of this model is for the state to control access to the network by purchasing additional subscriptions at discounted prices and selling those to "other" users usually at the higher market price (as proposed by the TopCon representative).

The main advantage of this business model is the use of a CPC that is owned, operated, and maintained by a private vendor, to host the network. This will remove a significant proportion of the initial and running costs that would otherwise be borne by the state agency if the system was completely owned and operated by the state. However, this requires that the state enters into an agreement with owners of existing CORSs and may have to provide incentives in the process (e.g., state to pay power and communication costs). The remaining CORSs needed to complete the network are to be implemented by the state. While this model significantly reduces the amount of state investment in the GNSS-RTN system, it provides the state with a lower level of control over the system (compared to model 1 for example). Another advantage of this business model is that technology upgrades and changes can be incorporated on time by the vendor compared to when the state agency is in charge of incorporating these upgrades using state funds.

5.1.7 Business Model 7

This business model is also based on a public-private partnership that was discussed during the interviews with technology vendors' representatives (64). In this model, the state would establish the CORSs network (alone or with partners) and will be responsible for the costs of operating and maintaining the network. The vendor would host and manage the network using their infrastructure but with full state control on operating the statewide network. The state network in this model will not be incorporated/added to the vendor's private network, and the vendor has no access to the state network. The state will pay the vendor annual fees for hosting and managing the network using a fixed-term agreement. The state is free to decide who can access the network and can impose fees for different products and user types within the state.

This business model shares many similarities with the previous model in regard to the ownership of the CORSs network and the network hosting infrastructure. The CORSs needed to complete the network are implemented, operated, and maintained by the state (alone or with partners), and the vendor uses its infrastructure to host the network. In this business model, the vendor has no authority over the network, it simply provides the CPC hosting and management services for an annual fee, allowing the state to hold full control over the network, its products, and users' fees. The operating costs of the system including network hosting costs, which is borne by the state, could be significant.

5.1.8 Business Model 8

In this business model, a technology vendor would establish, operate and maintain the CORSs network and provide hosting and management services through their own networks. The vendor would develop and use a business model for marketing the RTK services to end users including public and private entities. In this model, the system is 100 percent owned by the vendor and the state plays no role in establishing, operating and maintaining the system. A variation of this model is to have a consortium of private companies as the owners and operators of the GNSS-RTN system instead of a single technology owner such as the CORS-RTK network across the whole of France (63).

The main advantage of this model is the lower financial responsibility for the state. Like other end users, state agencies would need to purchase subscriptions to satisfy their RTN data needs. However, this model provides no control to the state over the system, which may not serve the best interests of the state (e.g., inconsistent or incomplete geographic coverage of the state).

5.2 BUSINESS MODELS: CONCEPTUAL ELEMENTS

Any business model for establishing and operating a GNSS-RTN system should address three major elements: infrastructure ownership, costs, and user access charges. This section discusses with some detail each of these conceptual elements.

5.2.1 Infrastructure Ownership

The ownership of the GNSS-RTN infrastructure largely determines the level of control a state has over the statewide GNSS-RTN system. The earlier section in this document presented business models in which the ownership combination of system components varies among state, partners, and vendors, so does the level of control the state has in each of the models.

The GNSS-RTN system infrastructure can be broken down into three main components: The CORSs, the CPC, and the supporting components primarily power and communications. For a better understanding, each infrastructure component is discussed independently in the following sections.

i. CORSs

A CORS primarily consist of hardware and the physical structure supporting the hardware. The hardware of each CORS is composed of a GNSS receiver along with an antenna to obtain high precision coordinates. Receivers and antennas are offered in a variety of types (different specifications) by most manufacturers such as Leica, Trimble, and TopCon.

The GNSS receivers available in the market today come in different types depending on receiver properties such as available storage memory, file size, life expectancy for a given sampling rate, and power-related features. The UNAVCO website provides a summary of receiver types that they consider reliable, and properties for each receiver type are also listed on the platform (65).

Antennas also come in different types and costs depending on features and specifications. The different antennas require different calibration methods. Some of the methods follow the guidelines set by the National Geodetic Survey (NGS). The stations for which the antennas are calibrated with the methods that comply with the NGS guidelines are prone to be integrated with the NOAA CORS Network (66). Similar to receivers, UNAVCO summarized all antennas that they consider reliable and provided the calibration method that applies to each of the antennas listed (65).

Each CORS needs a physical structure to ensure hardware support at a fixed location. This physical structure (a.k.a. monument) can generally be of two types, building mounts and ground mounts. Within these two categories, there are a number of different sub-types that have been designed to address specific site characteristics (67). Building mounts involve installing the CORS hardware on an existing building using a mounting mechanism. Ground mounts, on the other hand, involves building a physical post on the ground to support CORS hardware. The NGS set forth a set of guidelines for new and existing CORSs in the NOAA CORS Network (NCN). The NGS guidelines are based on monument designs used by the International GNSS Service (IGS), the objective of the NGS guidelines is to avoid monument designs that can negatively affect data precision (68).

ii. CPC

The central processing center is a major component of any GNSS-RTN system and its design is vital to the success of the RTN operation, i.e. to fully utilize and manage the entire infrastructure, and deliver services reliably in real-time (67).

The CPC hardware primarily consists of computers and data servers. The hardware needs to be capable of processing and storing data from all stations in the network, thus the required number of data servers is dependent on the number of stations included in the network. Much like the CORSs, the CPC also needs a physical structure to host the hardware, more specifically a building. All data collected at the stations is sent to the CPC wirelessly, which allows the location of the CPC building to be anywhere. A mirror of the CPC is highly recommended by the NGS (optional). Often for the cost of a few extra servers, the RTN can be mirrored at another physical location to ensure continued service should there be failures of a primary CPC or be utilized for load balancing and archiving redundancy strategies as well (67). Both sites can easily be maintained by the same staff remotely and there are strategies for synchronization of settings.

The other major component of a CPC is the software suite used for processing the data received from CORSs in real time. The software suite offered by technology vendors notably varies in capabilities, functionalities, and costs. To comply with the worldwide file format standard, the software used in the CPC to process all data from CORSs in real time should be able to convert the data into a Receiver Independent Exchange Format (RINEX) (69).

iii. Supporting Components

The CPC and CORSs do not compose a network on their own, other elements are needed for the RTN to function properly. Constant and reliable connectivity between the CORSs and the CPC is needed for the network to ensure optimum functionality. It was found in the survey conducted in Task 3 that the majority of GNSS networks across the country use internet or mobile networks to provide communication between the CORSs and the CPC (4). A radio-based communication can be useful for stations located in areas with low internet and mobile coverage. The NGS guidelines for CORSs consider radio-based communication but notes possible signal interference from other radio frequency sources (67). Receivers should be supplied with continuous power via a reliable source. The national electric grid is the most common source of power for the CORS receiver. However, solar panels, regulators and lead acid batteries are a viable alternative for uninterrupted power in remote locations (67).

5.2.2 Costs

This section provides an overview of the costs associated with establishing and operating a GNSS-RTN system. Both initial and running costs will be discussed under each system component.

i. CORSs

The initial costs involved in building a CORS include the cost of the hardware (receiver and antenna) and the cost of the physical structure and the mounting mechanism. The cost of a single CORS varies widely depending on hardware specifications and whether the hardware is building mounted or ground mounted. The running costs for operating a CORS include costs for communication, power, and regular maintenance for the hardware and structure.

ii. CPC

The initial costs of a CPC include the costs of the computers and servers, the cost of the software suite to process the GNSS network data, and the cost for the furnished physical building where the CPC is located (space owned or leased by the system operator). The running costs for the CPC primarily include the needed staff to manage/administer the network, regular software updates and license fees, upgrades and regular maintenance required for computers and servers. In the case of hosting all data on cloud servers, usage fees/charges will be part of the running CPC costs.

iii. Supporting Elements

The costs associated with supporting elements primarily involve the running costs associated with providing power to the CORSs and communication between the CORSs and the CPC.

5.2.3 User Access Charges

The GNSS-RTN location data has applications in many fields, which explains the diversity of potential system users, i.e., public agencies, private entities, and individuals. In the previous chapters, it became clear that system access privileges are handled in three different ways:

i. Systems that allow all end users, public and private, to access the system data and products free of charge.

ii. Systems that allow public agencies to access the system free of charge while requiring usage fees (often in the form of subscription fees) from all other users, namely; private entities and individuals.

iii. Systems that require all users public and private to pay usage fees to access the data and products of the system.

The scenario (iii) above exists when the technology vendor owns and operates the whole GNSS-RTN system.

5.3 GNSS-RTN SYSTEMS: POSSIBLE BUSINESS MODELS

The major business models identified in previous chapters are presented and discussed in section 2 of this chapter. Section 3 provided an overview of the conceptual elements of a GNSS-RTN business model. This section of the chapter attempts to analyze the information presented in the previous sections in order to select 2-3 business models for further analysis. This selection should consider the unique circumstances in the state of Montana such as the size of the network, the existing CORSs, and the potential end users of the prospective GNSS-RTN system.

As the use of the GNSS-RTN systems is relatively new in practice (most installations occurred within the past 15 years), and to be comprehensive in our approach, this section will consider all scenarios of business models using various combinations of the conceptual elements, i.e. ownership, costs, and user access charges.

Two possible owners for the CPC exist: the state or the vendor. For the CORSs, owners may be the state, other partners, or the vendor.

The CPC costs including system management and administration are usually borne by the state or the vendor regardless of ownership. The costs of implementing CORSs are usually borne by the owners which could be the state, the vendor, or other partners. However, other CORSs running costs including power, communication, and maintenance are often borne by the owners or by the CPC owner or RTN operator (as an incentive to incorporate existing stations in statewide networks).

For access privileges to system data and products, most of the existing systems either provide free access to all end users (public and private) or provide free access to government agencies but charge individuals and private entities for using the system (in the form of subscription or per-use fees). Only in the instance when the vendor owns the whole system (CORSs and the CPC) that all users private and public have to pay for the service.

Considering the three elements above, possible business models for the prospective Montana GNSS-RTN system are presented in **Table 7.**

Table 7. Possible GNSS-RTN Business Models

CPC Operations		**CPC – State**		**CPC – Vendor for Fee**		**CPC – Vendor Network**		
CORSs Operating & Maintenance Costs		**State**	**State + Partners**	**State**	**State + Partners**	**State**	**State + Partners**	**Vendor**
CORSs Ownership	**State**	FA*	---*	FA	---	FA	---	---
		UC*	---	UC	---	UC	---	---
	State + Partners	FA	FA	FA	FA	FA	FA	---
		UC	UC	UC	UC	UC	UC	---
	Vendor	---	---	---	---	---	---	UC

* FA: Free Access; UC: User Charges; “---": Not Applicable

As shown in this table, three different scenarios for CPC ownership and operation are provided; CPC owned and operated by the state, CPC owned and operated by the vendor for a fee, or CPC provided as part of the vendor network. The latter scenario requires the statewide network to be incorporated into the vendor’s network.

Under each of the CPC scenarios, two different cost possibilities for CORSs are provided; all CORSs are operated and maintained by the state, or CORSs are operated and maintained by owners, i.e., the state and other partners. A third cost possibility was added to the option “CPC – Vendor Network” when the vendor is responsible of CORSs operations and maintenance (vendor owns the whole GNSS-RTN system). The owners of CORSs always pay for building their CORSs, and therefore building costs are not part of the cost scenarios.

Regarding CORSs ownership, three different scenarios are provided to cover the different ownership possibilities: the state, the state and partners, and the technology vendor. All cost and ownership scenarios and their combinations in **Table 7** may include user access charges or not, except for a system that is fully owned by the vendor where access charges always exist. User access charges are shown in the cells as either free access (FA) or user charges (UC).

5.4 HIGH-LEVEL ASSESSMENT OF THE GNSS-RTN BUSINESS MODELS

This section provides a preliminary assessment of the business models discussed in the previous section and outlined in **Table 7**. To remove some of the subjectivity in the process, a high-level quantitative analysis of the merits or demerits of all possible business models is needed.

To provide an objective assessment for the different business models included in **Table 7**, certain criteria must be considered. Three major criteria are used in this high-level assessment, state control, sustainability, and state/agency costs. State control refers to the level of control the state has on the prospective GNSS-RTN system being planned and built to align with the state's best interests. A sustainable business model refers to a model that would help the state maintain and provide the desired level of location data service over time within available resources. For sustainability, the lower the running costs the higher the sustainability of the system. Similarly, having user access charges would help the state recover all or some of the operating and maintenance costs, which should result in improved sustainability.

For the assessment, the following star scoring scheme will be used for each criterion as follows:

Agency (state) control:

*	Very low control
**	Low control
***	Moderate control
****	High control
*****	Very high control

Sustainability:

*	Very low
**	Low
***	Moderate
****	High
*****	Very high

Agency/state costs (financial obligations):

*	Very high costs
**	High costs
***	Relatively high costs
****	Average
*****	Relatively low costs
******	Low costs
*******	Very low costs

Summing the number of stars for the three criteria will provide a composite score (out of 17) which refers to the overall merit of a specific business model. Using the star scoring scheme for the criteria above, and considering all possible business model scenarios in **Table 7**, **Table 8** shows a tentative assessment of the different business models considering the three criteria; state control, sustainability, and state/agency costs respectively.

In this high-level assessment, it should be kept in mind that while the scoring scheme described above attempts to provide a quantitative and systematic comparison among alternative business models, the process still has some subjectivity, i.e., two individuals using the same scoring scheme may end up having slightly different results.

In general, business models in **Table 8** show that the higher the level of agency (state) control over the GNSS-RTN system, the higher the financial obligations on the state. The two extremes shown here are: a system that is fully owned and operated by the state where the state has full control over the system and a system that is fully owned and operated by the technology vendor where the state has minimal control (if any) over the system. Further, it is evident that partners' contribution to the CORSs maintenance and operations costs as well as the user access charges both lead to improved sustainability. However, the partners' contribution to CORSs maintenance and operation costs may lead to lower state control over the GNSS-RTN system.

Table 8. Assessment of Possible Business Models Using the Star Scoring Scheme

CPC Operations		CPC – State		CPC – Vendor for Fee		CPC – Vendor Network		
CORSs Operating & Maintenance Costs		State	State + Partners	State	State + Partners	State	State + Partners	Vendor
CORSs Ownership	State	***** * **	NA	***** * *	NA	**** *** ****	NA	NA
		***** ** ***	NA	***** ** **	NA	**** **** *****	NA	NA
	State + Partners	**** * ***	*** ** ****	**** * **	*** ** ***	*** ** *****	** ** ******	NA
		**** ** ****	*** *** *****	**** ** ***	*** *** ****	*** *** ******	** *** *******	NA
	Vendor	NA	NA	NA	NA	NA	NA	* *** ****

Note: Cells highlighted in grey are for business models with user access charges

5.5 SUMMARY

The objective of the current chapter is to catalog possible business models for the prospective Montana GNSS-RTN system and provide an overview of the merits and demerits of the identified models.

The chapter started with a description of the major business models that were identified in the previous chapters, namely, the literature review and the practice screening. It was then provided an overview of the conceptual elements of any GNSS-RTN business model to help understand the different models for building and operating the system. Next, conceptual elements were used in laying out all possible business models using four variables: the CPC ownership/operation, CORSs ownership, CORSs operating and maintenance costs, and user access charges. Finally, a high-level assessment of possible business model was performed using the following criteria, agency control over system, sustainability of business model, and agency financial obligations.

6. CONCLUSIONS AND RECOMMENDATIONS

This project is intended to provide important information that would help the state's efforts in the planning and implementation of the Montana GNSS-RTN system. This chapter summarizes the major findings of each of the four tasks conducted in the course of this project and culminates with a few recommendations stemming from the project work.

Literature Review:

A comprehensive literature review was conducted at the onset of this project which focused on the various aspects regarding the planning, design, implementation and operation of statewide GNSS-RTN systems. Recent advancements in GNSS technology and an overview of conventional and emerging applications were briefly discussed to provide familiarity with the system and its potential uses. Further, GNSS-RTN business plans were summarized, and best practices and guidelines were presented. Finally, system design considerations were reviewed by examining characteristics of existing systems and reviewing available guidance. The review included published information on the GNSS-RTN systems in studies, reports, magazines, and websites both in the US and internationally.

State-of-the-Practice Assessment:

A state of practice survey was conducted to learn about the current practices of operating and managing the GNSS-RTN systems and providing accurate location services in different states around the U.S. Thirty-eight respondents submitted the survey representing 30 states. Additionally, phone interviews were conducted with major vendors/manufacturers of the GNSS-RTN products and services to learn about costs and recent trends in technology and system operations. The major findings of this task are summarized below.

- Most of the statewide GNSS-RTN systems surveyed are owned by state agencies (primarily DOTs). Approximately 90% of the systems in the U.S. are based on CORSs with an average spacing of less than 70 km resulting in an accuracy of 2 -4 cm in location data.

- The owners of central facilities are responsible for user and IT support service costs in approximately 64% of all the systems surveyed. In addition, the CPC owners are responsible for the cost of communication between the CPC and CORSs and for the cost of CPC maintenance.
- Approximately 60 % of GNSS-RTN systems offer entirely free access to both public and private users resulting in the majority of state agencies not generating revenues from user fees.
- The GNSS-RTN systems often provide data as corrected coordinates, network corrections, post processed data, and in fewer instances virtual RINEX.
- The funding sources for the establishment of most of the statewide GNSS-RTN systems are either only state funds or some federal funds along with state funds. However, the funding sources for the daily operation of GNSS-RTN systems are state funds and users' fees, when used.
- In the process of incorporating privately-owned CORSs to statewide networks, some states provide incentives to the private owners in various forms such as unlimited access to data, access to value-added services, free or discounted subscription(s), and educational opportunities for schools that host CORSs.
- The vendors/manufacturers interviews laid down average market prices of GNSS-RTN products and services including CPC and CORS components. It was estimated that approximately 120 CORSs placed across the state are required for Montana's network to achieve the desired accuracy of 1 to 2 inches in location data. To operate the system, the CPC was estimated to require 6 servers, and 4 CPUs.

Existing Infrastructure:

An assessment of all existing GNSS-RTN infrastructure in Montana was conducted in this task. The task identified aspects such as CORS ownership, sampling rate, location coordinates, mounting type, and the networks each station contributes to. The major findings of this task are summarized below.

- At the time of executing this task, this task identified a total of 62 CORSs in Montana owned by both public and private entities, of which 57 are publicly owned. The Montana State Real Time Network (MTSRN) is the largest public network in Montana; currently consisting of 54 CORSs covering different parts of the state.
- Currently, most of the CORSs in Montana provide a sampling rate of 15 seconds or less; with a considerable number of stations providing a sampling rate of 1 second.
- For MTSRN stations with known information, the communication between CORSs and the CPC were almost equally split between the internet and the cellular service.

Catalog Viable GNSS-RTN Business Models:

This task cataloged eight distinct business models that were identified in the previous project tasks, namely, the literature review and the practice screening. The business models were adequately described with a summary of the merits and demerits of each model. The report then provided an overview of the conceptual elements of any GNSS-RTN business model to help understand the different models for building and operating the system. Next, the report used the conceptual elements in laying out all possible business models using four variables: the CPC ownership/operation, CORSs ownership, CORSs operating and maintenance costs, and user access charges. Finally, a high-level assessment of possible business model was performed using the following criteria, agency control over system, sustainability of business model, and agency financial obligations.

Recommendations

Considering the overall project and findings from project tasks, the researchers would like to make the following recommendations regarding the planning, implementation, and operation of the Montana GNSS-RTN system.

I. Building public-private partnerships through incorporating existing CORSs owned by private and other public entities proved to be a cost-effective way for establishing the statewide network within fewer resources and a shorter time span.

II. Expanding the user base of the prospective statewide GNSS-RTN system is important for achieving sustainable operations of the system while maximizing benefits to the state’s economy and its citizens. This requires a scheme for user access charges that is competitive with those that already exist in the region and other neighboring states.

III. The role of technology vendors/manufacturers in building and operating the Montana GNSS-RTN system should be assessed carefully in a way to maximize benefits to the state and leverage its expended resources.

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APPENDIX A: GNSS-RTN Survey Questionnaire

SURVEY QUESTIONNAIRE

The purpose of this survey is to understand the state of practice in establishing and operating the Global Navigation Satellite System (GNSS) Real-Time Network (RTN) at the state level. GNSS-RTN may be owned and/or operated by state DOTs, other public agencies, or private entities. Private entities may own some of the Continuously Operating Reference (COR) stations that are part of a larger RTN network.

This survey is divided into two sections. Section 1 consists of general questions on the GNSS-RTN system including system ownership, system design, and system users among other aspects. Section 2 of the survey consists of questions related to the operation of the GNSS-RTN system such as system operating costs, system funding, and user' fees (if any).

This survey should be completed by those in your agency who are involved in the development, management, or operation of the GNSS-RTN system. Participation is voluntary, you can choose not to answer any question that you do not want to answer, and you can stop at any time. The survey has 23 questions in total and is expected to take approximately 10 minutes to complete. Thank you in advance for your participation.

Please enter your contact information: (We may wish to contact you if we need clarification or desire more information regarding a response)

NAME:
TITLE:
AGENCY:
PHONE:
EMAIL:

1. Your current State:

Select from dropdown list: Choose a State (*Choose a State*)

2. Does your state have a GNSS real-time network (RTN) system?
   - ○ Yes
   - ○ No
3. Does your agency own or operate a GNSS-RTN system?
   - ○ Yes
   - ○ No

Section 1. System General Information

4. Tell us about the GNSS-RTN system ownership in your state.

Central Control/Processing facility is owned by:

- ○ Public agency
- ○ Private entity

COR stations are owned by:

- ○ Public agency
- ○ Private entity
- ○ Both public and private entities

5. What company/vendor did supply hardware for the COR stations [check all that apply]?
   - ☐ Trimble
   - ☐ Lieca
   - ☐ NavCon
   - ☐ TopCon

Other, please specify: ☐

6. What company/vendor did supply hardware for the central facility [check all that apply]?
   - ☐ Trimble
   - ☐ Lieca
   - ☐ NavCon
   - ☐ TopCon

Other, please specify: ☐

7. What company/vendor did supply the software [check all that apply]?
    - ☐ Trimble
    - ☐ Lieca
    - ☐ NavCon
    - ☐ TopCon
    - ☐ Other, please specify: ☐

8. Total number of COR stations that are part of your GNSS-RTN system (including COR stations owned by entities other than the GNSS-RTN system owner/operator):
    - ○ Please specify: ☐

9. Your GNSS-RTN system provides coverage in:
    - ○ Whole State (system covers most of the state geographic area)
    - ○ Part of the State (system covers a certain region within the state)

10. On average, spacing between COR stations is about:
    - ○ 30-40 km
    - ○ 40-50 km
    - ○ 50-70 km
    - ○ More than 70 km
    - ○ Do not know

11. Communication method used to connect COR stations to the central processing station/server [check all that apply]:
    - ☐ Mobile network
    - ☐ Internet based
    - ☐ Radio signals based
    - ☐ Other, please specify: ☐

12. The accuracy of your GNSS-RTN system is approximately:
    - ○ 2-4 cm
    - ○ 4-6 cm
    - ○ 6-8 cm
    - ○ More than 8 cm

13. The users of your GNSS-RTN system are [check all that apply]:
    - ☐ DOT

☐ State survey department

☐ Universities

☐ Construction industries

☐ Engineering consultants

☐ Machine guidance (farming equipment, crop management, etc.)

☐ Private companies purchasing raw data for value-added services

☐ Other private and/or public entities --- please specify.

14. Does your GNSS-RTN system provide the following products to users [check all that apply]:

☐ Corrected coordinates (Real-time)

☐ Network corrections (Real-time)

☐ Post-processed data (Static)

☐ Other – please specify:

15. Provide the average number of users of your GNSS-RTN system:

Total system users	
Annual subscriptions	
Less-than-a-year subscriptions	
Other	

Section 2. System Operation

16. Users of your GNSS-RTN access the system [check all that apply]:

☐ Free of cost / zero charges

☐ Annual subscription fee

☐ Less-than-a-year subscriptions fee

☐ Charges based on access duration

☐ Charges based on data-size download

☐ Other, please specify:

17. Who is responsible for the following GNSS-RTN system costs? [check all that apply]:

RTN components	Central facility owner	COR stations owner	Other, please specify
User and IT support	☐	☐	☐
Communication b/w central facility and COR stations	☐	☐	☐
Maintenance of central facility	☐	☐	☐
Maintenance of COR stations	☐	☐	☐

18. Revenue from user fees/charges cover:

- ○ Total cost of system operation
- ○ 0 % of total system operation cost
- ○ 1% to 20% of total system operation cost
- ○ 20% to 40% of total system operation cost
- ○ 40% to 60% of total system operation cost
- ○ 60% to 80% of total system operation cost
- ○ 80% to 99% of total system operation cost
- ○ Do not know

19. Please specify the system funding sources by checking the applicable boxes in the table below.

GNSS-RTN cost component	Federal funds	State funds	Users/subscription fee	Other, please specify
Establishment of GNSS-RTN system	☐	☐	☐	☐
System operation	☐	☐	☐	☐
System maintenance	☐	☐	☐	☐

20. How many full-time equivalent (FTE) staff are assigned to the daily operation of the GNSS-RTN system?

- Enter approx. number.

21. Were already existing COR stations incorporated into your current GNSS-RTN system?
    - ○ Yes
    - ○ No
    - ○ No previous existing stations
    - ○ Other, please specify:

22. Do you provide any incentives to the owners of COR stations (other than the central facility owner/operator)?
    - ○ Yes
    - ○ No

23. Owners of COR stations (other than the central facility owner/operator) get incentives in the form of:
    - ☐ Reduced subscription charges
    - ☐ Unlimited access to data
    - ☐ Other, please specify:

APPENDIX B: GNSS-RTN Survey Raw Data

Q1	Q2	Q3	Q4a	Q4b	Q5	5a_TEXT
Alabama	Yes	Yes	Public agency	Public agency	Lieca	
California	Yes	Yes	Public agency	Both public and private entities	Trimble, Lieca, TopCon, Other, please specify:	Septentrio
Colorado	Yes	Yes	Public agency	Both public and private entities	Trimble, Lieca, NavCon, TopCon, Other, please specify:	NGS
Connecticut	Yes	Yes	Public agency	Public agency	Trimble	
Florida	Yes	Yes	Public agency	Public agency	Lieca	
Florida	Yes	Yes	Public agency	Public agency	Lieca	
Georgia	Yes	Yes	Private entity	Private entity	Other, please specify:	CHCNAV and HoWAY GIS
Hawaii	No					
Illinois	Yes	Yes	Private entity	Both public and private entities	Lieca, Other, please specify:	Mix of Leica and Novatel
Indiana	Yes	Yes	Public agency	Public agency	Lieca	
Iowa	Yes	Yes	Public agency	Public agency	Lieca, Other, please specify:	Leica ;-)
Iowa	Yes	Yes	Public agency	Public agency	Lieca, Other, please specify:	GPS receivers and Antennas only
Louisiana	Yes	Yes	Public agency	Public agency	Trimble	
Maine	Yes	Yes	Public agency	Public agency	Trimble	
Maryland	No					
Massachusetts	Yes	Yes	Private entity	Both public and private entities	Lieca	
Michigan	Yes	Yes	Public agency	Public agency	Lieca	
Minnesota	Yes	Yes	Public agency	Public agency	Trimble	
New Hampshire	No					
Ohio	Yes	Yes	Public agency	Public agency	Trimble, Lieca, TopCon	
Ohio	Yes	Yes	Public agency	Public agency	Trimble, TopCon	
Oregon	Yes	Yes	Public agency	Both public and private entities	Trimble, Other, please specify:	Septentrio
Oregon	Yes	Yes	Public agency	Both public and private entities	Trimble, Lieca, Other, please specify:	Septentrio
Pennsylvania	Yes	Yes	Public agency	Public agency	Trimble	
Tennessee	Yes	Yes	Public agency	Public agency	TopCon	
Texas	Yes	Yes	Public agency	Public agency	Trimble	
Utah	Yes	Yes	Public agency	Both public and private entities	Trimble	
Vermont	Yes	Yes	Public agency	Both public and private entities	Trimble	
Washington	Yes	Yes	Public agency	Both public and private entities	Trimble, Lieca, TopCon, Other, please specify:	Septentrio
West Virginia	Yes	Yes	Public agency	Public agency	Trimble	
No State Info	Yes	Yes	Public agency	Both public and private entities	Trimble	
No State Info	No					
No State Info	Yes	Yes	Public agency	Public agency	Trimble	

Q1	Q6	Q6a TEXT	Q7	Q7a TEXT	Q8	Q8a
Alabama	Lieca		Lieca		Please provide number below:	53
California	Other, please specify:	HP Blade servers for data processing and storage	Trimble		Please provide number below:	205
Colorado	Trimble, Lieca, NavCon, TopCon, Other	UNAVCO	Trimble, Lieca, NavCon, TopCon, Other, please specify:	UNAVCO	Please provide number below:	9
Connecticut	Trimble		Trimble		Please provide number below:	9
Florida	Lieca		Lieca		Please provide number below:	100
Florida	Lieca		Lieca		Please provide number below:	99
Georgia	Other, please specify:	My IT Department	Trimble, Other, please specify:	3 processing platforms. Trimble, Geo++, CHCNAV CPS	Please provide number below:	69
Hawaii						
Illinois	Lieca		Lieca		Please provide number below:	58
Indiana	Other, please specify:	Indiana Office of Technology	Lieca		Please provide number below:	45
Iowa	Other, please specify:	We use Iowa DOT servers	Lieca		Please provide number below:	103
Iowa	Other, please specify:	That would be Iowa DOT IT (State) hardware supplied.	Lieca		Please provide number below:	101
Louisiana	Trimble		Trimble		Please provide number below:	122
Maine	Trimble		Trimble		Please provide number below:	19
Maryland						
Massachusetts	Lieca		Lieca		Please provide number below:	20
Michigan	Other, please specify:	State-run VM's	Lieca		Please provide number below:	123
Minnesota	Trimble		Trimble		Please provide number below:	130
New Hampshire						
Ohio	Trimble		Trimble		Please provide number below:	64
Ohio	Trimble		Trimble		Please provide number below:	61
Oregon	Lieca		Lieca			
Oregon	Other, please specify:	State Data Center	Lieca, Other, please specify:	Septentrio	Please provide number below:	120
Pennsylvania	Trimble		Trimble		Please provide number below:	18
Tennessee	TopCon		TopCon		Please provide number below:	45
Texas	Trimble		Trimble		Please provide number below:	240
Utah	Trimble		Trimble		Please provide number below:	109
Vermont	Trimble		Trimble		Please provide number below:	18
Washington	Other, please specify:	Seattle Public Utilities	Trimble		Please provide number below:	150
West Virginia	Trimble		Trimble		Please provide number below:	23
No State Info	Trimble		Trimble		Please provide number below:	125
No State Info						
No State Info	Trimble		Trimble		Please provide number below:	52

Q1	Q9	Q10	Q11	Q11 TEXT	Q12
Alabama	Whole State (system covers most of the state geographic area)	40-50 km	Mobile network, Internet based		2-4 cm
California	Part of the State (system covers a certain region within the state)	40-50 km	Internet based		2-4 cm
Colorado	Whole State (system covers most of the state geographic area)	More than 70 km	Radio signals based		4-6 cm
Connecticut	Whole State (system covers most of the state geographic area)	40-50 km	Internet based		2-4 cm
Florida	Whole State (system covers most of the state geographic area)	30-40 km	Mobile network		2-4 cm
Florida	Whole State (system covers most of the state geographic area)	30-40 km	Internet based		2-4 cm
Georgia	Whole State (system covers most of the state geographic area)	50-70 km	Mobile network		2-4 cm
Hawaii					
Illinois	Part of the State (system covers a certain region within the state)	30-40 km	Internet based, Radio signals based		2-4 cm
Indiana	Whole State (system covers most of the state geographic area)	30-40 km	Internet based		2-4 cm
Iowa	Whole State (system covers most of the state geographic area)	40-50 km	Mobile network, Internet based		2-4 cm
Iowa	Whole State (system covers most of the state geographic area)	50-70 km	Mobile network		2-4 cm
Louisiana	Whole State (system covers most of the state geographic area)	50-70 km	Internet based		2-4 cm
Maine	Whole State (system covers most of the state geographic area)	50-70 km	Internet based		2-4 cm
Maryland					
Massachusetts	Whole State (system covers most of the state geographic area)	50-70 km	Internet based		2-4 cm
Michigan	Whole State (system covers most of the state geographic area)	30-40 km			2-4 cm
Minnesota	Whole State (system covers most of the state geographic area)	40-50 km	Internet based		2-4 cm
New Hampshire					
Ohio	Whole State (system covers most of the state geographic area)	30-40 km	Mobile network, Internet based		2-4 cm
Ohio	Whole State (system covers most of the state geographic area)	30-40 km	Mobile network, Internet based		2-4 cm
Oregon	Whole State (system covers most of the state geographic area)	Do not know	Mobile network, Internet based		
Oregon	Part of the State (system covers a certain region within the state)	50-70 km	Mobile network, Internet based, Other, please specify:	State Network	2-4 cm
Pennsylvania	Whole State (system covers most of the state geographic area)	More than 70 km	Internet based		2-4 cm
Tennessee	Whole State (system covers most of the state geographic area)	40-50 km	Internet based		2-4 cm
Texas	Whole State (system covers most of the state geographic area)	50-70 km	Mobile network, Internet based		2-4 cm
Utah	Whole State (system covers most of the state geographic area)	Do not know	Internet based		4-6 cm
Vermont	Whole State (system covers most of the state geographic area)	30-40 km	Mobile network		2-4 cm
Washington	Whole State (system covers most of the state geographic area)	50-70 km	Mobile network, Internet based, Radio signals based		2-4 cm
West Virginia	Whole State (system covers most of the state geographic area)	50-70 km	Mobile network, Internet based		2-4 cm
No State Info	Whole State (system covers most of the state geographic area)	40-50 km	Mobile network, Internet based		2-4 cm
No State Info					
No State Info	Whole State (system covers most of the state geographic area)	50-70 km	Mobile network, Internet based		2-4 cm

Q1	Q13	Q13 TEXT
Alabama	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	NOAA, NGS
California	DOT, State survey department, Universities, Construction industries, Machine guidance (farming equipment, crop management, etc.), Other private and/or public entities --- please specify	Counties, cities and public water entities. Fields using the RTN from these entities include Surveys, GIS, city water departments and irrigation districts.
Colorado	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	COUNTY AND MUNICIPAL
Connecticut	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services	
Florida	DOT, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	System is available to the public.
Florida	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Other private and/or public entities --- please specify	multiple municipalities, utilities and private companies - no fees
Georgia	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	Land Surveyors, GIS consultants, Remote Sensing consultants
Hawaii		
Illinois	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services	
Indiana	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	Utility, municipalities, etc.
Iowa	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	
Iowa	DOT, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	Counties, Cities, DNR, Federal USDA, USACOE, etc. User base in numerous, given FREE to access. And we do not have a specific State Survey Dept.
Louisiana	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Other private and/or public entities --- please specify	USACE, USGS, Plumbers, Land & Hydro Surveyors, UAV Pilots, Public Utilities, and more...
Maine	DOT, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	Agricultural Users, robotic mowers
Maryland		
Massachusetts	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.)	
Michigan	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Other private and/or public entities --- please specify	NGS data Gzip
Minnesota	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	NOAA NGS
New Hampshire		
Ohio	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services	
Ohio	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.)	
Oregon	DOT, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Other private and/or public entities --- please specify	UNAVCO

Oregon	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Other private and/or public entities --- please specify	Mapping and GIS services
Pennsylvania	DOT, State survey department, Other private and/or public entities --- please specify	The state has a DOT owned and operated RTN for DOT use only, that also shares data to a Private RTN run by Trimble for subscription users.
Tennessee	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.)	
Texas	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.)	
Utah	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.)	
Vermont	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services	
Washington	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services, Other private and/or public entities --- please specify	Utilities, agriculture, scientific agencies, federal, autonomous navigation, robotics
West Virginia	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.), Private companies purchasing raw data for value-added services	
No State Info	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.)	
No State Info		
No State Info	DOT, State survey department, Universities, Construction industries, Engineering consultants, Machine guidance (farming equipment, crop management, etc.)	

Q1	Q14	Q14a TEXT	Q15a	Q15b	Q15c	Q15d
Alabama	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static), Other, please specify:	Virtual Rinex	1188			
California	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		300	300		
Colorado	Other, please specify:	ONLY VIA NGS OR Software	10000	0	0	21
Connecticut	Corrected coordinates (Real-time), Network corrections (Real-time)					
Florida	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		5900	15600		
Florida	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		3600			
Georgia	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static), Other, please specify:	User statistics	500	200	300	
Hawaii						
Illinois	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		1000	700	300	
Indiana	Network corrections (Real-time), Post-processed data (Static)		4500			
Iowa	Network corrections (Real-time), Post-processed data (Static), Other, please specify:	Virtual RINEX	3700			
Iowa	Network corrections (Real-time), Post-processed data (Static), Other, please specify:	Adjusted Network Coordinates, last derived upon NAD83(2011) upon NAVD88/Geoid12B on Jan. 4th, 2019	2036	1781	392	
Louisiana	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static), Other, please specify:	Online Post-processing solutions, Real-time & Historical Tracking of rovers for clients				
Maine	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		50	600	0	
Maryland						
Massachusetts	Network corrections (Real-time), Post-processed data (Static)					
Michigan	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		5268	5268	0	0
Minnesota	Network corrections (Real-time), Post-processed data (Static), Other, please specify:	we send out a correction to the user in the field via internet. The end user's equipment supplies the real time coordinate.		5000		
New Hampshire						
Ohio	Network corrections (Real-time)		3000			
Ohio	Network corrections (Real-time), Post-processed data (Static)		7721	7721		
Oregon	Corrected coordinates (Real-time), Network corrections (Real-time)					
Oregon	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		1600	0	0	
Pennsylvania	Network corrections (Real-time), Other, please specify:	DOT system will provide Real-Time network corrections to users. The private RTN will provide more services.				
Tennessee	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		500	400	20	
Texas	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		2000	0	0	
Utah	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		130		0	
Vermont	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		451	40	25	
Washington	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static), Other, please specify:	Observation streams for science and industry	4500	288	0	
West Virginia	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		4000			

No State Info	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		3500	3500	0	
No State Info						
No State Info	Corrected coordinates (Real-time), Network corrections (Real-time), Post-processed data (Static)		1600			

Q1	Q16	Q16a TEXT	Q17a	Q17b	Q17c	Q17d
Alabama	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner
California	Other, please specify:	Direct access is only available to Municipalities. Public can access data from state owned station via the partner CRTN network.	Central facility owner ,CORSs owner	Central facility owner, CORSs owner	Central facility owner	Central facility owner, CORSs owner
Colorado	Free of cost, Annual subscription fee, Other, please specify:	ANNUAL LICENSING FEE BY PRIVATELY OWNED VENDORS	CORSs owner		CORSs owner	
Connecticut	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner
Florida	Free of cost		Central facility owner	Central facility owner	Other	Central facility owner
Florida	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner
Georgia	Annual subscription fee, Less-than-a-year subscriptions fee	Central facility owner	Central facility owner	Central facility owner	Central facility owner	
Hawaii						
Illinois	Free of cost, Annual subscription fee, Less-than-a-year subscriptions fee	Central facility owner	Central facility owner	Central facility owner	Central facility owner	
Indiana	Free of cost		Other	Central facility owner	Central facility owner	Central facility owner
Iowa	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner
Iowa	Free of cost		Central facility owner	Central facility owner, CORSs owner	Central facility owner	Central facility owner, CORSs owner
Louisiana	Free of cost, Annual subscription fee, Less-than-a-year subscriptions fee, Charges based on access duration, Other, please specify:	Research Agreements	Central facility owner	Central facility owner	Central facility owner	Central facility owner
Maine	Free of cost		CORSs owner	Central facility owner	Central facility owner	CORSs owner
Maryland						
Massachusetts	Free of cost		Central facility owner, CORSs owner	Central facility owner, CORSs owner	Central facility owner	CORSs owner
Michigan	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner
Minnesota	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner
New Hampshire						
Ohio	Free of cost		CORSs owner	CORSs owner	CORSs owner	CORSs owner
Ohio	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner
Oregon	Free of cost		Central facility owner ,CORSs owner	Central facility owner	Central facility owner	Central facility owner ,CORSs owner
Oregon	Free of cost		Central facility owner	Central facility owner, CORSs owner	Central facility owner	Central facility owner, CORSs owner

Pennsylvania	Other, please specify:	No access beyond DOT. Private RTN is subscription based	Central facility owner	Central facility owner	Central facility owner	Central facility owner
Tennessee	Annual subscription fee	Central facility owner	Central facility owner	Central facility owner	Central facility owner	
Texas	Free of cost		Central facility owner, CORSs owner	Central facility owner, CORSs owner	Central facility owner, CORSs owner	Central facility owner, CORSs owner
Utah	Annual subscription fee, Other, please specify:	1-year subscription only	Central facility owner	CORSs owner	Central facility owner	CORSs owner
Vermont	Free of cost		Central facility owner, CORSs owner	Central facility owner	Central facility owner, Other	Central facility owner, CORSs owner
Washington	Annual subscription fee, Other, please specify:	The majority of our users are cooperative partners	Central facility owner	Central facility owner, CORSs owner	Central facility owner	Central facility owner ,CORSs owner
West Virginia	Free of cost		CORSs owner	CORSs owner	CORSs owner	CORSs owner
No State Info	Free of cost		Central facility owner	CORSs owner	Central facility owner	Central facility owner
No State Info						
No State Info	Free of cost		Central facility owner	Central facility owner	Central facility owner	Central facility owner

Q1	Q18	Q19a	Q19b	Q19c	Q19a Text	Q19b Text	Q19c Text
Alabama	0% of total system operation cost	Federal funds, State funds	Federal funds, State funds	Federal funds, State funds			
California	0 % of total system operation cost	Federal funds, State funds	State funds	Federal funds, State funds			
Colorado	Do not know	State funds	Other	Other		PRIVATELY OWNED STATIONS COST IS UNKNOWN	PRIVATE VENDORS
Connecticut	0 % of total system operation cost	State funds	State funds	State funds			
Florida	0 % of total system operation cost	State funds	State funds	State funds			
Florida	0 % of total system operation cost	State funds	State funds	State funds			
Georgia	Total cost of system operation	Other	Other	Other	Private Business Ownership for profit	Self-funded	Self-Funded
Hawaii							
Illinois	80% to 99% of total system operation cost	Users/subscription fee	Users/subscription fee	Users/subscription fee			
Indiana	0 % of total system operation cost	Federal funds, State funds	State funds	State funds			
Iowa	0 % of total system operation cost	State funds	State funds	State funds			
Iowa	0 % of total system operation cost	State funds	State funds	State funds			
Louisiana	Total cost of system operation	Users/subscription fee	Users/subscription fee	Users/subscription fee			
Maine	0 % of total system operation cost	State funds	State funds	State funds			
Maryland							
Massachusetts	0 % of total system operation cost	Federal funds, State funds	Federal funds, State funds	Federal funds, State funds			
Michigan	0 % of total system operation cost	State funds	State funds	State funds			
Minnesota	0 % of total system operation cost	State funds	State funds	State funds			
New Hampshire							
Ohio	0 % of total system operation cost	State funds	State funds	State funds			
Ohio	0 % of total system operation cost	Federal funds ,State funds	State funds	State funds			
Oregon	Do not know	State funds	State funds	State funds			
Oregon	0 % of total system operation cost	State funds	State funds	State funds			
Pennsylvania	0 % of total system operation cost	State funds	State funds	State funds			
Tennessee	1% to 20% of total system operation cost	State funds, Users/subscription fee	State funds ,Users/subscription fee	State funds ,Users/subscription fee			
Texas	0 % of total system operation cost	State funds	State funds	State funds			
Utah	Total cost of system operation	State funds	Users/subscription fee	Users/subscription fee			
Vermont	0 % of total system operation cost	Federal funds, State funds	Federal funds, State funds	Federal funds ,State funds			
Washington	Total cost of system operation	Users/subscription fee, Other	Users/subscription fee, Other	Users/subscription fee, Other	Partner contributions, and initial investment by Seattle public Utilities,	Some partner constitutions for software upgrades	While there was no initial state funding, some DOT regions have contributed CORS hardware. There have been some contributions from universities from USGS grant funding.
West Virginia		Federal funds, State funds	Federal funds, State funds	Federal funds, State funds			
No State Info		Federal funds, State funds	State funds	State funds			
No State Info							
No State Info	0 % of total system operation cost	Federal funds	Federal funds	Federal funds			

Q1	Q20	Q21	Q21a TEXT	Q22	Q23	Q23a TEXT
Alabama	3	Yes		No		
California	1	Yes		Yes	Unlimited access to data, Other, please specify:	Access to "value added" data products like network corrected RTN data streams.
Colorado	1	Yes		No		
Connecticut	1	Yes		No		
Florida	3	Yes		No		
Florida	2	Other, please specify:	adjacent states and municipal	No		
Georgia	3	No				
Hawaii						
Illinois	2	No				
Indiana	2	Other, please specify:	Only 1	No		
Iowa	1	No previous existing stations				
Iowa	1	No previous existing stations				
Louisiana	3	Yes		No		
Maine	0	No				
Maryland						
Massachusetts	1.5	No				
Michigan	3	Yes		No		
Minnesota	3	Yes		No		
New Hampshire						
Ohio	3	No				
Ohio	1	No				
Oregon	2	Yes		No		
Oregon	1.5	Yes		No		
Pennsylvania	1	Yes		No		
Tennessee	1	No				
Texas	5	Yes		No		
Utah	2	Yes		Yes	Other, please specify:	One free subscription for a station
Vermont	2	No previous existing stations				
Washington	0.75	Yes		Yes	Unlimited access to data, Other, please specify:	Education opportunities for schools that host sites
West Virginia	4	No				
No State Info	1	Yes		Yes	Reduced subscription charges, Unlimited access to data	
No State Info						
No State Info	2	No				

APPENDIX C: Vendors/Companies Interview Questions

Vendors/Companies Phone/Zoom Interview Questions

SECTION ONE: PRODUCTS AND SERVICES

Which of the following products/services does your company offer?

i. CORS hardware

Types:	Approximate cost
1. –	
2. –	
3. –	

ii. Central Processing Center (CPC) hardware

Types:	Approximate cost
1. –	
2. –	
3. –	

iii. Central Processing Center (CPC) software

Types:	Approximate cost
1. –	
2. –	
3. –	

iv. Does your company provide ***design*** services for GNSS-RTN systems?
If YES,

- Design as a stand-alone service
- In conjunction with hardware or software procurement
- Only for GNSS-RTN systems solely built by your company

v. What is the approximate cost paid by clients for your design services and how is it determined?

vi. Does your company build and/or establish the following system components?

- CORSs
- Central Processing Center
- Both

If YES to any of the above, please indicate the type of service:

- Stand-alone service
- In conjunction with hardware/software procurement
- In conjunction with system operation contracts
- In conjunction with system design services
- Part of building a complete GNSS-RTN system

vii. What are the approximate costs for building system components and how are they determined?

viii. Does your company operate GNSS-RTN systems?

If YES to the above question, please indicate the type of service

- Stand-alone service
- Only for systems designed and built by your company

ix. How are operation costs paid by clients determined by your company? Any ballpark numbers?

x. Does your company provide maintenance services for GNSS-RTN systems?

If YES to the above question, please indicate the type of service.

- Maintenance of CORSs
- Maintenance of Central Processing Centers
- Both

Is maintenance provided as (check all that apply):

- Stand-alone service
- Only for systems designed and built by your company
- In conjunction with system operation contracts

xi. How are maintenance costs estimated by your company? Any ballpark numbers?

SECTION TWO: CURRENT AND PAST CLIENTS

xii. Which states have your company provided any of the following services?

- Complete GNSS-RTN systems operated by your company

- Complete GNSS-RTN systems operated by owner or other agency

- Building the Central Processing Center (both hardware and software)

- Provide software for existing GNSS-RTN systems

- Supply hardware for CORSs

- Providing stand-alone design services for systems built by other companies

- Provide system operation services

- Provide system maintenance services

xiii. For GNSS-RTN systems your company helped plan, design, build, and/or operate, have you incorporated **already existing CORSs** in a larger GNSS-RTN network (e.g., statewide system)?

- If YES to the above question, were incentives provided to the owners of the existing CORSs?

- If incentives were provided, what are those incentives?

APPENDIX D: Montana CORSs Geospatial Location and Mounting Type

Montana CORSs Geospatial Location and Mounting Type

Total Stations in Montana						
	Station	**Location**	**Latitude**	**Longitude**	**Ellipsoid height (m)**	**Mounting Type**
1	**HAML**	Hamilton, MT	46 11 42.80313 N	114 10 22.55733 W	1105.200m	Ground-based
2	**LOLO**	Lolo, MT	46 45 46.24771 N	114 05 48.67202 W	1109.859m	Ground-based
3	**MSOL**	Missoula Airport, MT	46 55 45.83764 N	114 06 31.84491 W	960.611m	Ground-based
4	**MTBR**	Bridger, MT	45 16 11.09210 N	108 54 51.42018 W	1106.667m	Ground-based
5	**MTCB**	Culbertson, MT	48 08 49.77412 N	104 30 11.22183 W	571.018m	Ground-based
6	**MTCU**	Cut Bank, MT	48 38 34.35059 N	112 18 58.49254 W	1134.073m	Ground-based
7	**MTDT**	Helena, MT	46 35 18.59145 N	111 59 36.96274 W	1217.743m	Ground-based
8	**MTEI**	Billings, MT	45 44 47.03568 N	108 36 00.73636 W	970.852m	Ground-based
9	**MTFV**	Flathead Valley CC, MT	48 13 38.89085 N	114 19 36.54279 W	905.671m	Roof-based
10	**MTGW**	Glasgow, MT	48 22 11.18755 N	106 47 36.41814 W	672.738m	Ground-based
11	**MTHC**	Butte, MT	45 56 16.19774 N	112 30 36.10882 W	1696.543m	Roof-based
12	**MTHM**	Harlem, MT	48 32 44.41440 N	108 46 46.76372 W	717.512m	Ground-based
13	**MTLG**	Lodge Grass, MT	45 18 44.66277 N	107 20 30.20525 W	1053.010m	Ground-based
14	**MTLO**	Loma, MT	47 57 02.41089 N	110 30 17.96950 W	835.250m	Ground-based
15	**MTLW**	Lewistown, MT	47 03 14.92966 N	109 26 33.76416 W	1236.960m	Ground-based
16	**MTMS**	MSU N. Havre, MT	48 32 27.42647 N	109 41 11.85839 W	773.908m	Roof-based
17	**MTOP**	Opheim, MT	48 51 17.11527 N	106 24 22.04353 W	980.556m	Ground-based
18	**MTPJ**	Pendroy Junct., MT	48 04 14.81121 N	112 20 09.16623 W	1310.411m	Ground-based
19	**MTRC**	Sidney, MT	47 42 38.17615 N	104 10 51.20554 W	584.659m	Ground-based
20	**MTSU**	MSU Bozeman, MT	45 39 40.37682 N	111 02 42.00897 W	1495.489m	Ground-based
21	**MTSY**	Scobey, MT	48 47 37.61523 N	105 23 55.55138 W	745.944m	Ground-based
22	**MTUM**	Sunset, MT	46 57 00.08260 N	113 28 20.62213 W	1122.778m	Roof-based
23	**MTWP**	Wolf Point, MT	48 05 58.09697 N	105 40 00.38540 W	617.360m	Ground-based
24	**MTZM**	Zoteman, MT	47 57 41.13086 N	108 18 18.92264 W	933.199m	Ground-based
25	**MTMI**	Miles City, MT	46 26 49.02766 N	105 47 48.62912 W	709.389m	Roof-based
26	**NOMT**	Norris, MT	45 35 48.6336 N	111 37 46.7118 W	1578.634m	Ground-based
27	**BKFB**	Browning, MT	48 32 56.35424 N	113 00 43.80884 W	1329.987m	Roof-based
28	**FTPP**	Popular, MT	48 06 56.40274 N	105 11 13.02263 W	595.395m	--
29	**MTPO**	Fort Peck RES., MT	--	--	--	--
30	**YBRA**	Red lodge, MT	45 07 19.56 N	109 16 02.64 W	2072.518m	Ground-based
31	**BUEH**	Lima, MT	--	--	--	--
32	**LCLN**	Lincoln, MT	46 56 51.7196 N	112 44 34.8798 W	--	Ground-based
33	**TWSD**	Townsend, MT	46 18 34.1861 N	111 30 53.2971 W	--	Ground-based
34	**DRLG**	Deer Lodge, MT	46 23 19.4530 N	112 44 04.6286 W	--	Roof-based
35	**WTHL**	Whitehall, MT	--	--	--	Roof-based
36	**EUKA**	Eureka, MT	48 54 42.9881 N	115 03 19.7636 W	--	Roof-based
37	**P045**	Dillon, MT	45 22 58.32584 N	112 37 01.82863 W	1618.799m	Ground-based

“--” Information unavailable

Total Stations in Montana - Continued

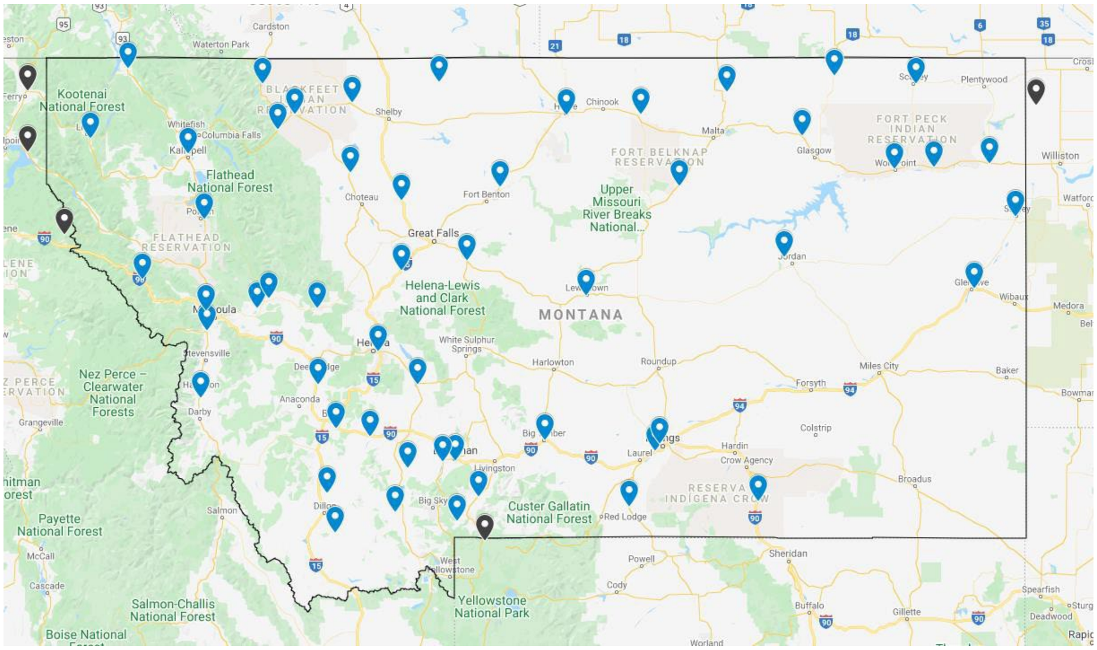
	Station	Location	Latitude	Longitude	Ellipsoid height (m)	Mounting Type
38	**P046**	Clearwater Junct., MT	47 01 46.52357 N	113 19 54.18527 W	1290.844m	Ground-based
39	**P047**	East Glacier, MT	48 25 16.78905 N	113 13 11.02622 W	1476.057m	Ground-based
40	**P048**	Four Corners, MT	45 39 10.944 N	111 12 15.156 W	1492.595m	Ground-based
41	**P049**	Armington Junct., MT	47 20 59.85056 N	110 54 22.38306 W	1186.651m	Ground-based
42	**P050**	Sweat Grass Hills, MT	48 48 34.09690 N	111 14 54.29693 W	1267.434m	Ground-based
43	**P051**	Billings Airport, MT	45 48 23.74192 N	108 32 46.07076 W	1081.757m	Ground-based
44	**P052**	Jordan, MT	47 22 29.02686 N	107 01 07.18536 W	859.285m	Ground-based
45	**P053**	Whitewater, MT	48 43 33.86527 N	107 43 31.45675 W	815.608m	Ground-based
46	**P054**	Ekalaka, MT	45 50 46.83313 N	104 26 29.06244 W	1093.859m	Ground-based
47	**P055**	Glendive, MT	47 07 00.14491 N	104 41 06.39476 W	668.450m	Ground-based
48	**P456**	W. Yellowstone, MT	44 51 48.564 N	111 13 30.396 W	2956.339m	Ground-based
49	**p457**	Big Sky, MT	45 02 28.392 N	111 16 21.432 W	2262.54m	Ground-based
50	**P458**	W. Yellowstone, MT	44 45 56.484 N	111 18 05.436 W	2393.924m	Ground-based
51	**P460**	Big Sky, MT	45 08 23.964 N	111 01 42.924 W	2197.818m	Ground-based
52	**P461**	Merriman, MT	45 21 15.3 N	110 45 31.284 W	1544.094m	Ground-based
53	**P680**	W. Yellowstone, MT	44 35 54.096 N	111 05 55.50 W	2315.94m	Ground-based
54	**P706**	Dillon, MT	45 02 36.47248 N	112 31 26.66902 W	1811.325m	Ground-based
55	**P707**	Red Rock Lakes, MT	44 43 07.55322 N	111 50 13.73844 W	2293.445m	Ground-based
56	**P712**	W. Yellowstone, MT	44 57 26.892 N	111 04 20.568 W	2161.49m	Ground-based
57	**P714**	Gardiner, MT	44 53 45.06 N	110 44 39.912 W	2250.18m	Ground-based
58	**P719**	Ennis, MT	45 13 03.936 N	111 47 20.508 W	1706.356m	Ground-based
59	**P721**	Silver Gate, MT	45 00 10.638 N	110 00 07.38 W	2236.31m	Ground-based
60	**P722**	Fishtail, MT	45 27 25.98575 N	109 34 15.58671 W	1453.451m	Ground-based
61	**P818**	Fishtail, MT	45 27 26.424 N	109 34 15.636 W	1463.00m	Ground-based
62	**P819**	Fishtail, MT	45 27 26.208 N	109 34 16.14 W	1463.00m	Ground-based
63	**MAWY**	Mammoth, WY	44 58 24.31914 N	110 41 21.43320 W	1824.920m	Roof-based
64	**RYA1**	East Hope, ID	--	--	--	--
65	**NDGR**	Grenora, ND	48 37 14.47271 N	103 55 59.20221 W	642.775m	Roof-based
66	**P024**	Sunset Peak, ID	47 33 43.92 N	115 50 32.784 W	1907.629m	Ground-based
67	**P025**	Bonners Ferry, ID	48 43 51.63211 N	116 17 14.98280 W	695.894m	Ground-based
68	***STMY***	*St. Mary, MT*	48 47 24.4521 N	113 24 28.4052 W	--	Ground-based
69	***CSCD***	*Cascade, MT*	47 15 39.8010 N	111 42 21.3293 W	--	Roof-based
70	***DUTN***	*Dutton, MT*	47 50 34.9700 N	111 42 24.4100 W	--	Roof-based
71	***LBBY***	*Libby, MT*	48 21 04.7988 N	115 31 27.2496 W	--	Roof-based
72	***PLSN***	*Polson, MT*	47 41 09.4416 N	114 07 29.0496 W	--	Roof-based
73	***SUPR***	*Superior, MT*	47 11 13.8800 N	114 52 54.5600 W	--	Roof-based
74	***BTMR***	*Big Timber, MT*	45 50 19.9608 N	109 56 53.3796 W	--	Roof-based

"--" Information unavailable

Stations to be added are presented in italic

APPENDIX E: Montana CORS Networks

MTSRN – CORSs Map and Table

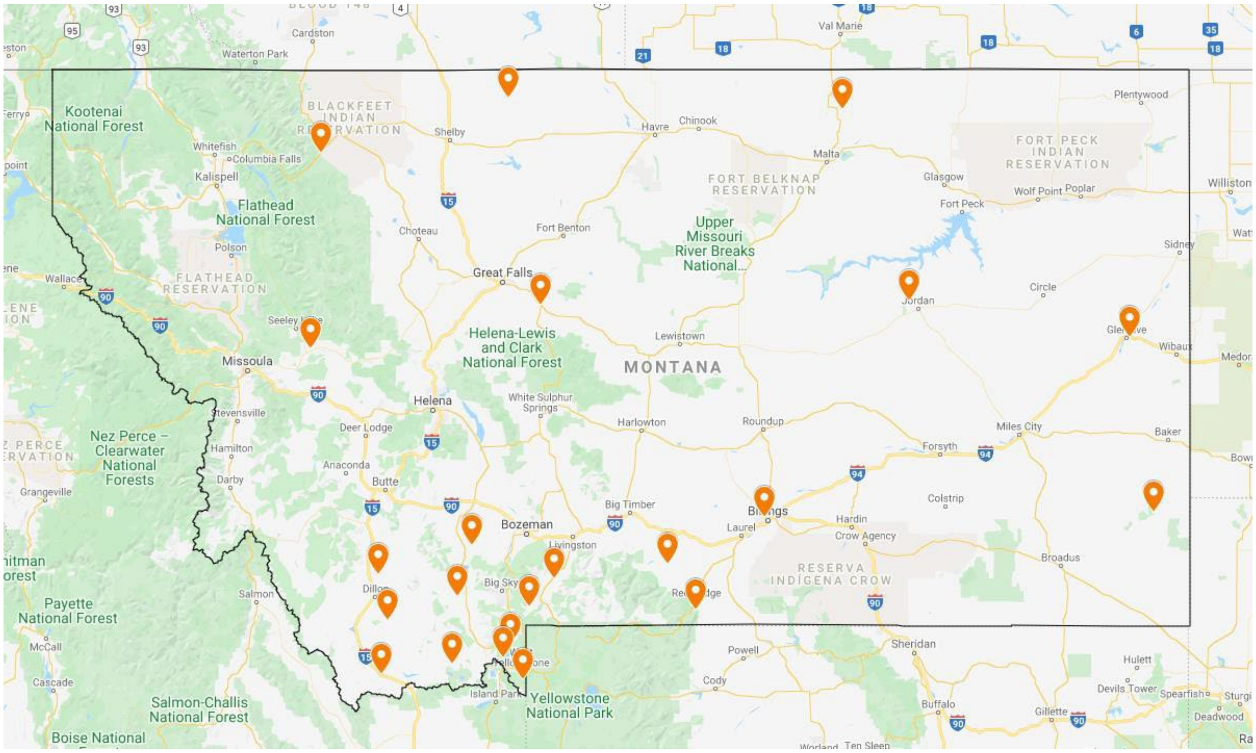


Stations in the MTSRN					
Station	**Location**	**Station**	**Location**	**Station**	**Location**
BKFB	Browning, MT	**LCLN**[1]	Lincoln, MT	**P051**	Billings Airport, MT
FTPP	Popular, MT	**TWSD**[1]	Townsend, MT	**P052**	Jordan, MT
HAML	Hamilton, MT	**DRLG**[1]	Deer Lodge, MT	**P053**	Whitewater, MT
LOLO	Lolo, MT	**WTHL**[1]	Whitehall, MT	**P055**	Glendive, MT
MSOL	Missoula Airport, MT	**EUKA**[1]	Eureka, MT	**P460**	Big Sky, MT
MTBR	Bridger, MT	**NOMT**[1]	Norris, MT	**P461**	Merriman, MT
MTCB	Culbertson, MT	**MTRC**	Sidney, MT	**P706**	Dillon, MT
MTCU	Cut Bank, MT	**MTSU**	Bozeman, MT	**P719**	Ennis, MT
MTDT	Helena, MT	**MTSY**	Scobey, MT	***STMY***[1]	*St. Mary, MT*
MTEI	Billings, MT	**MTUM**	Sunset, MT	***CSCD***[1]	*Cascade, MT*
MTFV	Flathead Valley CC, MT	**MTWP**	Wolf Point, MT	***DUTN***[1]	*Dutton, MT*
MTGW	Glasgow, MT	**MTZM**	Zoteman, MT	***LBBY***[1]	*Libby, MT*
MTHC	Butte, MT	**NDGR**	Grenora, ND	***PLSN***[1]	*Polson, MT*
MTHM	Harlem, MT	**P025**	Sheridan, WY	***SUPR***[1]	*Superior, MT*
MTLG	Lodge Grass, MT	**P045**	Dillon, MT	***BTMR***[1]	*Big Timber, MT*
MTLO	Loma, MT	**P046**	Clearwater Junct., MT	**MAWY**	Mammoth, WY
MTLW	Lewistown, MT	**P047**	East Glacier, MT	**RYA1**[1]	East Hope, ID
MTMS	MSU N. Havre, MT	**P048**	Four Corners, MT	**NDGR**	Grenora, ND
MTOP	Opheim, MT	**P049**	Armington Junct., MT	**P024**	Sunset Peak, ID
MTPJ	Pendroy Junct., MT	**P050**	Sweat Grass Hills, MT	**P025**	Bonners Ferry, ID
MTPO[1]	Fort Peck RES., MT				

Stations to be added are presented in italic

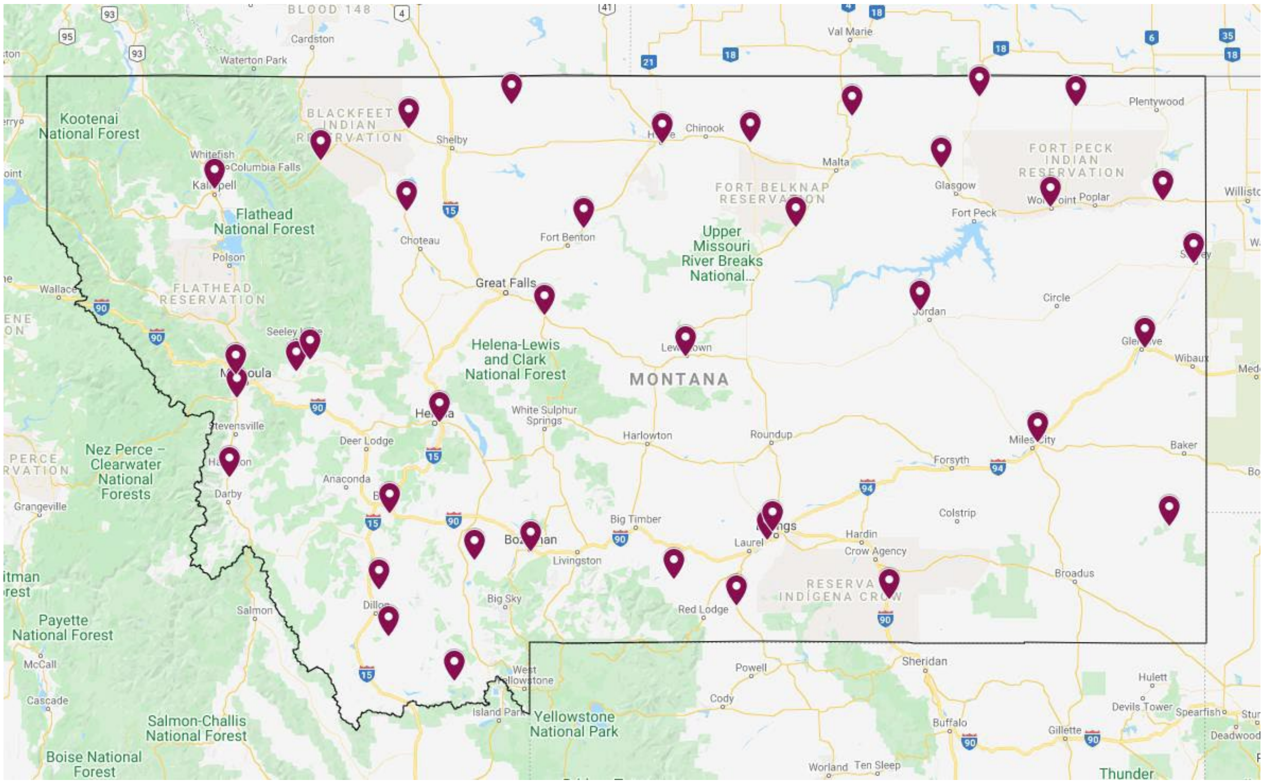
[1] Estimated location

UNAVCO – CORSs Map and Table



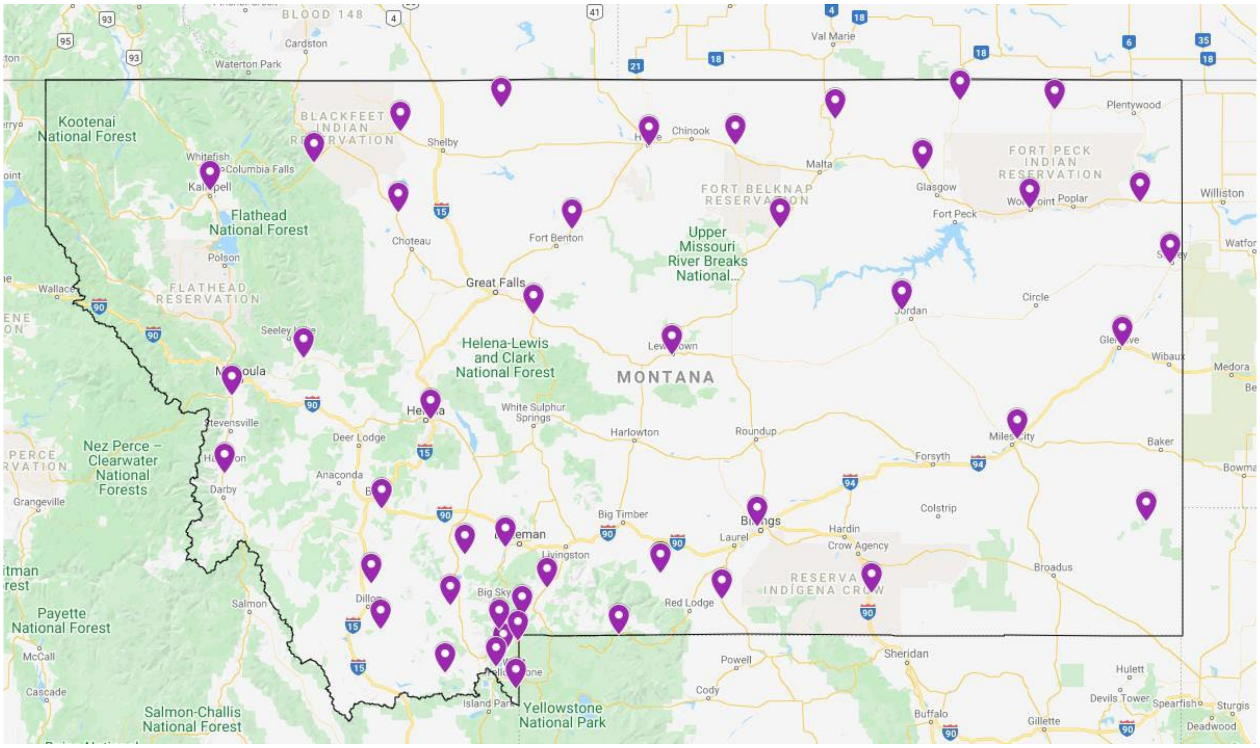
Montana CORSs - UNAVCO Network			
Station	**Location**	**Station**	**Location**
P045	Dillon, MT	**P458**	W. Yellowstone, MT
P046	Clearwater Junction, MT	**P460**	Big Sky, MT
P047	East Glacier, MT	**P461**	Merriman, MT
P049	Armington Junct., MT	**P680**	W. Yellowstone, MT
P050	Sweat Grass Hills, MT	**P706**	Dillon, MT
P051	Billings Airport, MT	**P707**	Red Rock Lakes, MT
P052	Jordan, MT	**P719**	Ennis, MT
P053	Whitewater, MT	**P722**	Fishtail, MT
P054	Ekalaka, MT	**NOMT**	Norris, MT
P055	Glendive, MT	**YBRA**	Red lodge, MT
P456	W. Yellowstone, MT	**BUEH**	Lima, MT

NCN – CORSs Map and Table



Montana CORSs - NCN					
Station	**Location**	**Station**	**Location**	**Station**	**Location**
HAML	Hamilton, MT	**MTLO**	Loma, MT	**P047**	East Glacier, MT
LOLO	Lolo, MT	**MTLW**	Lewistown, MT	**P049**	Armington Junct., MT
MSOL	Missoula Airport, MT	**MTMS**	MSU N. Havre, MT	**P050**	Sweat Grass Hills, MT
MTBR	Bridger, MT	**MTOP**	Opheim, MT	**P051**	Billings Airport, MT
MTCB	Culbertson, MT	**MTPJ**	Pendroy Junct., MT	**P052**	Jordan, MT
MTCU	Cut Bank, MT	**MTRC**	Sidney, MT	**P053**	Whitewater, MT
MTDT	Helena, MT	**MTSU**	MSU Bozeman, MT	**P055**	Glendive, MT
MTEI	Billings, MT	**MTSY**	Scobey, MT	**P706**	Dillon, MT
MTFV	Flathead Valley CC, MT	**MTUM**	Sunset, MT	**P707**	Red Rock Lakes, MT
MTGW	Glasgow, MT	**MTWP**	Wolf Point, MT	**P054**	Ekalaka, MT
MTHC	Butte, MT	**MTZM**	Zoteman, MT	**MTMI**	Miles City, MT
MTHM	Harlem, MT	**P045**	Dillon, MT	**P722**	Fishtail, MT
MTLG	Lodge Grass, MT	**P046**	Clearwater Junct., MT	**NOMT**	Norris, MT

TRIMBLE – CORSs Map and Table



Montana CORSs - Trimble's Network					
Station	**Location**	**Station**	**Location**	**Station**	**Location**
HAML	Hamilton, MT	**MTRC**	Sidney, MT	**P055**	Glendive, MT
LOLO	Lolo, MT	**MTSY**	Scobey, MT	**P456**	W. Yellowstone, MT
MTBR	Bridger, MT	**MTWP**	Wolf Point, MT	**p457**	Big Sky, MT
MTCB	Culbertson, MT	**MTZM**	Zortman, MT	**P458**	W. Yellowstone, MT
MTCU	Cut Bank, MT	**MTMI**	Miles City, MT	**P460**	Big Sky, MT
MTDT	Helena, MT	**NOMT**	Norris, MT	**P461**	Merriman, MT
MTFV	Flathead Valley CC, MT	**P045**	Dillon, MT	**P680**	W. Yellowstone, MT
MTGW	Glasgow, MT	**P046**	Clearwater Junct., MT	**P706**	Dillon, MT
MTHC	Butte, MT	**P047**	East Glacier, MT	**P707**	Red Rock Lakes, MT
MTHM	Harlem, MT	**P048**	Four Corners, MT	**P712**	W. Yellowstone, MT
MTLG	Lodge Grass, MT	**P049**	Armington Junct., MT	**P719**	Ennis, MT
MTLO	Loma, MT	**P050**	Sweat Grass Hills, MT	**P721**	Silver Gate, MT
MTLW	Lewistown, MT	**P051**	Billings Airport, MT	**P722**	Fishtail, MT
MTMS	MSU N. Havre, MT	**P052**	Jordan, MT	**P818**	Fishtail, MT
MTOP	Opheim, MT	**P053**	Whitewater, MT	**P819**	Fishtail, MT
MTPJ	Pendroy Junct., MT	**P054**	Ekalaka, MT		