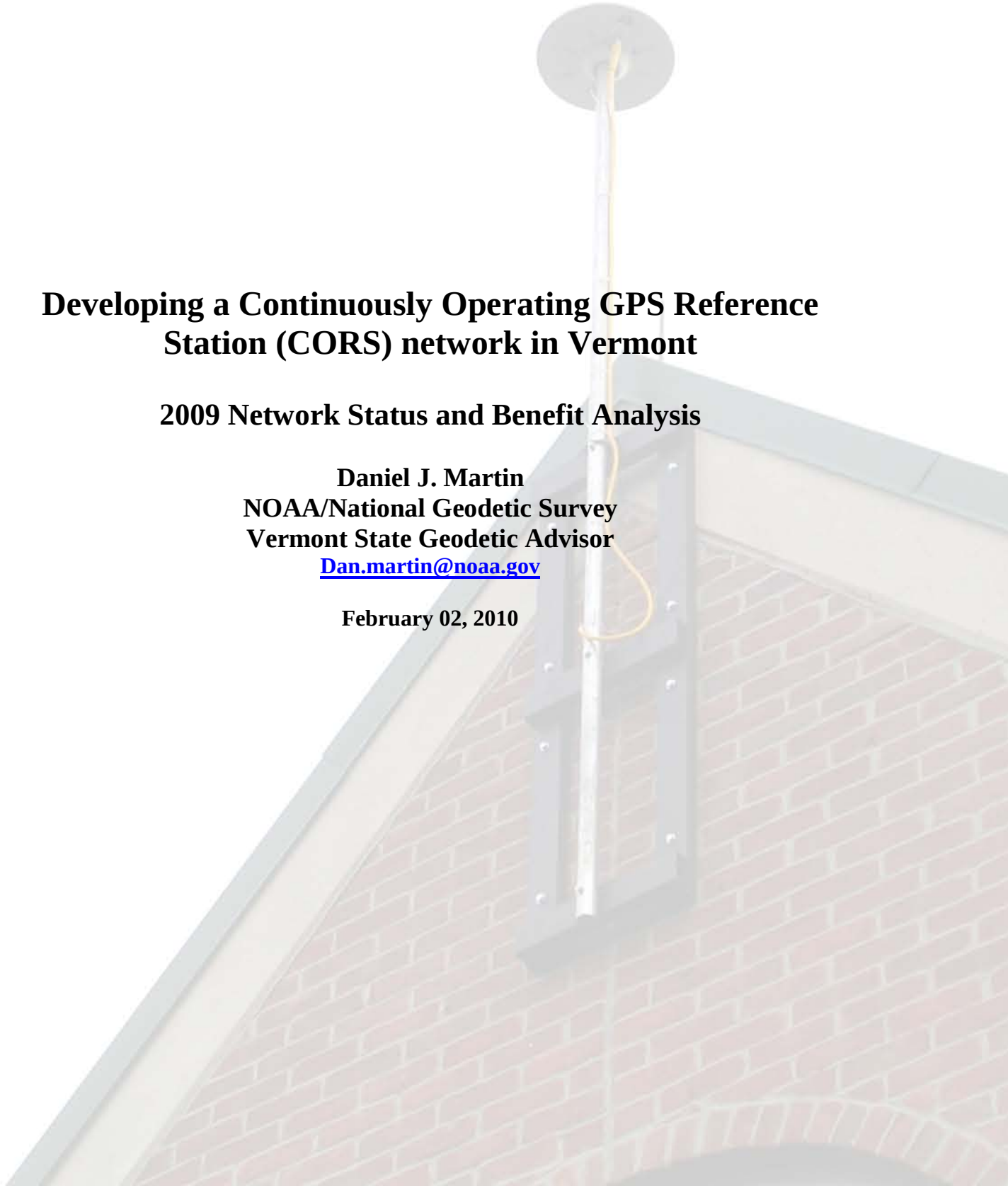

Developing a Continuously Operating GPS Reference Station (CORS) network in Vermont

2009 Network Status and Benefit Analysis

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Background

The use of the Global Navigation Satellite System (GNSS) for positioning and mapping has been steadily increasing since its introduction in the late 1980's. In the last few years, the use of GNSS has exploded across the country, primarily due to the establishment of regional or state-wide CORS networks that provide real-time correction data. The Vermont Agency of Transportation (VTrans) is in the process of building such a network with its primary purpose to support accurate positioning and mapping along Vermont's Interstate corridors and other major highways.

CORS are geodetic quality GNSS receivers and antennas that are permanently installed. These stations collect GNSS data continuously, and transmit data via the Internet to a central server. At the server, the data is archived for future use, and made available for download by any user. The incoming data is also processed at the server to generate corrections which are made available over the Internet to users in real-time. The Vermont network has been named VECTOR (**V**ermont **E**nhanced **C**ORS and **T**ransmission **O**f **R**eal-time corrections) to emphasize the expanded range of products available. For more information regarding VECTOR go to www.aot.state.vt.us/geodetic/CORS/vtcors.htm.

Real-Time Kinematic GNSS (RTK) is a method of surveying with GNSS that provides positioning accuracy at the 1-3 cm level. This is a form of differential GNSS requiring two receivers, one stationary (base) located at a known control station, and one rover to locate new positions. Since the base is located at a station with known coordinates, corrections can be computed and transmitted in real-time to the roving receiver, where they are applied to the raw positions being collected. Using this methodology, the occupation time required to determine accurate positions at the new locations ranges from seconds to minutes. This methodology therefore lends itself to projects where a large number of new positions are desired as the increase in efficiency can be as much as 300 to 500 percent over other methods. The CORS stations will serve as permanent bases.

The Interstate portion of Vermont's CORS network was designed to have a nominal spacing of approximately 40 km. Locating these stations in Vermont can be problematic due to site and infrastructure requirements. Ideally, the antenna needs to have an unobstructed view to the sky down to the local horizon; there must be a masonry building on site where the antenna mast can be mounted with maximum stability, and there must be power and high-speed internet available. Also, it is desired to have these stations in secure locations and it is preferred that they reside on State property.

In order to cover the interstate corridor, 10 CORS stations are required. There is an existing CORS at the University of Vermont that has been incorporated into the network. Nine additional locations were determined. These are:

- Transportation District 2 office in Dummerston

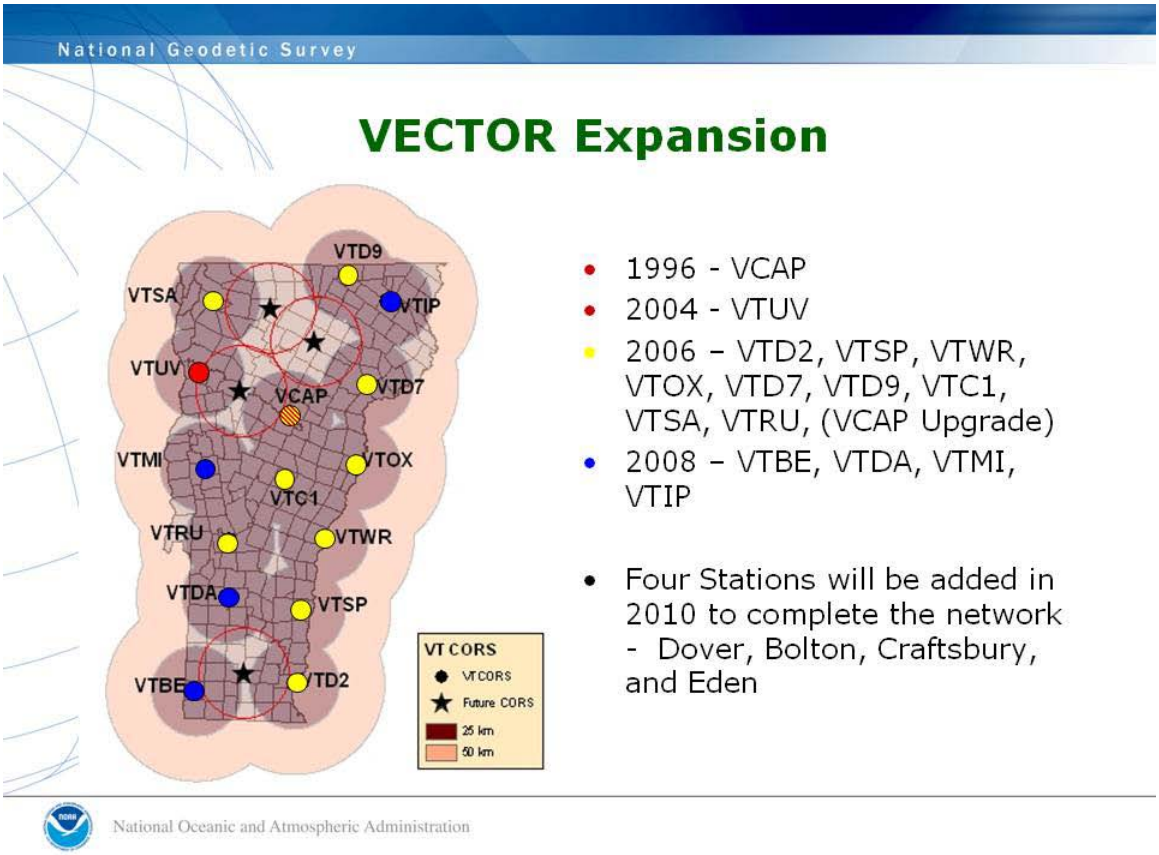
- Springfield High School in Springfield
- District Court House in White River Junction
- Oxbow High School in Bradford
- Transportation District 7 office in St. Johnsbury
- Transportation District 9 office in Derby
- Vermont Technical College in Randolph
- 133 State Street in Montpelier (existing station being retro-fitted)
- Bellows Free Academy in St. Albans

VTrans had previously secured separate funding for a station in Rutland. This station along with the previously mentioned stations were installed in 2006.

These stations were submitted to the National Geodetic Survey for inclusion into the National CORS Network. The National CORS Network currently consists of over 1300 stations that cover the entire United States, as well as the US Territories. For more information on the National CORS Network, go to http://www.ngs.noaa.gov/CORS/

Network Expansion

In 2007, The VTrans Geodetic Section funded the purchase of an additional four stations through their federally funded work program. These stations were installed in Bennington, Danby, Middlebury, and Brighton late in 2008. In 2009, four additional stations were purchased and will be installed 2010. These stations will be located in Dover, Bolton, Crastsbury, and Eden. The installation of these four stations will complete the network.



How is the VT CORS Network being used?

Data from the VT CORS network is being used for many different applications, far too many to list here in significant detail. However, it is fair to say that it is being used in virtually any application which requires the determination of precise coordinates. Some of these applications include:

- Highway surveys
- Collection of inventory and resource data including
    - Culvert inventory, Rest Area re-design, and ITS elements such as RWIS, PCMS/VMS, and WIMS location and planning
- Control surveys for aerial photography and LiDAR (Light Detection and Ranging)
- Topographic and Boundary Surveys
- Flood Plane mapping
- Wetland surveys
- Construction stakeout
- Geodetic and Geophysical applications and research such as:
    - Ionospheric modeling
    - Plate tectonics
    - Precipitable Water Vapor modeling (weather forecasting)

Who is using the VT CORS Network?

VTrans is making significant use of the VT CORS Network. Beginning in 2007, they began using the network to establish geodetic control along the I-89 and I-91 corridors to support the eventual placement of fiber optic cable. Additionally, the Roadway Design section of the Agency was undertaking a project to inventory all of the small culverts along the VT interstates. They were able to take advantage of the newer technology which allowed them to locate the culvert ends much more accurately (horizontally and vertically to within a few inches) than they could have otherwise done. An added benefit of having the culverts located so accurately is that the data can be used to aid in the design of the fiber optic line. The accurate horizontal and vertical location combined with an accurate elevation model allows the determination of whether the line can go over a culvert or if boring is needed to go under the culvert.

It is difficult to quantify just who is using the data from the VT CORS Network aside from VTrans as much of the data is made available through anonymous downloads via the Internet. However, through interaction with the user community, it can be broadly determined as to the type of users of the system. Some of these users include:

- Land Surveyors
- Engineering firms
- GIS Professionals
- Foresters

- Other State Agencies such as the Agency of Natural Resources and Department of Agriculture
- Other non-Vermont State Agencies
- Federal and International Agencies, and educational institutions
    - National Weather Service
    - Army Corps of Engineers
    - National Geodetic Survey
    - US Geological Survey
    - Geodetic Survey Canada
    - International GNSS Service
    - Universities of Vermont, Maine, and New Hampshire; Lyndon and Johnson State Colleges, Norwich University

The six stations along Vermont's western border stream data to the NY DOT where they are included in the New York network NYSNET. This allows users of NYSNET to compute network corrections while working along the border. The data for all VT stations is also streamed to a privately run RTN where network corrections (value added service) become available to users in Vermont for a subscription. Another vendor has also shown interest in acquiring the VT real-time data for inclusion into their network.

How is the VT CORS Network being accessed?

There are a number of ways that the raw data or derived products from the VT CORS Network are available. Below is a brief description of these data products.

Raw Data

- Raw data from the VT CORS Network is available for download from the State of Vermont Geodetic Survey Web Page www.aot.state.vt.us/geodetic or through a password protected ftp site run by the Vermont Geodetic Survey. Applications have been written that track the download activity.
- Data for all Vermont stations that are currently part of the National CORS Network are also available for download from the National Geodetic Survey's "User Friendly CORS" (UFCORS) application at www.ngs.noaa.gov/UFCORS and the NGS provides an online utility that provides download statistics for each station on a monthly basis.

Derived Products

- The NGS provides a service called the Online Positioning User Service (OPUS) www.ngs.noaa.gov/OPUS that allows a user to collect a minimum of 15 minutes of GNSS data (OPUS_RS) or a minimum of 2-hours of GNSS data (OPUS_S) and submit it for processing by NGS' computers relative to stations in the National CORS Network. OPUS_S uses three CORS stations to compute the user's position while OPUS_RS uses up to nine CORS to compute the user's position. There are many advantages to using OPUS, but the primary advantages are that the user does not need a second GNSS receiver, the user does not need to process their own data, and the results are e-mailed to the user within a few minutes. OPUS submissions can be tracked monthly by county.

- The NGS also provides a service whereby a user can have the coordinates of their OPUS_S observation published in the NGS Database for others to use. This service is named OPUS_DB. OPUS_DB is a very attractive alternative (do to its simplicity and time savings) to the other accepted method of publishing GNSS data in the NGS database (BLUEBOOKING). Submissions to OPUS_DB can be tracked by county, by submitting user e-mail, or visually on an interactive map.
- The State of Vermont makes real-time corrections available to users over the Internet www.aot.state.vt.us/geodetic/CORS/vt-real-time.htm for use in Real-Time Kinematic (RTK) Surveys. Users in the field who have the proper equipment, access to a cellular data network, and who have requested a user account for real-time access can make use of these corrections to position themselves in the field to within a couple of inches or better. Occupation time for these users can be as little as a few seconds. Usage of Vermont's real-time corrections can be tracked by user and by the duration of connection to the service. Another 19 real-time user accounts were added in 2009 bringing the total to 51. Of these 51 users, 36 accessed the real-time 2009.

Cost/Benefit of the VT CORS Network (Initial investment)

Cost - The initial system investment into the VT CORS Network which was made to support the fiber optic project on VT's Interstates was approximately $340,000, which includes nine CORS receivers and antennas, system software, installation, and the required field equipment needed to make use of the system.

Benefit - The benefit of any system investment can really only be measured in terms of some kind of savings. In the case of the VT CORS Network, these savings can be quantified by measures such as:

- Reduction in person hours to accomplish a task
- Reduction in the amount of purchased equipment required to accomplish a task
- Reduction in purchased software

The above measures are fairly easy to quantify as they are primarily based on production time. Benefits in the way of time saved can be determined by simply comparing time and associated equipments costs of one method vs. that of another

There are often many less obvious benefits or ones that are difficult to quantify, such as having to keep up with training on many different types of equipment or software or even the cost of maintaining many different types of equipment instead of just one. Other benefits that are difficult to quantify are the consistency and reliability of a system. Though these are important, we will not attempt to quantify these.

In order to quantify the benefits of the VT CORS, some generalities have been made.

1. One CORS station replaces the need for one field receiver and one operator.

2. Without the CORS Network, an observer and field receiver would need to spend an average of two hours to collect and download one hour of data (including travel time.)
3. The average UFCORS download consists of two hours of data (reported by NGS.)
4. The cost for one observer and field receiver is $50/hour each.
5. FTP users are more likely to be using "resource-grade" equipment which does not require the same observation time, and the CORS does not need to be nearby. Therefore, a resource-grade user could operate in VT (though with less accuracy) by using non-VT CORS. It is thought to be that the benefit of FTP data is half of that of data retrieved from the web page.
6. The average time and software investment to BLUEBOOK and submit a GPS observation to NGS is eight hours.

Based on the above, the following benefits or savings have been computed for each of the previously mentioned VT CORS Products:

Product	*User Benefit*
UFCORS	$200/download
VT Web Download (VTDL)	$100/1-hour file
VT FTP Download	$50/1-hour file
OPUS_S	$600/solution
OPUS_RS	$600/solution
OPUS_DB	$400/submission
RTK	$100/hour

Table 1 – User Benefits per VT CORS Product

Direct Benefit to VTrans

RTK
The RTK Logs for 2009 were downloaded and filtered to only include connections by known VTrans usernames. It was found that the duration of VTrans user sessions was 812 hours in 2009.

OPUS_S
VTrans Geodetic Section submitted 97 stations to OPUS_S for the purpose of having them published in OPUS_DB

OPUS_DB
VTrans Geodetic Section submitted 97 stations to OPUS_DB in 2009.

Other
VTrans used other VT CORS Products (downloads, OPUS_S, OPUS_RS) in 2009 however since a username is not required for these products, there is no way to track VTrans specific use.

Based on the user benefits listed in Table 1, the chart in Figure 1 was developed to show the direct benefit of the VT CORS Network to VTrans. As shown in figure 1, the total benefit to VTrans in 2009 was $178,000. This added to the previous VTrans benefit of $214,000 gives a total VTrans benefit of $382,000 which is 112% of the initial investment.
As predicted last year, the direct benefit derived by VTrans paid for the initial system investment in only three years of operation. This again demonstrates the high benefit to cost ratio of real-time CORS networks.

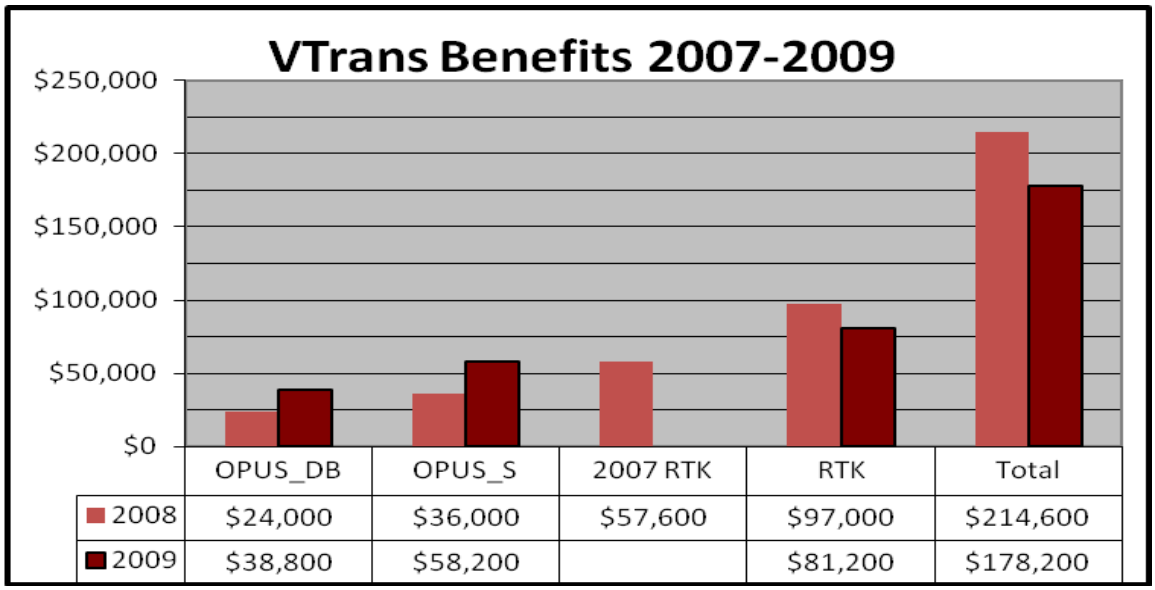


Figure 1 – VTrans Benefit (2007-2009)

Cost/Benefit of the VT CORS Network (Current level of investment)

As stated above, eight additional CORS stations have been purchased by Geodetic Survey since 2007. The cost of these eight additional stations and site licenses was approximately $195,528. Additionally, each year the State purchases extended warranties for the CORS receivers as well as the primary system software. The total extended warranty cost for the system since it was implemented is $32,140. This brings the current level of system investment to approximately $567,668.

When measuring benefit it is reasonable to include ALL benefit to the taxpayers of VT not just the benefit to the tax payer as realized by VTrans' use. Since the data and products of the VT CORS Network is available to the public and is being used by the public, it is reasonable to assume that they are deriving a benefit from its use. This use has been tracked for the year 2009 and is reported below in Table 2 and Figure 2.

Product	*2009 Usage*
UFCORS Downloads	2364 2-hr files (ave)
VT Web Download (VTDL)	5880 1-hr files
VT FTP Download	8098 1-hr files
OPUS_S	816 Solutions
OPUS_RS	564 Solutions
OPUS_DB	97 Submissions
RTK	1614 Hours

Table 2 – VT CORS Data and Product Usage in 2009

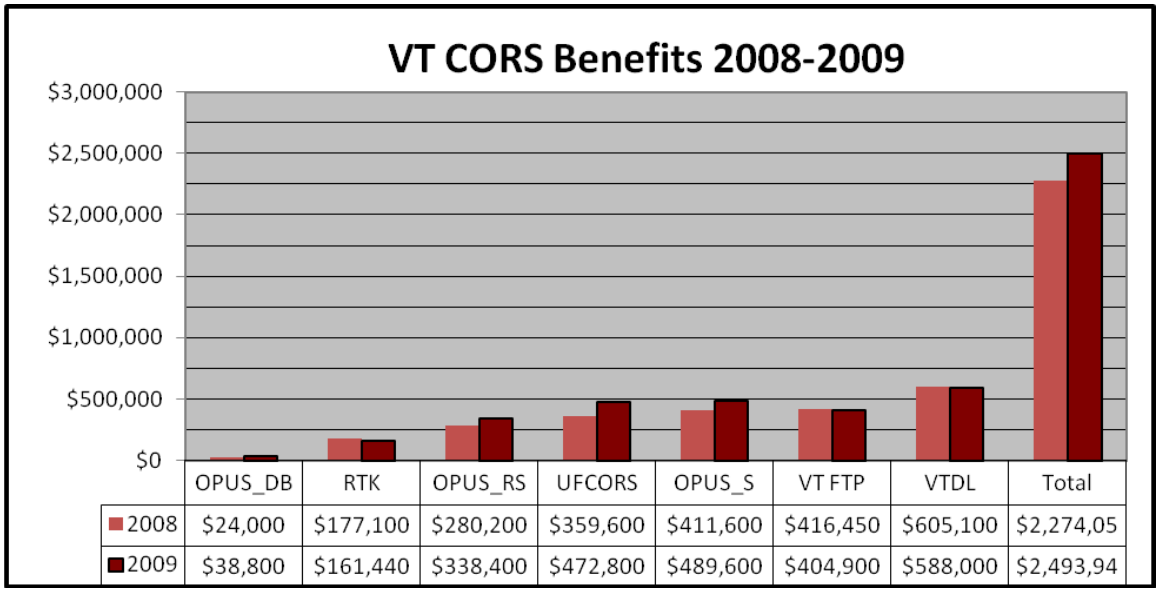


Figure 2 – Taxpayer Benefits in 2008 and 2009

Based on the user benefits listed in Table 1, the chart in Figure 2 was developed to show the total benefit of the VT CORS Network to the tax payers of VT. As shown in figure 2, the total benefit of the system in 2008 was $2,274,050 or approximately 472% of the system investment as of 2008. An additional benefit of $2,493,940 was realized in 2009 for a total benefit of $4,767,990 or 840% of total system investment in only three years of use.

Summary

The VT CORS Network has provided significant benefit to VTrans users and the tax payers of VT, and supports a variety of different applications from a diverse user community outside of VTrans. The information in this report shows that the direct savings VTrans has realized has paid for the initial system investment and should be on track next year to overcome the total system investment. There was only a modest increase in usage/savings from 2008 to 2009. This may be a reflection of less survey activity due to a sluggish economy.