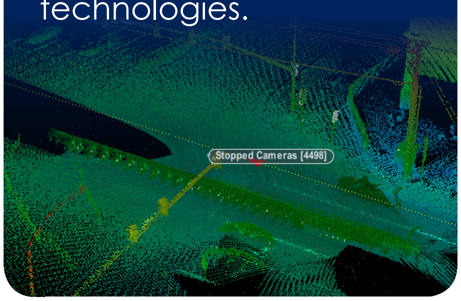
3D Engineered Models:

Schedule, Cost and Post-Construction

PROGRAM CASE STUDY

This case study highlights the Oregon Department of Transportation's journey in setting the groundwork for better use of survey data for both engineering and geographic information system workflows, with a focus on the Oregon Coordinate Reference System implementation. It is offered as a general aid for those considering similar efforts and as an educational resource for understanding the geospatial foundation for 3D engineered model-based technologies.



The Oregon Coordinate Reference System: A Surveying Approach for Supporting Geospatial-Based Technologies in Transportation Applications

State transportation agencies (STAs) rely on survey data to develop contract plans for roadway and bridge construction. The introduction of global navigation satellite systems (GNSS[1]) and other geospatial surveying tools has made it more efficient to collect data than with tools of the past. GNSS-based technology has made it possible to use automated machine guidance (AMG) equipment for roadway and bridge construction and disseminate information via geographic information systems (GIS). Additionally, it has created a society that is more geospatially aware, with expectations for real-time information (road conditions, work zone updates, etc.) via mobile devices, thus making geospatial data collection an essential activity to support the entire organization in meeting its mission. However, integrating survey data with GIS geodatabases and other geospatially based technologies is not as easy as it may seem, mainly due to differences in data accuracy and how it is referenced to the ground.

Considering the benefits of geospatial data for both engineering- and GIS-related business practices, STAs are looking for ways to better integrate the two. Setting a geospatial foundation that can accommodate the accuracy needs for survey and engineering data, and support GIS-based mapping, is critical to solving the data integration challenge. Figure 1 illustrates some of the GNSS-based technologies used in transportation applications.

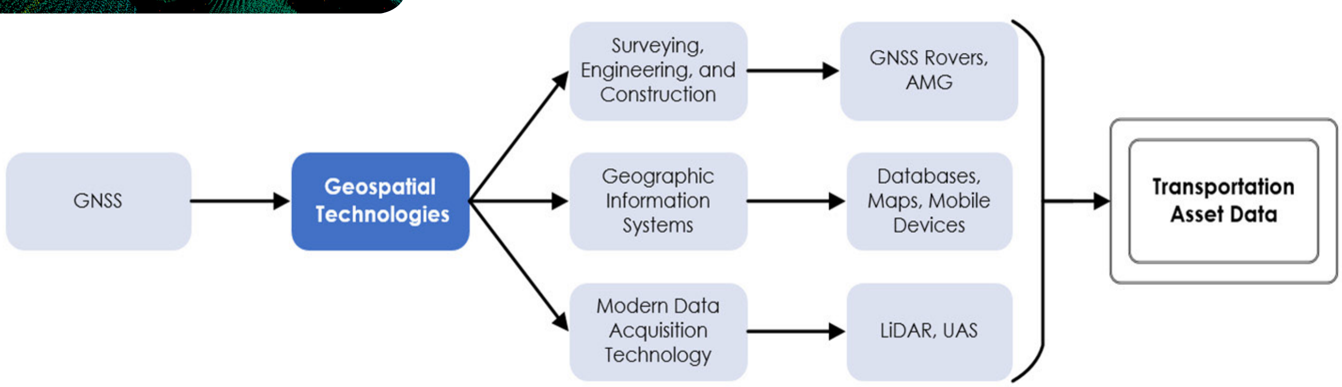


Figure 1: GNSS-Based Technologies Used in Transportation Applications

1 GNSS is the generic name for any country's global navigation satellite system, such as the U.S. NAVSTAR Global Positioning System (commonly called GPS), the Russian GLONASS (GLObal NAvigation Satellite System), the Chinese BeiDou Navigation Satellite System, and the European Galileo system.

Oregon: Organizational Overview

The Oregon Department of Transportation (ODOT) manages more than 9,000 centerline miles of state highways and nearly 3,000 bridges. The Highway Division is the largest agency functional group. It provides technical and engineering support for project delivery, maintenance, and operations for the organization through its centralized units in Salem and five geographic regions.

One of the centralized groups in Salem is the Technical Services Branch, which provides technical support for the organization's project delivery, construction, maintenance, and planning programs. Specifically, the Engineering Automation Section provides leadership and technical services for all aspects of engineering automation for survey, design, construction, and supporting systems. The section is further divided into two units: Geometronics and Engineering Technology Advancement.

The Geometronics Unit provides support for survey operations, geodetic control and administration of the statewide real-time GNSS network, remote sensing and photogrammetry, right-of-way engineering, unmanned aircraft systems, and records maintenance for maps and plans related to project delivery activities (survey, engineering, etc.). The Engineering Technology Advancement Unit is responsible for leading the research of new, innovative solutions and implementing engineering-related technology initiatives through collaboration with the ODOT Region Technical Centers to benefit the entire organization.

Understanding Geospatial Data

Even as industry has come to rely heavily on GNSS, it is still difficult to align survey data with GIS and other geospatially based technologies. This is because, while both survey and GIS data provide location information, they are often not compatible. The challenge of integrating survey data collected for engineering purposes into GIS maps and databases lies in the accuracy and characteristics of the data itself.

The fundamental purpose of survey data collection is to provide location and elevation positioning to support engineering design and construction-type functions, thus requiring a certain level of accuracy to meet the needs of the construction equipment and practices. However, until GPS became a mainstream technology used in many types of construction equipment, survey data was not necessarily tied to a standard geospatial coordinate system; although the data was always linked to a local reference system location and elevation (i.e., benchmarks) using geomatic techniques[2]. On the other hand, GIS data has always relied on a standardized grid coordinate system suitable for creating two-dimensional maps that only required a level of accuracy to approximate the location to a general area.

Like other STAs, ODOT has been collecting survey data with a variety of surveying equipment and techniques for as long as the highway construction program has been in existence. Surveying instruments and techniques have evolved to improve speed and accuracy of data acquisition over the years to support the development of highway and bridge construction plans based on topographic and contour maps. Geodetic surveys collected for larger projects were based on the state plane coordinate system positions projected to ground distances, but smaller projects were based on some *assumed* coordinate system[3].

As engineering became more automated (in the 1980s), ODOT saw value in collecting survey data for all projects on the state plane coordinate system, commonly called the Oregon State Plane Coordinate System. The state plane coordinate systems were designed for each state by the U.S. Coast and Geodetic Survey

2 Geomatics is the science and technology of gathering, analyzing, interpreting, distributing, and using geospatial information. It encompasses 3D surveying and mapping, geographic information systems, and global navigation satellite systems. http://healthcybermap.org/HGeo/pg2_1.htm. Accessed February 4, 2016.

3 Arbitrary points not referenced to a known coordinate reference system

starting in the 1930s. However, it quickly became apparent that there was a lot of linear positional distortion[4] inherent in the state plane coordinate system, based on the topography of the region in which the data was collected and on other factors.

The linear distortion inherent in state coordinate systems was acceptable when survey standards were based on the accuracy achieved with legacy surveying systems. However, it was very clear that this legacy state coordinate system was not going to support modern systems that use geospatial technologies (i.e., GPS, AMG, and GIS), and a new solution had to be found.

> "As we started automating more, and AMG started being used in construction as a standard practice, the old system was no longer acceptable. We began searching for something else that would work better for modern times."
>
> – Ron Singh, PLS, ODOT Engineering Automation Manager/Chief of Surveys

ODOT realized that the following considerations were necessary to achieve accurate three-dimensional (3D) geospatial positions using GNSS:

- Minimize error inherent in GNSS positioning by providing real-time differential correctors through establishing a statewide real-time GNSS network
- Improve the geoid model to yield better elevation information
- Reduce distortion resulting from use of the legacy state plane system by implementing a low-distortion coordinate system

ODOT first accomplished the establishment of the Oregon Real-Time GNSS Network (ORGN), shown in Figure 2, which allowed for GNSS positioning algorithms that would yield accurate positions without having to set up a temporary base station on control points. Then the agency focused on improving the Oregon geoid model through a statewide height modernization campaign in collaboration with the National Geodetic Survey (NGS). Lastly, ODOT created a new coordinate reference system that would minimize distortion to achieve values as close as possible to ground coordinates. The system would be standardized as ODOT survey project data is collected and shared with other functional units in the agency using geospatial-based technologies.

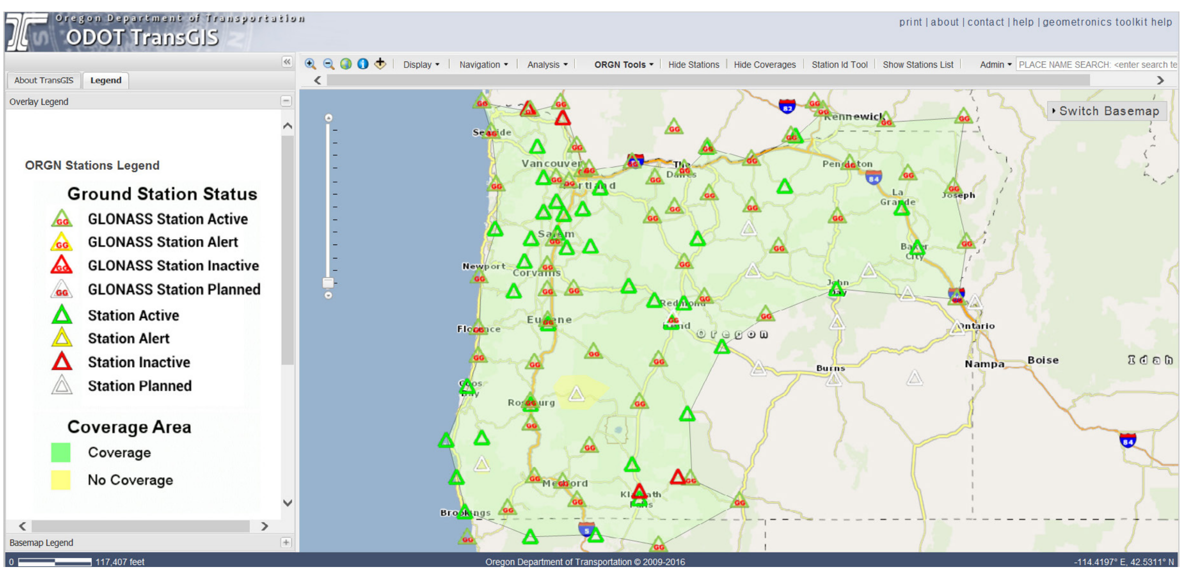


Figure 2: Oregon Real-Time GNSS Network (ORGN) Status Map

4 Linear distortion is the difference in distance between a pair of grid coordinates when compared to ground coordinates. It can be positive (grid length longer than ground) or negative (grid length shorter than ground).

A New Coordinate Reference System to Support 3D-Based Technologies

The history of surveying practices and the current challenges of working with legacy coordinate reference systems helped ODOT identify major issues to eliminate or avoid when establishing a new system. Lessons from the past also helped prioritize the characteristics wanted in a new solution. The new solution needed to ensure that the coordinate reference system could do the following:

- Become a standardized system accepted by the geospatial community
- Be tied to the National Spatial Reference System and be recognized by the NGS
- Minimize distortion of coordinate values
- Support geospatially based technologies today and in the future

Developing a new coordinate reference system is not an easy task, and ODOT understood there would be a significant level of effort to achieve their goal. There were essentially a number of campaign efforts to implement what is now the Oregon Coordinate Reference System (OCRS). Specifically, the subsequent campaign efforts were part of the agency's implementation plan:

- Educational outreach
- Research and development
- Revisions to the Administrative Rules and State Statutes

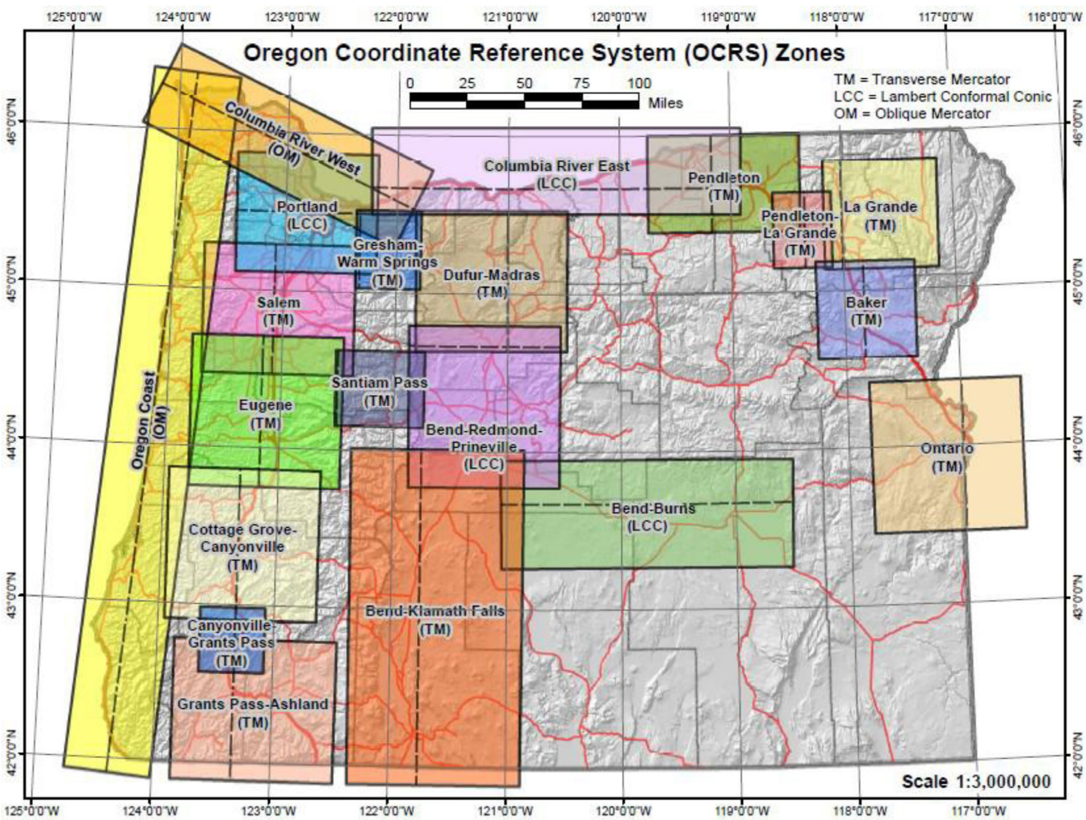


Figure 3: Map of the OCRS Zones. (Image Courtesy ODOT)

Challenges and Lessons Learned

One of the challenges was the level of effort involved to communicate to various stakeholders why the problem existed and why it was important to solve. They needed to understand (1) that there was a problem, (2) the root of the problem, and (3) why it was necessary to make a change.

ODOT gained support from the surveying and geospatial community through an active educational outreach program. The education campaign was conducted through workshops and presentations to the state geospatial and surveying community. Another effort related to this campaign was to engage the NGS early on to be part of the discussions. ODOT hosted a one-day workshop and invited the NGS director and the public and private geospatial community to participate. The educational outreach campaign resulted in garnering the support of the geospatial community as a single voice.

Another challenge the agency encountered was technical in nature. It was apparent that there were several solutions for developing a low-distortion coordinate system, but the right approach for meeting the needs of the surveying community had to be identified. The goal was to minimize the linear distortion in such a way that led to coordinates that were as close as possible to the ground values. It is important to note that it is impossible to create a low distortion system that results in grid coordinates equaling ground, as the latter is constantly changing. However, the goal was to minimize the linear distortion in regions with acute topographic changes.

One of the approaches considered was a county-based coordinate system, but it was ruled out simply because low-distortion coordinate zone design is dependent on topography and not political boundaries. ODOT consulted with a professional geodetic consultant to come up with the mathematical solution to calculate a system that would produce the least distortion possible based on the topographic characteristics of the state. ODOT created a technical team of public, private, and academic professionals to work alongside the consultant in developing the OCRS. The team also wrote language that would be used in a legislative bill that eventually became state law. ODOT developed a handbook and user guide to serve as a single source of information, including the history and technical approach for developing the OCRS[5].

"We wanted to be transparent and let the geospatial community know that the OCRS was not only for ODOT's use, but a valuable system that could be utilized by everyone in Oregon. We wrote into the law that the OCRS would be managed by a committee that includes members from the Oregon geospatial community."

– Ron Singh, PLS, ODOT Engineering Automation Manager/Chief of Surveys

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The implementation of the OCRS was successful due to the vision and support of ODOT leadership, efforts to collaborate with all stakeholders that may be impacted by the new system, and previous work ODOT did in establishing the statewide real-time GNSS network, improving the geoid model, and establishing the partnership between the public-private industry and academia.

A state Senate bill with language to include the OCRS as a legal coordinate system available for state surveyors was introduced in 2011 and passed into a state law that went into effect on January 12, 2012. The statute established the new zones associated with the system, but does not oblige anyone to use the OCRS. ODOT surveying specifications require the use of the OCRS for all roadway work.

5 User guide can be accessed through: ftp://ftp.odot.state.or.us/ORGN/Documents/ocrs_handbook_user_guide.pdf

Oregon laws refer to State Administrative Rules, which indicate all the detailed specifications and regulations and are managed by specific agencies, thus making ODOT responsible for keeping the new administrative rules regarding state surveying coordinate systems. As required by the Senate bill, ODOT established a State Advisory Committee to manage the OCRS Administrative Rules. This committee has members from ODOT, private and public agency land surveyors, and the GIS community. All members have specific terms. Both the Administrative Rules and the Advisory Committee create transparency in the process.

The Future of Surveying in Transportation Applications

Survey data has long been used in the design and construction of roadway and bridge projects, but its use goes beyond project delivery. Geodetic surveys provide the foundation for collecting geospatial data that can benefit the entire organization. Geospatial data that is accurate, sustainable, and accessible is an asset in itself, and it should be treated as such.

STA's project delivery and transportation asset management processes rely on GNSS-based solutions (such as AMG and programmatic asset inventory collection), so it is critical to set the geospatial foundation in such a way as to optimize resources and maximize data use for making intelligent business decisions for managing transportation assets.

ODOT's goals for geospatial data are to capture it, manage it, and use it often. ODOT is not alone in setting the vision for using geospatial data beyond the project, which is a small portion of the asset's lifecycle. In fact, it is a vision shared by many STAs, but achieving this goal is not easy and requires much planning and significant investment to manage this vast data correctly.

Geospatial data should be captured, stored, shared, and validated to ensure sustainability and accessibility over time, taking into account changes in technology. Moreover, the benefits that can be realized from geospatial data require a commitment to implement geospatially referenced 3D design.

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Every Day Counts (EDC), a State-based initiative of FHWA's Center for Accelerating Innovation, works with State, local and private sector partners to encourage the adoption of proven technologies and innovations aimed at shortening and enhancing project delivery.

U.S. Department of Transportation
Federal Highway Administration

FHWA-HIF-16-023