

**OREGON
DEPARTMENT
OF
TRANSPORTATION**

Highway Division

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Engineering Automation
Key Concepts for a 25 Year Time Horizon

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Introduction

ODOT has been involved in automating its engineering efforts for the past 25 years. The agency transitioned from utilizing mechanical survey instruments; performing hand calculations; designing on paper; and hand drafting, to the use of electronic survey instruments; personal computers; and software for design and drafting in a fairly short timeframe. These systems were fully implemented within the first five years or so, and although evolved somewhat since then and become part of routine business, the basic framework, functionality, and limitations remain the same.

Although this document focuses primarily on engineering automation issues, it will also discuss systems or technologies that effect, or are affected by, engineering automation.

ODOT's approach to utilizing engineering technology within these first 25 years was primarily focused on speeding up the project development process with the end goal of producing paper construction documents. This effort although appropriate, has reached the end of its lifecycle, and needs to undergo a complete transformation in order to position the agency for the next 25 years. The next 25 years will see engineering data being used for much more than simply producing construction plans, or managing agency assets. For example, we could expect with reasonable certainty that construction machine automation (described later in this document) will be fully implemented and part of our routine business. Although much less certain, we could also imagine intelligent vehicles plying intelligent freeways within, or shortly after, this time period.

25 Year Time Horizon

A *Time Horizon* is how far you look ahead to develop a plan. Different types of tasks, jobs, and plans require different time horizons.

Due to the size of the agency; the volume of data and/or documents produced or archived; the complexity of the work; and a completely new set of engineering automation goals, a long time horizon is required for managing engineering automation initiatives.

This document suggests a 25 year time horizon be developed and then modified annually to adjust to changes in needs, emerging technologies, and automation accomplishments. The 25 year term does not imply that there will be technology initiatives being planned for 25 years out, but simply suggests that staff managing engineering automation plans look far into the future to forecast where we can expect to be, and then best position the agency to get there successfully. Shorter 5 and 10 year plans with specific automation initiatives would need to be developed with those long range goals in mind. Each of these major initiatives would need to be further broken down into manageable tasks to be performed within an annual or biannual period.

Purpose of This Document

This document presents the “big picture” as it relates to engineering automation in ODOT’s future. It will describe, from a very high level viewpoint, the “key concepts” that should be very much a part of the agency’s future automation plans. The document will also illustrate the

connectivity of these key concepts, which is vital to the success of a well thought out overall engineering automation plan.

This document will also serve to promote discussion to get to a common understanding and agreement of the big picture; to document the agency's long term goals; and to define the roles and responsibilities of various groups involved.

Lessons Learned

There were many lessons learned in the first 25 years of engineering automation. Hardware manufacturers, software developers, and forward thinking technology administrators, learned from positive experiences and are further exploiting them. They also learned from negative experiences and are developing solutions to overcome them. However, some of these negative experiences have created a strong belief by many that those barriers will always exist.

Most engineering software was designed to emulate the processes of the past. This was reasonable for the early transition to automation, but reinforced the minds of many that those processes should never change. For example, "levels" or "layers" in CAD files were developed to emulate the layering of Mylar sheets on top of others, giving the engineer the ability to view certain types of data superimposed over others. There are better ways to selectively view data today, but users typically resist.

We need to be open to new and different ways of accomplishing tasks, and not perpetuating the limiting processes of the past. Engineering automation leaders should be educating the users and championing the need for change.

Various Groups and Their Roles

In the context of Engineering Automation, there are various groups involved. These groups are listed below along with their suggested roles and responsibilities:

Group	Description	Roles and Responsibilities
Automation Leaders	Those involved in developing and maintaining the agency's long range engineering automation plans.	Should be the developers and keepers of the long Time Horizon plan. Should understand engineering processes and the needs of the users. Should work closely with hardware and software developers to influence the direction of their development.
Users	Those involved in performing the actual surveys, design, drafting, and associated engineering work. These include ODOT and consultant staff.	Should input towards automation ideas and provide feedback on strengths and weaknesses of their current process, but should not be burdened by evaluating, configuring, or testing new technology.
Information Systems (IS) Staff	Those involved in determining the technical IT requirements, compatibility with existing systems, and	Should work closely with the automation leaders to understand the long and short range plans and provide IT expertise and resources to accomplish specific tasks.

<i>(Continued from previous page)</i>	performing the installation.	Limited internal IS resources should not be a factor in the decision to implement an initiative. These resources may be contractors.
Viewers	Those that have a need for final engineering products for non-engineering related needs	Should have controlled access to the non-sensitive data, but should not be able to add, modify, or delete content.
Hardware Manufacturers	Companies involved in developing the hardware related to engineering automation.	Should develop their systems to input and output exchangeable file formats. Should solicit input from users.
Software Developers	Companies involved in developing software related to engineering.	Should develop "Open" or 100% exchangeable file formats. Collaborate in further development of the XML concept. Should solicit input from users.

Common Misconceptions

There are numerous misconceptions engrained in the minds of many that need to be dispelled in order to move forward with new engineering automation initiatives. Some are listed below:

- *"We have always done it this way"*
This is a huge institutional barrier. It is important to remind those that think this way, that processes were developed to accommodate the abilities and limitations of the era. It is not just reasonable, but may also be vital to abandon some of those tried and true processes for new ones that are designed around the functionality of systems today. However, changes to long standing processes should be made only after careful consideration for the current situation, and those of the future.
- *"Paper records will outlast digital files. Try opening a file developed with an obsolete software package, stored on a 5 1/4 inch floppy disk"*
This is true... so far. Users and software developers have all learned this lesson and are taking steps to mitigate this. It is important to have staff whose job is to manage data. They should be responsible for data storage, backups, retrieval, and forward migration as storage media and/or file formats change.
- *"Coordinates have little value"*
In years past, coordinates were given little value due to their resultant nature and limited use. Today, coordinates are easy to develop and have tremendous use. This use is limited today by the fact that individual project sites, even though on a State Plane coordinate system, have been developed using their own local factors. For coordinates to have the ultimate value in a transportation environment, all elements of the highway system need to be on a common low distortion coordinate system (described later in the document).

- “GIS data is not for engineering”

There is nothing preventing engineering data from being stored and retrieved in a GIS environment. The primary distinction between engineering data and what is typically considered GIS data today, is positional accuracy and level of detail.

- “We cannot afford automation initiatives”

If this was true 25 years ago, we would still be hand drafting today. Some of the primary purposes of automation include, reducing development time and cost, and increasing precision and safety. If these goals are not achieved by the automation initiative, then that holds true... we cannot afford it. However, if managed well, investments in automation will prove that “we cannot afford not to automate”.

Key Concepts for the Future

As mentioned earlier, it is nearly impossible to determine the technologies that will exist 25 years into the future. However, it is fairly easy to envision certain aspects of engineering automation that will exist in the future, and identify current issues that are keeping us from getting there.

This section of the document will list some key concepts that should be reviewed and approved to become a fundamental part and guiding principle of ODOT’s future engineering automation efforts. Each concept will be described very briefly, and would need to be further studied and detailed once approved as part of the overall engineering automation plan.

If a thirty-year projection sounds like science fiction, it may be wrong. If it doesn't sound like science fiction, then it's definitely wrong.

Chris Peterson

Digital Data – Creation, Storage, Retrieval, and Forward Migration

It doesn’t take any imagination to envision an ever increasing digital data world. Although we may all agree that there will be more digital data in the future, we need to consider several factors that must be part of that digital data future.

Our engineering automation efforts should always include the creation of digital data. For this data to be of value from the time it was created, to even beyond the time it becomes obsolete, the data must be:

- Reliable – Quality Control systems should be developed to ensure that the data truly represents what it should.
- Retrievable – Backups and archives should be strictly maintained, and data storage locations published.
- Secure – Provisions should exist for managing check out/check in, revision, privacy, and general security.
- Readable – The data should follow a rigid and published file format so that current and future systems can open and read the file. These data standards should be universal and not specific to a specific owner or agency.

Data Management Philosophy:

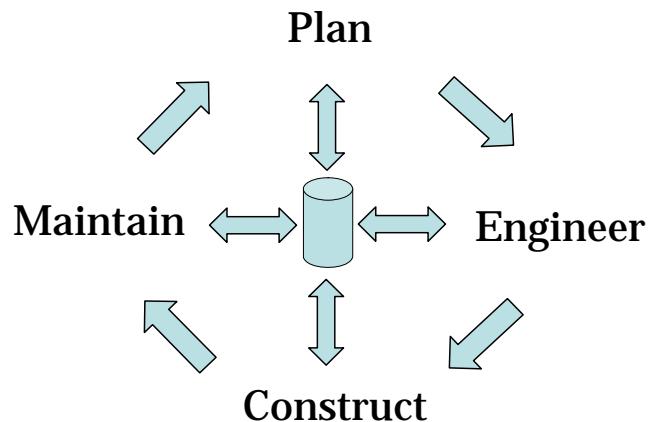
- Create Once
- Manage Well
- Publish Many Times
- Utilize Continuously

- Traceable – Metadata should be included with the data to provide information relating to its source, accuracy, etc. Any data superseded by new data should not be deleted, but kept for historical reasons.
- Spatially Enabled – Engineering data should be geospatially enabled. In addition to a normal query, a user should be able to search for any type of engineering data by its geographical location. Documents such as CAD drawings, geo-referenced images, and GIS shape files, are inherently spatially oriented, while others such as Microsoft Office documents would need to be geospatially referenced.
- Migrated Forward – Data managers must ensure that all engineering data is migrated forward to replacement file formats and storage media as the existing ones become obsolete.

Managing Infrastructure Life Cycle Data

The life cycle of any section of highway could be described as sequencing through phases as shown in the diagram to the right. The traditional project management approach considers that the life cycle begins at the Plan stage and progress though the Engineer, Construct, Maintain, and back to the Plan stage again. This is shown by the single headed arrows forming the outer circle.

The diagram also may be used to describe the data flow in the engineering management of that section of highway. The double headed arrows in the center indicate that each stage could retrieve data from a central data repository; modify it or create new data and store it back.



The engineering data management life cycle is best considered to begin at the construction phase, because that is when the construction element is first created (or born) and its life cycle begins. Once a post construction survey is completed (described later in the document) and the beginning data stored in the central repository, it is imperative that it is maintained through out the life cycle. Any activities within the right-of-way corridor that modifies or adds to any highway features must provide coordinate correct updates to the database. This includes the work of ODOT Maintenance, utility companies, local agencies, or developers. All permits issued should require the submission of engineering data that reflects the changes to the facility.

The ultimate goal is to develop and maintain engineering data for this endless loop in the life cycle of all ODOT highways.

Structured Data Exchange - LandXML

During the first 25 years of engineering automation, proprietary file formats and limited data exchange facilities made it very difficult and inefficient to move data from one system to another. As we further automate engineering, surveying, construction, and asset management, moving data across systems becomes extremely important.

The Extensible Markup Language (XML) is an open standard general purpose specification for the exchange of structured data across different information systems. The XML concept was developed about 10 years ago.

LandXML is a version of XML dedicated to land development, civil engineering, and survey. It was ratified as an industry standard in July, 2002. It facilitates the transfer of data from one proprietary engineering data format to another. This is accomplished through the use of published "Schema's". Each vendor's Schema describes and constrains the contents of their XML document. Other vendors needing to read or write to their system develop translators using the published Schema.

LandXML enables the exchange of data between survey, CAD, transportation design, automated construction machine control, GIS, architectural applications, and more.

From this author's point of view, it appears that the LandXML concept hasn't been implemented as thoroughly and quickly by most software developers, as we would have liked. ODOT, in collaboration with AASHTO and FHWA should encourage software developers to fully implement LandXML data exchange in their software.

Digital Signatures

The much sought after paperless environment has eluded realization due to numerous factors: technology hasn't yet produced a substitute for the printed paper; portable display devices are either too small or too bulky and inconvenient to carry around; the majority of the population is slow to adapt to new technology and still insist on producing paper; and digital signatures on digital documents are rarely used.

The subject of digital signatures is described in detail in a separate document entitled "Digital Signatures for Engineering Documents" by Ron Singh.

The goal of achieving a paperless engineering environment is not simply to reduce the usage of paper and its storage. The primary reason is to enable automation to increase efficiency, accuracy, and reliability.

In order to get closer to the goal of a paperless engineering environment, and to enable the agency to fully integrate the development, transmittal, execution, archival, and retrieval of digital engineering documents, digital signatures must be an integral part of the automation plan.

All final engineering products must be digitally signed by the registrant in responsible charge and archived in its digital state. These digitally signed files should be considered "original" documents, and any hard copy versions of these files simply copies.

It is expected that by the end of May, 2008 the Oregon State Board of Examiners for Engineers and Land Surveyors will adopt an Oregon Administrative Rule allowing the use of digital signatures by engineers and land surveyors.

Data Silos

Prior to the advent of computers and the internet, it was important to house all the official records in one central location. Anyone looking for records (relating to a highway for example), would go to, or contact, a central repository. This person would utilize various indexing aids (Microfiche, catalogs, etc) to find the document needed, and the records manager would provide copies as needed. Having all related records in one centralized location was vital in decades and centuries past, as making contact with, or traveling to, the repository was a difficult and time consuming task.

Today and in the future, this process is unnecessary. If the data is available in digital format and properly indexed, it can be found and transmitted anywhere in the world within seconds. The need for a single centralized data repository does not exist any more. Furthermore, it may be wiser to segregate the data by type and store it in data silos managed by their owners. Data owners are more apt to care for and manage their data.

In today's world the term "silo" has negative connotations. It implies being walled off - with little or no collaboration or communication.

In the context of data, silos are beneficial. They allow proper management of data flowing in and out with respect to format, quality, revision, and security.

Each engineering data element should have an official (possibly even legal) owner; data format; and storage location. All this information should be placed in a registry and published on the ODOT web site.

Since all engineering data will be maintained and made available by each data element owner, it should not be permitted for others within the agency to develop their own libraries of this data. There should only be one official copy of each data element.

Engineering Data Management System

In the course of performing engineering work, especially in a collaborative environment where there are multiple internal and external teams working on a project, an organized engineering data management system is needed.

This system should be more than just a document management system. It should provide the following capabilities:

- Engineering Content Management – Optimized to handle engineering content.
- Collaboration – Allowing multiple teams working at multiple locations to create, review, and modify data.
- File Access Control – Providing security features for Read, Write, or View data by specific users or groups.
- Workflow Management – Granting or denying users access to specific data depending on the stage in the project workflow.
- Review/Redline – Enabling the review and/or markup of documents.

Data Management Philosophy:

To ensure that the Right People see the Right Version of the Right Information at the Right Time

- Check-in Check-out – Managing the check-in and check-out of documents by authorized users.
- Version Control – Tracking changes made to files.
- Standards Checking – Checking products for compliance with standards.
- File Posting to Final Data Repository – Integrated with the features inventory database.
- Powerful Search Capabilities – Utilizing detailed metadata to enable searches by a variety of subject matters.
- Geo-Spatial Support – Enabling search and recovery of data by spatial position.
- Support for Dynamic Document Production – Described later in the document.

Engineering Data and Asset Management

ODOT is in the process of developing an Asset Management system and has numerous efforts underway to collect existing (or legacy) data for certain roadway features. Asset Management requires access to a reliable inventory of assets.

The data collection for an asset management inventory should be two pronged:

1. Collect legacy data utilizing resource grade GPS, video logs, aerial photography, etc.
2. Capture engineering data for the asset, as it is created.

Engineering data and Asset Management should be closely integrated. Engineering data for new features being constructed should be captured and included in the asset inventory. Also, when new surveys are conducted which provide a more accurate location for an existing asset; the legacy data should be superseded and moved to historical records. Superseded data should not be deleted.

In addition to other attributes of the asset, metadata standards must include the quality and accuracy of the positional information.

Post Construction Surveys

Currently, upon completion of construction, a set of “As-Constructed” construction plans are required to be developed. In the past a full size set of construction plans were red-lined by hand, signed by the construction Project Manager, and sent to the archives in Salem. More recently, these plans have been developed in Microstation and plotted to Mylar. The Mylar plans are sent to the archives in Salem and the digital file stored.

In either case, the As Constructed plans are unreliable and not very useful to anyone wanting to use it for engineering in the future. The quality and accuracy of the changes shown in the plans is very dependant on the inspector keeping track of the changes. Even the best of these plans are simply an update to the construction plans, and not to the engineering data.

As Constructed plans should be considered a relic of the past and should be replaced by a “Post Construction Survey”. In order to develop and maintain an engineering data life cycle inventory that can be utilized by asset management; GIS; maintenance; future surveys; design; etc, the beginning of the life cycle should be considered to be the completion of construction. To establish this beginning, a complete survey should be performed. This would include

establishing the final project horizontal and vertical control; right-of-way monumentation; and a complete topography and feature map. The project site should also have a complete orthorectified image produced and video log developed.

This post construction survey should be performed during, and upon completion of the project. As features are constructed, its position should be surveyed and the data utilized for payment and inclusion into the engineering data features inventory.

This survey should be the most thorough and elaborate survey conducted on that section of highway in its life cycle. It should establish the data frame work for that section. This survey should be stamped by a Professional Land Surveyor.

The cost for this survey should be included in the construction engineering cost, and is estimated to add significantly less than 1% to the total construction cost.

Under this post construction survey paradigm, future project development surveys will be very quick and inexpensive, consisting of a field verification and survey of changed areas. It is estimated that this could reduce the project development survey time and cost by 80% or more.

Any further maintenance, utility, or other work performed on the site should require a coordinate correct post construction survey to update the engineering data features inventory.

Underground Utility Location

The location of underground utilities continues to be a significant problem today, as it did in the past. The typical method of locating these utilities has been by surveying paint marks placed on the ground by utility locating companies. The placements of these marks are time consuming, unsafe, and very inaccurate. They do not provide any depth information, which results in designers assuming adequate clearance, or requiring potholes to be dug to determine the elevation at specific locations. It is not uncommon for incorrectly located utilities to cause last minute design adjustments, delays, and claims during construction.

Although not very prevalent today due to prohibitive costs and availability, technologies such as ground penetrating radar, will facilitate the rapid location of existing underground features.

In order to develop and maintain the infrastructure life cycle data mentioned previously, all new, or relocated, underground installations within ODOT right-of-way must provide 3D as-built data for inclusion into the asset database. Future design projects should also strive to utilize emerging technologies to 3 dimensionally locate underground utilities to produce more reliable designs, and to add to the utility asset database.

Dynamic Documents

Currently, as in the past, almost all engineering documents produced in ODOT are “static”. That means that the document never changes, but is a snapshot in time. Although conditions may have changed, the document would not reflect that. In many situations this is appropriate, however, in others it is not. For example, consider a right-of-way map. It represents the conditions at the time it was produced, but becomes obsolete almost as it is completed. This is

appropriate if it's used as a record of conditions at that moment in time. However, if the map is utilized as a reference for current situations, a static right-of-way map has limited value. In that situation, the map should be "dynamic". That means that it should be created on demand utilizing current data.

By storing individual data elements (in data silos mentioned earlier) rather than resultant composite products, we can enable the on-demand production of dynamic composite documents. By maintaining status and history data for those data elements, a document reflecting conditions at any specific date could be created. As in the right-of-way example above, the best of both worlds could be achieved; an on-demand map produced to reflect the conditions at the time of map production, or that of the current situation.

Information:

The result of processing, manipulating and organizing data in a way that adds to the knowledge of the person receiving it.

Engineering Data and the GIS Connection

The concept of dynamic documents (described above) is not new to the Geographic Information System (GIS) community; as a matter of fact it is the fundamental principle of the system. Those involved in engineering have traditionally produced static documents as their final products, and could continue to do so for specific documents such as construction plans, however, data elements that produced those static documents should be made available for other uses and ultimately stored for on-demand document assembly.

Engineering data and current GIS data can co-mingle. Strict Metadata rules should be further developed and enforced.

The existing Statewide GIS map projection should also be considered obsolete and a hindrance to our abilities to integrate engineering data into the GIS system

The Transportation Data Division's role should be enhanced to include managing engineering infrastructure life cycle data.

IT Infrastructure

Engineering automation depends heavily on an elaborate and robust Information Technology (IT) infrastructure. It's all about data. Data needs to be created, moved, archived, and retrieved with near 100% reliability.

In the context of this document the IT infrastructure would include wired and wireless data communications; desktop, portable, and handheld computers; computer servers; data storage; and backup devices. The system should be similar to the concept of the World Wide Web where no single point of failure could bring the system down.

The system needs to be considered a "super utility", like electricity and water, except much more. To the user, the data should be always there, just as we are accustomed to flipping a switch and seeing a light turn on, we should expect uninterrupted access to the data via this infrastructure.

Much like our expectations for electricity service, the user should not be concerned with data storage requirements, communication protocol and bandwidth, backups and redundant systems, etc. This should be handled by our IT service provider – Information Systems.

Wireless Communication

Maintenance, Asset Management, Surveying, Construction, Traffic Management, Incident Response, and almost every other aspect of ODOT's business could tremendously benefit from a wireless data communication network that covers all ODOT facilities. This includes the buildings, highway corridors, rest areas, and other facilities.

This wireless network should also be used for access to the internet by the general motoring public. On the public side of this wireless network, the development could be incremental. At first, all rest areas could be enabled, next, certain sections of freeways that are easy to provide connection could be enabled and publicized as wireless zones, and eventually the entire highway corridor.

The uses for a wireless network available to motorists are limitless. For example: even in today's world, inexpensive Global Positioning System (GPS) navigation devices can receive real-time traffic information that allows the driver to select a different route that is experiencing lower congestion.

New Statewide Coordinate System

The Oregon State Plane Coordinate system was developed and put into place in the 1930s and is currently in use. The system is based on a Lambert Conformal Conic projection with 2 zones. Each zone has a 158 mile standard parallel separation with the intended projection accuracy of 1:10,000, with no consideration for elevation distortion.

Shortly after the introduction of the State Plane system to Oregon, the State Highway Department developed the Local Datum Plane Coordinate system (LDPC) with the goal of adjusting the State Plane 'Grid' coordinates to 'ground' to yield ground distances.

With the advent of long range high precision distance measuring survey instruments, GPS, and demand for higher accuracies, the 1:10,000 State Plane Coordinate system and LDPC should be considered obsolete and a hindrance to current and future engineering work.

There is a need to develop a better coordinate system to facilitate modern needs. It should be based on an Earth Centered Earth Fixed (ECEF) system; tied to the National Spatial Reference System (NSRS); providing higher accuracy by minimizing the distortion created by projection and elevation; facilitating engineering and GIS data to co-mingle; and above all – producing a reasonable representation of ground coordinates on the grid.

The development of a new statewide coordinate system must be done in collaboration with the National Geodetic Survey, Bureau of Land Management, State GIS, Department of State Lands, County Surveyors, Professional Land Surveyors of Oregon, American Society of Civil Engineers, Oregon universities, and other interested parties.

The Oregon Real-Time GPS Network

GPS technology is widely used by a multitude of disciplines to locate their assets and/or data on a geospatial framework. Those GPS users that need a positioning accuracy greater than a few feet need to correct their data either in real time or after the fact (post processed).

In order to provide an effective and efficient means for GPS users to correct their data and increase their positional accuracy on the statewide geospatial framework, and to significantly reduce the agency's need to maintain the network of physical monuments, the Oregon DOT Geomatics Unit is in the process of developing a statewide GPS reference station network known as the "Oregon Real Time GPS Network" (ORGN).

This GPS network consists of strategically located GPS Continuously Operating Reference Stations (CORS) that provide real-time kinematic (RTK) correctors via cellular phone and/or radio broadcast. Surveyors with survey grade GPS systems that are properly equipped to take advantage of these correctors can survey in the field with up to 0.03 feet accuracy in real time. Other users' positioning accuracy achieved will depend upon the type of GPS receiver being utilized.

All of the permanent GPS reference stations in this network are referenced to the National Spatial Reference System, so all users of the GPS network are tied to a common geodetic horizontal and vertical network. This provides consistency and accuracy for all data collected by GPS users, thus assuring efficient exchange of geospatial data and less duplication of effort by state and other agencies.

For Geographical Information Systems (GIS), geodetic control provides a common, consistent, and accurate reference system for establishing coordinates for all geographic data. A permanent GPS reference station network ensures the availability of easily accessible, high quality geographic information, which is one of the goals of the State of Oregon's (Department of Administrative Services) Geospatial Enterprise Office.

Height Modernization

In addition to developing a modern statewide coordinate system and a real-time GPS network to support the measurement of these coordinates, the vertical control within Oregon needs to be revitalized.

The vertical control infrastructure in Oregon was established during the 1930s, 1940s, and 1950s. This was a huge collaborative effort by various Federal Agencies and ODOT. This campaign resulted in establishing about 13,000 Benchmarks all across Oregon which forms the foundation for all elevation work in the State. The National Geodetic Survey (NGS) now only maintains Federal Base Network monuments, which amount to less than 3% of the monuments in Oregon. We estimate that over 60% of the total number of monuments has been destroyed over the years and the reliability of the remainder is questionable. Monuments are being destroyed every day and the situation continues to worsen.

The historical approach to solving this would have been to simply replace destroyed or disturbed monuments and remeasure and republish the level lines. The ultimate goal of Height

Modernization (a term coined by the NGS) is to develop systems and procedures that enable the measurement of accurate and repeatable heights by utilizing GPS technology. The need for thousands of physical monuments in the ground and differential leveling techniques to establish elevations will no longer exist. Surveyors will be able to utilize GPS to establish not only good horizontal coordinates, but also good elevations.

Although not engineering automation in itself, the development of a new coordinate system; a GPS reference network; and height modernization all form the foundation for an integrated engineering automation system.

Remote Sensing

In the context of this document, the term Remote Sensing will be used to describe any data acquisition of mapping features by devices that do not come in physical contact with the object to be mapped. *Passive* systems include aerial photography and satellite imagery, while *Active* systems include airborne LiDAR, and ground based stationary or mobile 3D laser scanning.

Both, high and low level, airborne LiDAR; ground based (static and mobile) high resolution 3D point clouds; satellite imagery; digital Photogrammetry and other forms of remote sensing will play a significant role in future engineering automation. The gap between transportation design systems and these technologies is significant and, unfortunately, growing wider due to the extremely rapid development pace of point cloud technologies. CAD and highway design systems cannot easily and effectively accommodate the massive volume of data generated by these point cloud systems.

Point cloud data collection speed, accuracy, detail, and cost effectiveness may render the single point collection technique utilized by surveyors today, somewhat obsolete. These 3D point clouds will need to be supplemented by data captured by other means in areas obscured from the sensor.

High Resolution Imagery/Point Clouds for Design

A map is a depiction of terrain and features for a portion of land. Paper maps are drawn to scale, while digital maps produced for highway design purposes are "coordinate correct" or "life size". Even though these topography basemaps are life size, the elements contained in them are simply symbols representing features. For example, a manhole is represented by a symbol showing 2 concentric circles. The size of the symbol does not represent the size of the manhole. The basemaps that we produce today are essentially the same as what was produced generations ago. They should be considered 'stick figures' and obsolete, in the world of solid object modeling.

3D Laser scanning technology is developing extremely fast and is far ahead of the capabilities of typical CAD software. CAD software has not been able to keep up with current and emerging data capturing devices. As a result, the extremely dense and rich point cloud data captured by scanners is filtered and dumbed down to the contents of a traditional basemap. Producing these basemaps essentially throws away very valuable data, and is expensive to produce.

This also holds true for high resolution orthorectified aerial imagery, where its dense rich data is being filtered to produce traditional basemaps.

There should be no need to do this. Designers need to be able to utilize accurate orthorectified imagery, point clouds, and traditional survey data (independently or in combination) instead of a traditional basemap. In cases where a physical vector is needed in this raster image, the CAD software should be able to create it for the designer on demand. To meet these needs CAD developers will need to make significant changes to their software.

3D and 4D Design

Prior to the use of computers and software, the designs produced by ODOT were 2 dimensional (2D). Since the implementation of Microstation and InRoads (for drafting and road design), the agency has evolved into creating 'pseudo' 3 dimensional (3D) survey and design products. These products are not true 3D since each design element is simply a 2D symbol placed at its correct 3D position.

In order to develop a truly effective design, all major components of the design should be full scale 3D (solid object) elements. Performing 3D design would require reliable 3D basemaps depicting elements below, on, and above the ground surface within the 3D project limits.

3D cell libraries would need to be created and a conversion routine developed to convert from 3d life size cells to the existing 2D cells for use on construction plan sheets, and visa-versa.

Performing 3D design may sound to be more complex to a designer accustomed to operating as we do today. On the contrary, once past the learning curve, the process will prove to be simpler and far more effective than our current methodology. Designers in other fields that utilize full 3D, find it far simpler and superior than their previous 2D process.

Even the most experienced designer may not see conflicts with elements of design until construction. True 3D design enables detection of conflicts in design elements; determines element clearance and sight distances; produces materials lists and quantities; facilitates construction machine automation; produces engineered visualization; and much more.

4D design places 'time' tags to certain design elements. This provides the ability to determine and convey construction staging. Think of it as a project schedule built into the design. Slide the time scale to the date of interest to see the construction completed to that point in time.

Visualization

There has always been an interest in visualizing a design. The typical lay person struggles to visualize the design depicted in a set of construction plans. Therefore, in years past, perspective drawings or physical models were constructed by experienced artists and model builders to show the affected public what was intended to be built. These drawings and models were simply depictions and not engineered products, and therefore had limited use.

Today, even though visualization technology may be utilized on certain projects, it is a separate and time consuming task performed by a specialist. However, once true 3D designs are

produced, realistic visualization is simply a by-product of the design. The result is a virtual model produced in real-time utilizing real engineering data; as accurate as the design; and capable of perspective views from any location in any direction. Design conflicts would show up visually; measurements may be made between any element in the design; and the effects of lighting, shadows, obstructions, rainfall, etc., may be studied.

Construction Automation

The first 25 years of engineering automation in ODOT placed little emphasis on construction. Construction engineers have been using CAD and Road Design software, and surveyors have been using modern survey technology, however, it stops there. Future efforts should include:

- Construction Machine Automation – Design data should be available for machine guidance and control systems; surveyors should be trained to manage the supporting data and performing quality control checks; as-constructed data developed by the machine automation system should be accepted for intermediate pay quantities; and real-time tracking, monitoring, and recording of construction equipment should be utilized.
- Handheld Computers for Inspectors – These devices should be GPS enabled to provide an inspector reasonably accurate real-time positions on the project coordinate system. The device should contain project design elements to allow the inspector to validate the positions of items being constructed. Inspectors would also use these devices for managing their construction records, daily progress reports, material certification and testing, and access to specifications and standard drawings. These devices should be capable of wireless communication for email, online meetings, transmittal of engineering data, and access to ODOT servers.
- Enhanced use of GPS – The use of GPS devices in construction surveying has been minimal and needs to be further exploited. The Oregon Real-Time GPS Network facilitates the use of GPS for construction surveyors, inspectors, and machine guidance and control systems, at a significantly reduced cost, providing accurate, reliable, and repeatable positioning on the construction coordinate system.
- Remote Construction Site Monitoring – Construction engineers, inspectors, and administrators should be able to monitor certain construction activities by remote means. Web cameras facilitate monitoring and recording construction work progress; contract compliance; jobsite conditions; actual construction schedules; as-built information; and safety compliance.
- Materials Delivery and Certification – Radio Frequency Identification (RFID) tags have been used extensively for product inventory, tracking, identification; and payment. This, and other related technology could be utilized in construction material delivery, certification, and payment. Since the RFID tags are passive (not requiring any internal power), their use could be further exploited in managing assets once installed. For example, all signs delivered and installed during construction would have RFID tags containing information tying it to the asset inventory database. Future maintenance,

asset inventory, or surveying activities could query a specific sign's RFID tag to gain access to all the database information. RFID tags could also be placed on existing asset features as part of the asset management program. Future surveys performed in the area could update the coordinate position of the asset by referring to its RFID identification.

Maintenance Automation

This document will only discuss maintenance activities that are related to engineering automation.

Maintenance activities are very much part of the life cycle of engineering data. Any highway element that is added, removed, or modified by maintenance or others, must be reflected in the data archive. For example: If a highway shoulder is widened and the guardrail extended as part of routine maintenance, these changes must be surveyed and entered in the data archive. If cost or time limitations prohibit this, the survey does not need to be of engineering accuracy, however, the metadata for this survey must indicate the method utilized and accuracy achieved.

Other maintenance activities that relate to engineering automation include guidance for striping and snow removal; and feature and spare part inventory.

Engineering Data and Intelligent Transportation

Engineering data will be required to support development of advanced Intelligent Transportation systems. Once GPS sensors can cost effectively produce sub-foot positions in real time, the possibilities for developing intelligent vehicles and highways expand tremendously.

Departments of transportation will need to play a significant role in partnership with the automotive manufacturing sector in order to achieve these intelligent transportation goals. DOT involvement should go beyond simply designing and constructing intelligent transportation features; it should recognize the dependency of intelligent transportation on other issues such as seamless coordinate systems, real-time cost effective GPS positioning, and accurate roadway geometry and related engineering data.

Design Data as Primary and Construction Plans as Secondary

Today, as in the past, the construction plans (supported by the specifications) are the contractual primary documents. The representation of the design and information contained in the plans controls what is built. As we move into the world of construction machine automation, this paradigm must change. Even today, construction contractors are demanding access to the 'behind the scenes' engineering data. However, this introduces the possibility for confusion. Often, the plans are creatively modified (from the actual design) to clearly depict something that may be too cluttered to read clearly. If there is a conflict between the plans and supporting data, today, the plans still control.

Over time the role of the construction plans should change. They should become more of a visualization and bidding document rather than one containing true engineering data.

We need to carefully study this concept and develop a new model where a package of engineering data is provided to the construction contractor and held as the primary data controlling construction.

Strategies

Annual Update of the 25 Year Time Horizon

The long range engineering automation plan should be updated annually to reflect changes in needs, new information, emerging technologies, and automation accomplishments. The shorter 5 and 10 year plans should also be updated to support the long range plan.

Budget Planning

It would be very difficult and inaccurate to develop a cost estimate for the long range engineering automation plan. However fairly reliable cost estimates could be developed for the shorter 5 and 10 year plans. These estimates would then be a good starting point for developing biennial budgets.

Proof of Concept Project

In order to evaluate the feasibility, complexity, and value of these engineering automation initiatives, pilot projects should be conducted. Rather than conduct several pilot projects in various parts of the state, it is recommended that one manageable section of highway be designated as the place to test as many of the initiatives as practical. Some of the initiatives will need their own unique test site.

The recommendation is that Highway 217 in Region 1 be that designated proof of concept site. The entire highway is only 7 miles long; it is typical of many urban sections of highway; it carries high volumes of traffic; and is expected to be impacted by numerous projects in the future.

Implementation

Some of the suggested automation initiatives are already occurring while some have not been considered. It is suggested that the key concepts listed in this document, and any proposed by others, be considered and approved to form a long range engineering automation plan. This long range automation plan would need to be studied to determine dependencies and interconnectivity and then sequenced to ensure success. This final long range plan should be utilized to develop shorter, 5 and 10 year plans.

The Engineering Automation Steering Committee should be charged with developing, maintaining, and implementing these plans. They should also provide cost estimates for biennial budgeting.

Collaboration with AASHTO and FHWA

It seems reasonable to expect that other DOTs or transportation authorities have similar needs for engineering automation. ODOT should place greater emphasis in collaborating with the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Association (FHWA) in researching new technologies and leveraging hardware and software developers to produce systems that work as we need them to. ODOT's involvement in national engineering automation efforts should be stepped up if we are to learn from other's experiences and/or influence the development of technology and related standards.

Publicizing Goals

One of the reasons for this document is to present the engineering automation "big picture" so that all staff can understand the significance and interconnectivity of individual initiatives.

An easy to locate engineering automation web site should be created with the goal of publicizing the automation plans and their development status. This should be kept current and available to internal and external viewers. This web site should contain an inventory of all existing and future engineering automation initiatives and contact information for the responsible teams.

An informed internal staff will: help prevent the development of individual automation initiatives that contradict the agency's long range goals; develop creative ideas in support of published goals; and "buy in" to these initiatives that they may not have understood otherwise.

Influencing Technology Developers

Rather than simply waiting for hardware manufacturers and software developers to produce technologies that they think we need and then try to convince us that we should use it, ODOT in collaboration with AASHTO and other DOTs should publicize our engineering automation goals, meet with technology developers to explain our needs, and take steps to influence the direction related technology progresses.

Conclusion

As we enter the next 25 year engineering automation era, we should do so with a common understanding; agreement in the direction; and a well thought out cohesive plan.

Important debates should happen early, and critical groundwork for future development (such as the creation of a new coordinate system) should be undertaken well before it's needed. These investments in the future will ensure a successful transition to future development. The farther in advance an action is taken, the greater effect it can have by a given date.

Those with financial resources have a special responsibility to make sure that funding doesn't overly constrain what can and needs to be done.

Definitions

For the purpose of this document, some of the terms used in it are defined as follows:

Asset Management	Involves the collection, storage, retrieval, analysis, and reporting of data for cost effective maintenance, upgrades, and operation of physical assets.
Data	Factual information, numbers, characters, measurements, output from devices, used as a basis for reasoning and calculation.
Document	Contains information, an actual product of writing or recording, intended to communicate or store collections of data, physical printed pages, "Virtual" document in digital format.
GIS	Geographic Information System - A collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.
LiDAR	Light Detection And Ranging – An optical remote sensing technology that utilizes laser pulses to measure ranges and other data, by measuring the time delay between transmission and detection of the reflected laser signal.
Metadata	"Data about data". i.e. If the data was a digital photo, the metadata could be the date the photo was captured; the camera model; the shutter speed, aperture, etc.
NSRS	The National Spatial Reference System, defined and managed by the National Geodetic Survey (NGS), is a consistent national coordinate system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the Nation, as well as how these values change with time.
Orthorectified Photograph	An Orthorectified photograph (orthophoto) is an aerial photograph that has been geometrically corrected for distortion caused by lens imperfection, camera tilt, and differences in photo scale due to changes in terrain elevation.
Raster Graphics	An image made up solely of colored pixels. Also known as a bitmap.
Vector Graphics	An image made up of geometric objects such as points, lines, curves, and polygons.