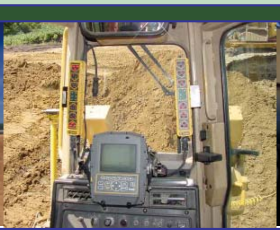
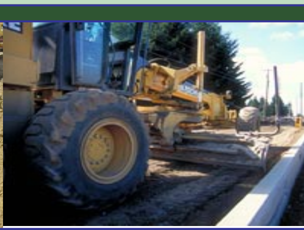
Best Practices – Machine Control Evaluation

Minnesota Department of Transportation



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Shortly after 3D Machine Control Systems were introduced, Mn/DOT began an initiative program within the agency to investigate the technology. Late in 2006, Mn/DOT selected Alliant Engineering, Inc, to conduct an evaluation of the current machine control program and develop recommendations for furthering the use of the technology throughout the State of Minnesota.

3D Machine Control technology spans several functional groups within Mn/DOT Program Delivery Area and affects all stakeholders, public and private, involved throughout a project's life cycle. Many of these stakeholders have differing opinions on how to propagate the use of the technology to benefit all stakeholders and the traveling public.

The project was split into two separate research phases. The first phase focused on conducting a literature research of 3D Machine Control technology, available systems and the future applications for the system. The second phase of the project consisted of gathering input from stakeholders through the preparation and administration of a survey and in-person interviews.

The results from these two phases were used to identify issues limiting the increased use of the technology and formulating recommendations to meet the agency's goal of increasing the use of machine control technology.

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Final Report

Prepared by:

John Dillingham, P.E.
Thomas Jensen, P.E.
Nick Schulist, E.I.T.

Alliant Engineering, Inc.
233 Park Avenue South
Suite 300
Minneapolis, MN 55415

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St. Paul, Minnesota 55155-1899

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Executive Summary

In the field of heavy civil construction; engineers, contractors, and owners continually embrace new technologies to improve quality, efficiency, and safety. Three Dimensional (3D) Machine Control and Guidance Systems are one of the new technologies that accomplish all three of these improvement initiatives.

The earliest versions of 3D Machine Control and Guidance Systems appeared on the market in the late 1990's. These systems integrate a computer within the cab of construction equipment with Global Positioning System (GPS) satellites to relay position information from the GPS receivers mounted on the machines. The computer evaluates the machine's actual horizontal and vertical position relative to its location in a proposed computer generated model of the project. The operator utilizes information from the onboard computer to control the machine's equipment. In advanced cases the onboard computer can be directly linked to the machine hydraulics, controlling their operation with minimal input from the operator.

Most current applications of 3D Machine Control relate to large earthwork and grading projects. Many of these applications are related to mining or private sector site grading projects where moving large areas of earth benefit from the use of these systems. Corridor construction projects, in both the roadway and rail markets, have also adopted the technology, albeit at a slower pace. The technology has proven, through numerous operational tests, that the accuracy, efficiency, and ease of use of these applications provide benefits to owners and contractors. As a result, 3D Machine Control is now widely utilized within the civil industry, specifically in site grading and excavation of land development projects. The application of 3D Machine Control to roadway and rail grading is in the early stages of implementation, and the development and testing of future applications is ongoing. Most of this development focuses on extending these concepts into other areas of construction beyond grading, such as paving and underground operations.

Because of these improvements in quality, efficiency, and safety, the Minnesota Department of Transportation (Mn/DOT) realizes that the use of 3D Machine Control in roadway construction projects will benefit stakeholders and the public. Utilizing this technology will provide higher quality roads sooner and, ultimately, for less cost than current construction practices allow. In order to facilitate a faster, more widespread roll-out of the use of the technology, Mn/DOT has commissioned a project to evaluate the existing 3D Machine Control program. Along with evaluation, the project generated a list of recommendations satisfying the goal of rapid, widespread implementation of 3D machine Control Systems

The first phase of the project consisted of a thorough review of the 3D Machine Control technology, equipment, and software vendors. Information was then collected and analyzed to gather input from other Departments of Transportations in the United States that are embracing this technology. Interestingly, and to the credit of Mn/DOT, most of the other state DOT's regard Mn/DOT as a leader in the use of this technology and are interested in the results of this project to improve their own construction practices.

The second phase of the project compiled information collected from a survey sent to stakeholders in Minnesota regarding their machine control experiences and their expectations for future use of the technology. These stakeholders included construction contractors working in Minnesota, agency engineering and construction staff, and the Associated General Contractors of Minnesota. The third phase of the project formulated recommendations for expanding 3D Machine Control throughout the state.

The results of the first two phases of the project identified the areas where concerns and issues must be addressed to increase the use of GPS Machine Control in Minnesota. The core issues of concern are:

- **Acceptance** - At present, agency staff are more reluctant to accept 3D Machine Control than contractors. With the understanding that the process of preparing a project for the use of this technology differs from the conventional method, emphasizing the benefits that 3D Machine Control brings to both Mn/DOT staff and the public is important.

- **Accuracy –** Some agency staff and smaller contractors indicated concern regarding the accuracy of 3D Machine Control Systems presently in use. Staff attitudes ranged from confidence to uneasiness in using these systems on grading projects.

- **Cost** - The primary cost issues in 3D Machine Control include equipment purchases, model creation, training, and project management. These concerns were shared among agency and contractor staff.

- **GPS Coverage** - The lack of GPS coverage in a project location is a major concern among both agency staff and contractors.

- **Changing Roles and Responsibilities of Staff** - The introduction of 3D Machine Control as a delivery method necessitates changes to the tasks that agency and contractor staff must perform on projects.

- **Liability** - Contractors and agency staff have concerns regarding which party should be held responsible for the quality and accuracy of work. Additionally, both groups have somewhat differing opinions as to who bears this responsibility.

- **Training** - Both contractors and agency staff indicated that training was their highest priority in moving forward with machine control. Both stakeholder groups indicate that additional training would help them better understand the protocol in administering a project and increase the efficiency of the project.

Based on these findings, recommendations were formulated to meet the goals of the stakeholders. These recommendations are detailed in Chapter 6 of this study. In the short term, Mn/DOT needs to gain acceptance by communicating across disciplines and districts in the form of a statewide forum on machine control. A discipline specific training program should then be implemented. This will change the way some engineers, surveyors, and construction managers perform their duties. Concurrently, a quality control and assurance process should be developed and implemented. These first steps will lay the groundwork for implementing the remainder of the recommendations and continuing Mn/DOT's leadership in 3D Machine Control implementation in the public sector. The table below previews the recommendations made in this report and documents the issues that each recommendation will address.

Summary of Recommendations

Number	Recommendation	Timeline	Issues Addressed						
			Acceptance	Accuracy	Cost	GPS Coverage	Changing Roles and Responsibilities of Staff	Liability	Training
1	Outreach to other departments internal to Mn/DOT	3 Months	●				●		
2	Outreach to other agencies and organizations external to Mn/DOT	3 Months	●				●		
3	Provide Training to all Stakeholders	6 Months	●	●	●		●	●	●
4	Develop and Implement a Quality Control and Assurance Process	6 Months	●	●			●	●	●
5	Develop Innovative Contract Bidding Techniques	6 Months			●			●	
6	Equip Field Staff with Required Equipment	Phased	●	●			●	●	
7	Convince Engineers of the Benefits of Modeling during the Design Process	6 Months to On-going	●	●			●	●	
8	Modify the Responsibilities of the Construction Stakeout Surveyor	6 Months to On-going	●	●			●	●	
9	Support and Expand the Mn/DOT CORS Network	On-going	●	●		●			
10	Create a Pre-Qualified or Certified List for Machine Control Model Creation	6 Months	●	●					
11	Consider New Partnering Opportunities	On-going	●	●	●			●	●
12	Develop a Work Flow for Machine Control Delivery	On-going	●	●	●			●	●

In order to fully utilize the advantages of technology in the construction industry, the industry must continually evaluate and challenge existing business processes. Each industry member's specific role and the methods used to accomplish tasks should evolve accordingly. Through the continual refinement of these processes, the public can be assured that stakeholders are delivering high quality projects with the best use of resources.

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Chapter 1
Introduction

Throughout history, the construction industry has evolved and become more efficient as a result of technology. Many times these technological advances revolutionize the way construction occurs. Frequently, engineers are required to accommodate these new innovative construction techniques in their designs. Over the past 150 years, construction techniques have evolved to include the use of a network of satellites circling the earth providing real time position information. Central to these innovative technologies is the desire for the completion of projects in a more efficient manner. Efficiency reduces costs and schedule duration.

One of the newest and fastest growing technologies in the construction industry is Three Dimensional (3D) Machine Control and Guidance Systems. The Minnesota Department of Transportation (Mn/DOT) realized the potential benefit of the 3D Machine Control technology early in its development. Mn/DOT formulated several pilot projects to test the technology and equipment in real world construction settings. Although there have been and still remain several obstacles to its widespread implementation, this technology is the future of construction.

In order to adequately prepare for continued transition to 3D Machine Control, Mn/DOT retained the services of Alliant Engineering, Inc. to evaluate the current method that Mn/DOT uses in delivering these projects. The evaluation consisted of an analysis of the opinions and experiences of stakeholders involved in these projects in the past. These opinions and experiences were collected from both electronic surveys and in-person conversations. Furthermore, input from other state DOTs was used to benchmark Mn/DOT's use of the technology. Based upon the evaluation and analysis, Alliant Engineering prepared recommendations with regard to increasing the use of this technology throughout the State of Minnesota. Furthermore, this report identifies a documented strategy to increase the deployment of 3D Machine Control on projects statewide.

To accomplish these goals, Alliant approached this project in three distinct phases. The first phase consisted of a thorough review of the 3D Machine Control technology, equipment, and software vendors. Additionally, Alliant collected and analyzed the input of other Departments of Transportation in the United States that embrace this technology. The second phase of the project compiled and administrated a survey sent to stakeholders in Minnesota and DOT officials in other states. The Minnesota stakeholders included construction contractors working in Minnesota, agency engineering and construction staff, and the Associated General Contractors of Minnesota. The third phase of the project evaluated the survey results, which led to the formulation of recommendations for expanding 3D Machine Control throughout the state.

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Chapter 2
Literature Search

<u>Overview of Machine Control Systems</u>

Various forms of machine control have been around since the late twentieth century, using relevant forms of technology. The first systems relied on hydraulic valves following string lines, and subsequently lasers, for control. The technological trend is to make the machine more “intelligent”, providing abundant and more easily understood information to the operator. These procedures, though always improving overall efficiency, had the distinct disadvantage that they were heavily reliant upon manual survey methods. Surveyors were usually on site daily placing hubs and establishing cut and fill information off of those hubs. A hard copy, hand calculated cut sheet was generally given to the crew foreman to complete the work. These technologies required someone to interpret the plans in order for construction to occur.

3D Machine Control and Guidance Systems first appeared on the market in the late 1990’s. These systems put a small computer within the cab of earthwork machines that utilized Global Positioning System (GPS) satellites to relay position information to the computer. The computer evaluates the machine’s actual position relative to its location in the proposed model. The operator uses the information from the onboard computer to control the machine’s equipment. In advanced cases, the onboard computer can be directly linked to the machine hydraulics, controlling their operation with minimal input from the operator. Appendix A contains promotional materials for existing machine control systems on the market.

The success of 3D Machine Control systems relies upon several variables, including:

- The quality of the proposed construction model.
- The ability of the owner to approve and review the design.
- The ability of the operator to accurately apply the design in the field.

Conversely, the lack of tools required to create effective models leads to 3D Machine Control Systems failure and design workflow change.

Figure 2.1 – Motor Grader & Dozer outfitted with 3D Machine Control System from Trimble

Figure 2.2 – Motor Graders outfitted with 3D Machine Control System from TopCon

Figure 2.3 – Machine Operator Controller by TopCon

Figure 2.4 – Machine Operator Control Box by Trimble

Comparison to Other Industries

One of the largest obstacles to implementing 3D Machine Control technology is the inability of most people to visualize three dimensions from a two dimensional medium. The field of civil engineering produces two dimensional paper plans as the final product, or deliverable, for a project. Although the introduction of the computer into the design process allows for an increase in the amount of detail in these final plans, the deliverables still consist of alignments, profiles, and cross sections; each a two dimensional view of a three dimensional design.

In comparison to other industries, civil engineering is often slow in accepting emerging technologies. The aerospace, architecture, automotive, manufacturing, and plant industries have long embraced three dimensional modeling as a standard part of the design process. The closest related industry to civil engineering is the mining industry, which has adopted 3D Machine Control and Guidance Systems. As a result, many of the systems on the market today were created to meet the needs of mining engineers and operators. The industry is now developing the next generation of machine control systems. Removing the operator from the cab of the machine will allow for remote control of the equipment, either by a human using a large control interface or by computer control with no direct human interaction.

It is important to not overlook the experiences these industries have had in three dimensional modeling. Likewise, the benefits these other industries have enjoyed from this technology need to be applied to civil engineering and construction practices.

Future Applications

Most applications of 3D Machine Control occur on earthwork and grading projects. The technology has proven through numerous operational tests that the accuracy and ease of use of these applications are beneficial. As a result, 3D Machine Control is now becoming more prevalent within the industry. The development and testing of many future applications is ongoing, with focus on extending this concept into other areas of construction beyond grading. Applying this technology to paving is one of the initiatives that the manufacturers are currently pursuing.

To apply machine control technology to concrete or bituminous paving, it is necessary to outfit machines with several GPS receivers to triangulate the machine's position, elevation, and slope. Although the technology works in theoretical application, real world accuracies and tolerances prove problematic for these systems.

The present technology's elevation accuracy for a typical GPS receiver is approximately three feet without any correction factors. The accuracy can be improved to one tenth of a foot by utilizing a Continuously Operating Reference Station (CORS) network which provides correction factors. Minnesota, as with many other states, is developing a network of these stations statewide so that GPS technologies can be reliably used by both the agency and private industries. This one tenth of a foot tolerance is generally acceptable for most rough grading operations, but does not meet paving tolerances. To compensate for this problem, most vendors offer add-on components to the GPS system to improve the system's accuracy. These components include laser augmentations and automatic total stations that provide corrections based on the GPS receiver's location. The corrections provided by these add-on components typically improve the accuracy of the system to four hundredths of a foot. The tradeoff of improved accuracy comes with a significant financial cost. Furthermore, an automatic total station is limited in the number of pieces of machinery it can provide corrections to and track. A large fleet may require several total stations to obtain the necessary accuracy.

Another potential disadvantage in applying this technology to paving equipment is the potential for poor signal reception. Although GPS satellites constantly circle around the Earth, there are momentary lengths of time when GPS equipment cannot receive a signal from the satellites. These times vary in length and frequency as a result of time of day, location of the receiver relative to satellite orbit paths, and project specific obstructions that may interfere with the satellite signal reception.

Both the accuracy and signal reception issues are expected to improve with the addition of satellites by the United States, European Union, and Russia. The United States plans on deploying the newer L5 frequency in the 2007 – 2010 timeframe. The European Union intends on having the Galileo system complete by 2010. Russia proposes to complete their Global Navigation Satellite System (GLONASS) system by 2011. An increase in satellites circling the earth will improve position triangulation and mitigate the frequency of poor signal reception.

A lost GPS signal is detrimental regardless of the type of paving operation being performed; it is especially significant in the case of concrete paving. If the paving equipment is idle due to a lost signal, on-site materials may begin to harden prior to their placement. Discarding wasted material, purchasing new material, and transportation costs would result in a highly inefficient paving project.

Differing opinions in the industry exist regarding how 3D Machine Control efforts should be applied to paving. Despite the multitude of issues, there are efforts within the industry to extend 3D Machine Control to paving machinery. The driving reason for this discussion is the fact that the design of most paving operations is for a constant thickness. One reason that string lines are currently used on paving projects is to smooth out the local variations in the road subgrade. If 3D Machine Control can improve the quality of the subgrade grading by reducing these local variations, there will be less reason to install paving operations with machine control. Conversely, others feel that the tolerances can be met in applying the machine control directly to the paving machine.

It is recommended that Mn/DOT put forth its efforts in preparing stakeholders for the full implementation of 3D Machine Control on grading projects. Sufficient experience has been noted by stakeholders industry wide to ensure that 3D Machine Control can efficiently deliver a grading operation at the required tolerances. Software and equipment has reached a robust enough level to ensure the success of these projects. Paving operations, in contrast, should not be considered for 3D Machine Control at the present time. The relative inexperience of the industry and the concerns of GPS signal loss make this a high risk pursuit at this time. It is expected that significant advances will likely occur in this area within the next 2 to 5 years. Once the manufacturers produce more mature products with proven success industry wide, the agency should reevaluate the technology at that time.

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Chapter 3
Evaluation and Documentation of Current Machine Control Processes

Evaluation of Machine Control Systems

As with any new technology introduced into the market, a comprehensive study and evaluation of its applicability should be conducted. The purpose of these evaluations is to determine whether the benefits exceed the efforts of implementing the technology. The two key items in a feasibility evaluation are the benefit/cost ratio and a qualitative analysis of the perceived improvement the technology will have on the project deliverables.

Benefit/Cost Ratio

Traditionally, the most easily understood method to measure the relationship between the advantages and disadvantages of implementation is the benefit/cost relationship. The benefit/cost relationship is computed by quantifying all of the benefits and drawbacks of using the technology. Benefits include cost savings, monetary savings from reduced liability, fuel savings, etc. The drawbacks, typically the costs of implementing, may include additional staff labor and equipment purchases. The total of all the benefits is then divided by the total of all the costs. The result, if greater than one, would show that the benefits of implementing the technology outweigh the cost associated with doing so.

With respect to 3D Machine Control, there are several benefits that can be attributed to the use of the technology. These include [1. *See page 93 for References*]:

- Lower bids from contractors
- Lower fuel requirements from reduced equipment operating time
- Lower emissions from reduced equipment operating time
- Safer work environment

Additionally, all of the stakeholders agree that grading with machine control yields a product of higher quality.

Like any other technology, there are costs associated with implementation of 3D Machine Control. The most commonly cited cost is the high initial investment in equipping earthmoving machines. According to one source, outfitting one bulldozer can range from $100,000 to $125,000. [1]. Additional costs incurred from investing in machine control include training, staffing, and 3D model creation.

One of the goals of this project was to compute a benefit/cost ratio for 3D Machine Control technology. Unfortunately, this goal could not be accomplished for several reasons. First, existing data was not available for performing a benefit/cost ratio calculation. None of the Mn/DOT stakeholders were aware of any data collection efforts that would be useful in the calculation of a benefit/cost ratio. The most likely candidate project for data collection was Mn/DOT's P069 project. Although machine control was not specifically part of the P069 project, a substantial amount of 3D model creation was performed. According to those involved with the project, the modeling portion of the project quickly grew beyond the original scope. This resulted in staff being tasked with more model creation and construction related responsibilities than originally expected. The project therefore would be ideal for tabulating the costs and benefits of model creation. Unfortunately, owing to staff being over tasked, data collection was not a priority.

An additional source for information on the cost and benefits of 3D Machine Control would be grading contractors. Contractors using the technology for an extended period of time likely possess data supporting their investment in the technology. However, contractors are unwilling to share this information in public forums for fear of disclosing sensitive information to their competitors.

Second, the factors involved with a benefit/cost ratio are difficult to assign to one particular stakeholder group. In some instances, Mn/DOT incurs a larger share of the additional labor costs, while the contractor realizes a bigger share of the benefits. Due to the inequities in sharing the benefits and burdens, the ratio would not be relevant to each individual stakeholder group. A more useful benefit/cost quotient is one that includes only the benefits and costs associated with each stakeholder group.

Lastly, no two projects are the same. The best comparison of the technology would be to complete two nearly identical projects, one with machine control technology and one without. This would clearly indicate any time savings and resulting cost savings associated with using the technology.

Alternative Evaluation Methods

Although quantitative data is not readily available to calculate a benefit/cost relationship, there is enough subjective data available to complete a qualitative evaluation of 3D Machine Control technology.

The commitment of equipment manufacturers is the most significant indication that the technology has a firm acceptance within the industry. Caterpillar and Trimble, leaders in earth moving machinery and field data equipment respectively, have joined together to form a joint venture company Caterpillar Trimble Control Technologies, LLC. The formation of this company further demonstrates the commitment by Caterpillar and Trimble Navigation to increase the presence of the technology in the industry. Ziegler, Inc., the local dealer in Minnesota, became the world's first joint CAT/Trimble dealer. Furthermore, representatives from Ziegler Inc. indicate that one of the base options available when ordering new models of Caterpillar equipment provides the installation of all necessary wiring and interfacing for the Trimble 3D Machine Control system.

Most of the benefits of machine control technology can be attributed to the reduction in time required to complete earth moving tasks on a project. Claims of increased efficiency by as much as 50% [2] and increase equipment utilization by as much as 30% [3] have recently been made. In one instance, the use of 3D Machine Control helped a contractor compress the construction schedule of a project for the North Carolina Department of Transportation by nearly a year. [4]

Table 3.1 shows a qualitative comparison of several GPS technologies with traditional methods [3]. All of these GPS technologies are employed with the use of 3D Machine Control technology.

GPS Technology	Compared with	Estimated Savings
Grade Checking	Manual Method	Up to 66%
Reduction or Elimination of Stakes	Using Stakes	Up to 85%
Improved material yields/select fills/undercutting	Overruns using manual methods	3% to 6% in volume
Un-interrupted earth moving production under any weather conditions (24/7)	Operation in daylight and good weather	30% to 50%
RTK, robotics stakeout	Traditional survey stakeout	More than 100% in speed and 66% in staffing

Table 3.1 – Comparison of GPS Technologies

The acceptance of 3D Machine Control technology is demonstrated by the types of projects where the technology is being utilized. In the past, the technology has been viewed as a tool for projects with large amounts of earth to be moved. Presently, contractors are operating the technology on smaller sites while still realizing the same benefits seen on large earthwork projects. It is now fairly common to see 3D Machine Control technology in use on small and medium sized commercial pad development sites.

All of the qualitative information above proves that the technology is not only feasible, but also beneficial to the industry. Despite the high initial investment and some of the problems associated with reception, contractors are utilizing the technology on an increasing number of projects. As disclosed by the survey responses from contractors on this project, contractors in Minnesota are investing large sums of money into 3D Machine Control technology. Figure 3.1 illustrates the range of investments that surveyed contractors have committed to 3D Machine Control equipment. The data represents 24 out of the 25 contractors surveyed; only a single contractor had not made an investment in 3D Machine Control Equipment. More than half of those polled had invested over a quarter of a million dollars in equipment. This sizeable investment clearly implies that the return on investment that contractors gain from the technology is considerable.

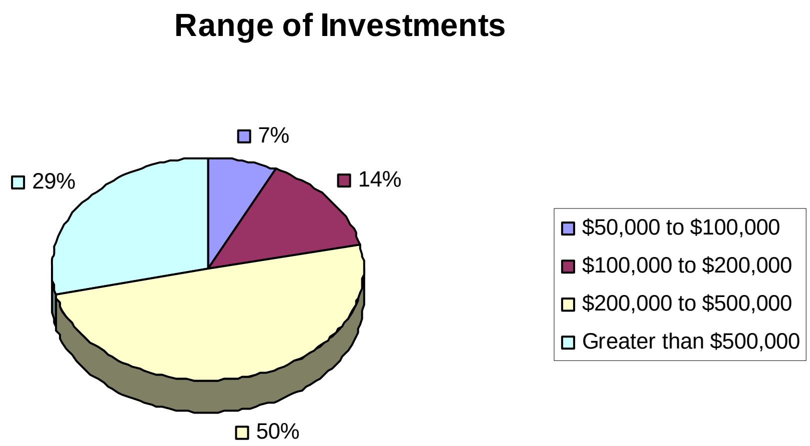


Figure 3.1 – Range of Investments by MN Contractors

(Source: Survey Reponses from16 Contractors with Machine Control Experience out of 18 total, See Chapter 4)

Documentation of Existing Mn/DOT Processes

Mn/DOT has taken several steps to prepare for the implementation of 3D Machine Control technology. Realizing the use of 3D Machine Control systems was increasing in Minnesota, Mn/DOT began testing their applicability to DOT projects. Mn/DOT encouraged stakeholders to evaluate the advantages and disadvantages of using these systems on future projects. Additionally, Mn/DOT has prepared specifications and developed procedures for model generation. As a result, Mn/DOT presently has a well defined program to support the use of machine control. The overall goal of this report is to evaluate this current program, and make recommendations to ensure the success of future machine control projects.

Mn/DOT's History in 3D Machine Control Technology

In order to appreciate the development of Mn/DOT's current program, it is necessary to understand the prior experiences of the organization with 3D Machine Control. The lessons learned by staff and engineers will be imperative in producing a future program.

Early in 2001, Mn/DOT gave GEOPAK notice to proceed on the P069 project, valued at more than $1.8 million. This project intended to address ways Mn/DOT can improve efficiency across the 13 functional groups that encompass the Program Delivery area. The ultimate goal of the project was to leverage more design data into the field for construction. Mike Coleman, Project Manager on the P069 Project, emphasized the project goals:

> "Mn/DOT has a need to more effectively generate, share and reuse data associated with the transportation design process, removing automation bottlenecks and opening the way for emerging technology applications. The objective of the P069 project is to improve the entire process of program delivery, streamlining the work between disciplines and shortening project timeframes." [5]

Mn/DOT received a significant amount of recognition for their innovation and leadership on the P069 project. In addition to numerous press releases and printed media coverage, Mn/DOT received the BE Award of Excellence, from Bentley Systems, in 2004.

One of the several technologies the program evaluated was 3D modeling. Mn/DOT initially required the contractor to use the technology on the construction of a few select storm water detention ponds along TH 23 in Willmar, MN. Both the contractor and the agency were satisfied with the results and modeling was extended to all 40 storm water detention ponds, grading, and aggregate surfacing. Mn/DOT estimated that the time savings for construction staking was between 8 and 12 hours per pond when 3D Machine Control was used in construction.

Another Mn/DOT pilot project for 3D Machine Control technology was the construction of TH 64 in Hubbard County, MN. The technology was used to construct a storm water detention pond along with grading and aggregate surfacing.

Overall, all Mn/DOT districts have had limited experience with machine control technologies. Although some of these have been pilot projects initiated by Mn/DOT, an increasing number of these projects are being requested by the contractors winning the bid.

Specifications and Special Provisions for the use of 3D Machine Control Systems

Mn/DOT's role in allowing 3D Machine Control on grading projects varies depending on a variety of factors. In the past, Mn/DOT has either mandated the use of the technology on a project or permitted its use. The fact that the agency has had experience with the application of 3D Machine Control means that documentation and specifications have already been developed. These documents establish Mn/DOT's policy on managing these projects.

A boiler plate special provision exists within Mn/DOT regarding 3D Machine Control. This special provision was drafted by the Office of Technical Support with the input of engineering and construction staff members experienced in 3D Machine Control. The specification is usually listed as (2011) Machine Control and is in line with Division II Construction Details from Mn/DOT's Standard Specifications for Construction. A copy of Mn/DOT's boiler plate special provision is included in Appendix B.

The 3D Machine Control provision is not included within the boiler plate Special Provisions provided to the public on Mn/DOT's Technical Support web site. As a result, the provision is not readily available to the industry. On projects where the use of 3D Machine Control is permitted and reliant upon GPS equipment, Mn/DOT Special Provisions allow for systems manufactured by Trimble and TopCon.

At the current time, there is no mention of 3D Machine Control in Mn/DOT's Standard Specifications for Construction. As the use of 3D Machine Control is both site and project specific, it is understandable that it is not included. This omission is also understandable since the Standard Specification for Construction is not updated frequently. The newest version is the 2005 edition which replaced the previous 2000 edition. Revisions to the Standard Specifications for Construction may not be frequent enough to keep up with the changing or emerging technology. However, as the technology becomes more commonplace, Mn/DOT will need to consider including a base provision regarding 3D Machine Control in the Standard Specifications for Construction.

Comparison to Iowa Department of Transportation's Specifications

A comparison of the Mn/DOT specifications for machine control to the Iowa Department of Transportation's (Iowa DOT) Developmental Specifications for Global Positioning System Machine Control Grading was performed. This comparison provides feedback to Mn/DOT regarding a neighboring DOT's experiences in managing 3D Machine Control projects. Iowa DOT permits the use of 3D Machine Control grading on roadway embankments only. By comparison, Mn/DOT does not limit the scope of using machine control so long as all work meets the required specifications of the project. Both Iowa and Minnesota place the liability of using electronic files on the contractor. Mn/DOT provides a disclaimer stating that the electronic files are for information only. Iowa DOT simply states that the contract documents govern the design.

Iowa DOT has documented a specific list of requirements that the contractor must meet when using machine control. Included is the requirement that the contractor provide secondary control on the project. The contractor is required to provide a means of verification of the work's accuracy for the DOT. Specifically, the contractor must provide hubs, set with traditional survey methods, for all hinge points of a cross section at 1,000 foot intervals along the main alignment. At least two cross sections on every ramp and side road must also be provided. Additionally, conventional grade stakes must be provided at critical points such as Points of Tangency (PT) and Points of Curvature (PC). This network of control enables Iowa DOT staff to check that the machine control grading work meets project tolerances. This contrasts with Mn/DOT which does not allow for any change in the interval for hub placement. Mn/DOT requires the surveyor to place hubs at the same interval whether machine control will be used or not. In instances where machine control will be used, this requirement eliminates a portion of the time and cost savings of using the technology. This requirement does provide a backup system in instances where machine control equipment might be malfunctioning or in times of signal outage.

Mn/DOT and the Iowa DOT differ in their basis of payment for using 3D Machine Control Systems. In Minnesota, all machine control work is considered incidental, and does not warrant direct payment. Iowa allows for a lump sum bid item on the project contract. The lump sum includes all work associated with preparing electronic data files, system checks, calibration, training for DOT staff, and all of the contractor's requirements that are indicated in the specifications. Neither Mn/DOT nor the Iowa DOT provides compensation for delays incurred by poor GPS reception. The Iowa DOT Developmental Specification is found in Appendix C.

Mn/DOT Machine Control Check List

In order for a project to be a candidate for machine control within Mn/DOT, it is recommended it be evaluated against a check list that has been prepared by the CAES Unit. The check list covers topics such as local GPS coverage, Digital Terrain Model coverage, plan preparation techniques, and plan designer. The full version of the check list is included in Appendix D.

In all, there are ten criteria that the check list addresses in order to help district staff determine if a project is a suitable candidate for machine control.

Criterion #1 – GPS Coverage

The user of the check list is to rate the expected GPS coverage on the project as good, fair, poor or none. If the user feels the GPS coverage on the project is poor or none, they are directed to list in the special provisions that the project is not supported for machine control.

As mentioned before, there are various add-on components to 3D Machine Control systems that help compensate for poor signal reception. Rather than restricting the use of machine control on any particular project, it may be more appropriate to modify the special provisions allowing the contractor to use machine control technology on any project as long as the contractor demonstrates the tolerances can be met with the technology and all stakeholders agree. To clarify, tolerances should not be changed or relaxed due to the contractor's choice in equipment or technology.

Criterion #2 – Existing Ground Surface Model

The second item on the check list attempts to gauge the amount of coverage and quality of the existing ground surface model. The user of the check list evaluates the coverage of the digital terrain model as covering the whole project, portions of the project, or no coverage.

The criteria further states that the digital terrain model should be from a file provided by the Photogrammetrics functional group or can be generated from field surveys. The criterion cautions that LIDAR data is typically not within the desired accuracy to generate the necessary models.

Similar to the first criterion, this criterion may be prohibiting the more widespread use of machine control within the state. The lack of an existing ground surface does not necessarily mean that 3D machine control would not be beneficial on a project. Up to this point, Mn/DOT has defined a machine control model as a complete project model; one that is from tie down to tie down. For this definition of a project model, an existing ground digital terrain model is required in order to determine the tie down locations.

Changing the definition of a project model to a portion of the project, such as pavement surface for example, can still benefit the construction process greatly. Construction with this type of model would be a hybrid combination of new technology and traditional survey methods.

The reference to LIDAR data not containing the accuracy for construction is a real concern. This only applies to modeling efforts that will directly support machine control construction. The process of 3D modeling can be beneficial throughout a project, including preliminary design, where the accuracy of LIDAR digital terrain models would not be detrimental.

<u>Criterion #3 – Project Size and Dollar Value</u>

The check list is vague on this item since it leaves the monetary threshold for determining whether machine control should be allowed on a project up to the user of the check list.

Projects involving large amounts of earthwork are easy candidates for application of machine control technology. Mn/DOT likely does not have enough data to determine what the exact dollar amount should be in order to determine the benefit of the technology. The contractors will undoubtedly know the return on investment calculation for the purchase of their 3D Machine Control systems.

This criterion should only be applied when Mn/DOT is committed to providing the models to the contractor without any direct compensation to the agency for the time involved.

As mentioned elsewhere within this report, 3D Machine Control is being used on more projects and projects of smaller size. If the goal of the agency is to increase the use of machine control throughout the state, then dollar value of the project should not be a considering factor. One way to potentially limit the direct costs to Mn/DOT as a result of model creation is to use innovative contracting methods to have the contractor share the associated costs. Some contracting methods, such as Value Engineering, could be applied in such situations. This implies that one stakeholder will not reap all the benefits at the expense of the other stakeholder.

<u>Criterion #4 – Project Designer</u>

For projects designed by consultants, the user of the check list is instructed to evaluate the candidate project on a case by case basis. A thorough review of the data must be completed in order for the project to remain a candidate for machine control. No further instructions are provided to the user if the project was designed in-house by Mn/DOT staff.

This criterion does not apply to the use of machine control and should be deleted. Each and every project, whether designed in-house or not, should be evaluated solely on the project data.

Consultants are hired as extensions to Mn/DOT staff and therefore must be held to the same standards, both in project delivery and accuracy of the data, as Mn/DOT employees. Mn/DOT typically requires consultants to adhere to the Level II CADD Standards, often requiring signature of an affidavit affirming this fact. In addition, Mn/DOT already has processes in place for rating consultants on their ability to meet project standards.

Criterion #5 – Existence of Project Cross Sections

This criterion is used as an indication on how difficult it will be to create a complete project model, tie down to tie down. As stated previously, Mn/DOT has focused on modeling as a complete project model. As stated in one of the options for this criterion, it will be difficult to make a non-pavement model if cross sections do not exist. The software utilized for modeling is heavily reliant upon the criteria for building cross sections in generating the 3D model. Therefore, if cross sections exist, it will be easier to create the necessary 3D model. It is important to note that model can be created without cross sections. However, the existence of cross sections makes for a more rapid development of the model.

Criterion #6 – Criteria Files used in Cross Section Generation

Criteria files are used by the design software in order to create cross sections. The criteria files are a type of programming file containing logic tests which execute a particular block of code depending on the outcome of the test. These tests and the subsequent drafting are the way in which the generation of cross sections is automated on a project. Without these criteria files, each individual cross section would have to be hand drafting which is an extensive process both in time and exposure to errors.

This criterion asks the user of the check list to evaluate whether standard criteria files were used on the project and cite any non-standard criteria files that were used. Standard criteria files are those criteria which are delivered by Mn/DOT through the CAES Unit and freely available to both public and private sector designers. The standard criteria files are to be used in most cases, as they contain a sufficient amount of logic tests for most design situations.

Non-standard criteria files are those that are typically project specific and address very unique features for that project. These non-standard criteria files may be written by a project design team staff or a consultant. The presence of non-standard criteria files does not automatically exclude a project for consideration for machine control, but rather should raise the level of awareness for potential problems during the modeling process. Criteria files have to be written with a very particular syntax in order to be interpreted correctly in the modeling software.

Criterion #7 – Cross Section Hand Edits in Finished Grade

As a follow up to the previous criterion, this criterion further investigates the quality of the data by asking the user of the check list to estimate the number of hand edits that exist in the finished grade portion of the model.

During project design, the goal for the percentage of hand edits would be zero. A hand edit is a remedy to an instance where a criteria file did not accurately draw the cross section in its entirety. In such a situation, the project designer is faced with a decision to modify the criteria file in order to draw the cross section accurately, or to perform a hand edit.

Many project designers take the easier remedy which is performing a hand edit. A hand edit is basically a manual correction, or drafting, to the cross section. Each time the cross sections are regenerated, the hand edit must be repeated. This inefficiency is only one reason why the goal is zero hand edits during design.

Since criteria files are a type of programming language, not all users of criteria files are capable of writing or modifying criteria files to function correctly. This is another reason users often decide to perform hand edits rather than modify the criteria file.

In the modeling scenario, hand edits to cross sections equate to hand edits in the resulting 3D model. Unlike cross sections however, hand edits to a 3D model are much more difficult for most users to perform. Therefore, the larger the percentage of hand edits in the cross sections, the greater the effort required for corrections to the model.

The preferred method to correct these instances for the modeling software is to revise the criteria file such that the hand edit is no longer required.

Criterion #8 – Cross Section Hand Edits in Subgrade

Continuing the evaluation of the cross sections from the previous two criteria, this criterion asks the check list user to estimate the number of hand edits in the subgrade portion of the cross sections. This criterion is nearly identical to the previous one which estimated the number of hand edits in the finished grade surface.

The same disadvantages and challenges that were mentioned for hand edits in the finished grade apply to hand edits in the subgrade. The greater the number of hand edits, the more difficult the 3D model will likely be to construct.

Criterion #9 – GEOPAK Site Objects

This criterion is more or less a comment to the user of the check list regarding portions of the design that were modeled with GEOPAK Site. This criterion notifies the user that GEOPAK Site object or models require minimal time to incorporate.

Criterion #10 – Exception Areas

This criterion is also a comment to the user of the check list regarding exception areas not to be used for machine control. The exception areas listed are approach treatment areas around walls and bridge abutments. The user is directed to list these as exceptions in the special provisions.

Variations of Mn/DOT Support for 3D Machine Control

Mn/DOT currently provides for the use of machine control in one of the following four ways:

- Mn/DOT will allow 3D Machine Control and has already constructed the models.
- Mn/DOT will allow 3D Machine Control and prepares models at the contractor's request.
- Mn/DOT will allow 3D Machine Control, but will provide electronic base files.
- Mn/DOT will not allow 3D Machine Control and will not provide electronic base files.

The specific method of providing for machine control on a project is determined before letting and included within the Special Provisions.

If Mn/DOT opts to allow 3D Machine Control on a project, electronic design files are transferred to the contractor. When Mn/DOT is directly involved in modeling such as the first two items above, they transfer the applicable three dimensional models; when indirectly involved such as the third item above, the transfer consists of Computer-aided Design (CAD) files and supporting GEOPAK files.

Mn/DOT has a standard disclaimer regarding electronic design files. The disclaimer makes the recipient responsible for verifying the accuracy of the electronic design files' contents. On 3D Machine Control projects, the recipient of the electronic design files is the contractor. In instances where the contractor forwards the information onto a hired representative, the contractor is still considered the recipient. Therefore, the contractor is required to sign and return the disclaimer to Mn/DOT prior to the release of the electronic files. The disclaimer states that Mn/DOT does not guarantee the accuracy of the electronic files and that the paper plans govern the execution of the contract. A sample copy of Mn/DOT's disclaimer is included at the end of this report as Appendix E. If Mn/DOT decides to support 3D Machine Control on a project, the special provisions include an additional disclaimer, which reads as follows:

> Mn/DOT believes the electronic data it will provide is accurate, but does not guarantee it. The documents originally provided with the Contract remain the basis of the Contract, and the electronic data being provided is for informational use only in order to assist the Contractor with the use of machine control. Therefore, if use of this data causes an error, any costs to the Contractor in time or money to make corrections as a result of this error will not be considered "extra work" [6].

Current Mn/DOT Machine Control Modeling Methods

The Minnesota Department of Transportation is one of 47 states that use MicroStation software from Bentley Systems, Inc. MicroStation software is the underlying CAD platform used in project design. GEOPAK software, also from Bentley Systems, Inc., is the civil engineering add-on used by Mn/DOT. These are the standard programs used to design and produce construction documents for a typical construction project. Mn/DOT requires consultants preparing plans for the agency to use these software packages. Additionally, consultants must adhere to the same CAD standards used by agency designers.

When Mn/DOT has determined that 3D Machine Control may be used on a project and the agency will be directly involved with model creation, one of four work flows is typically used to create the necessary models. These four work flows are:

- Metro District of Surveying and Mapping Spreadsheet Method
- Modeling with GEOPAK Site
- Post Design Modeling using GEOPAK Modeler
- Concurrent Modeling using GEOPAK Modeler during Design

Each of these four methods is detailed below in the following sections. The methods are introduced in the order with which they have developed, with the first workflow representing the earliest method developed and the last being the most recent method implemented.

Metro District of Surveying and Mapping Spreadsheet Method

The Metro District of Surveying and Mapping has long been responsible for construction stakeout on various construction projects. The office has developed a process for supporting 3D Machine Control that utilizes the staff’s experiences. The process is a conglomeration of several individual steps, and has been used for traditional construction stakeout and the preparation of cut sheets. The process was not developed to support 3D Machine Control; the method has been adapted to support it.

As the name implies, the practice is heavily reliant on the use of spreadsheets, specifically Microsoft Excel. It has been enhanced and improved via custom Visual Basic for Applications (VBA) routines, written within Mn/DOT.

The procedure consists of reverse engineering the construction plans, most often after the design has been completed. The concept of the process is to create cross sections at a small enough interval to accurately represent the proposed project. In addition to selecting a small interval between data points, the method includes the critical points of the design plan. These include PC’s and PT’s from both the horizontal and vertical alignments, median noses, ramp gores, superelevation transition points, beginning and ending locations of walls, and other points that the surveyor deems important.

The process requires the completed construction documents, supplemented by electronic files. Availability of the GEOPAK Coordinate Geometry (COGO) database decreases the time needed to complete the procedure. However, the database is not required if the profile and alignment information can be recreated from the construction plans.

The progression starts by invoking a VBA routine within MicroStation, which pulls finished grade elevations from the design profile in the COGO database. The user defines the interval that these elevations are pulled, typically five feet. The VBA routine outputs these values to a Microsoft Excel file.

Upon locating the centerline data within Microsoft Excel, the method continues with entering formulae into various cells. These formulae calculate the new elevation based on the offset and slope at that location. This process continues horizontally from the centerline towards the tie down location. The formulae vary depending on the design elements located along the cross section.

Once the elevations have been computed for the entire length of the project, another VBA routine converts the station, offset, and elevation (SOE) data into x-, y-, and z-coordinates. These coordinates are compiled into a GEOPAK Data (DAT) file, which is a 3D representation of all of the critical points that comprise the model surface. The DAT file is then triangulated to form a 3D surface model in the form of a GEOPAK triangulated irregular network (TIN) file. GEOPAK has tools that convert this TIN file into the file formats required for the machine control equipment.

The spreadsheet method has advantages over other 3D Machine Control processes that Mn/DOT uses. First, the length of time the process has been in use has enabled it to become refined via constant use in the field. The employees currently involved with processing the data have documented the procedure extensively and know the method well. Secondly, since this workflow is completed after construction documents have been prepared, it functions as an independent quality review of the design. Errors and omissions are caught with this process prior to the locations being staked in the field. Finally, the spreadsheet method is flexible when it comes to making design revisions as many of the formulae are dynamically linked. Changing a centerline elevation will update all elevations at that station.

However, some of the same items listed as advantages can also be leveraged as criticisms of the process. The process is nearly a complete reverse engineering of the construction documents. When looking at the life cycle of the entire project, it becomes clear that reverse engineering construction documents is not efficient. Beyond efficiency, reverse engineering introduces the potential for errors and omissions that would not otherwise occur. Depending on the size of the project, the spreadsheet method may require substantial effort and time. Staff members have voiced concern that the spreadsheet method is difficult to use if timelines for preparing the data are short, especially if available staff is limited. This combination of short timelines and overworked staff leads to decreased quality of finished products. Furthermore, the spreadsheet procedure performs an extensive number of calculations, generating large amounts of data. As there is no defined quality control process for checking calculations and their results, any quality benefits gained from checking the design may be lost in implementation.

The spreadsheet method also creates some difficulties with implementation in the field. When using this method, the project surveyor determines the interval spacing the spreadsheet method will use for creating the SOE data. In the past, project surveyors have opted on five foot interval spacing with occasional one foot spacing when the cross section includes changing superelevation or curvature. This interval spacing is carried throughout the alignment of the proposed roadway. As a result, the TIN file created tends to be very large. Since the processor on the earthmoving equipment can only process files of a certain size, it becomes necessary to break the large files down into several smaller files. By not providing all of the project information to the equipment, the machine operator can only grade small sections of the project. The inability to continually grade over long distances is a hindrance of the spreadsheet method and results in inefficiencies in grading operations.

Another of the spreadsheet method's deficiencies is that the model created is not a tie down to tie down model. The spreadsheets used in this process do not incorporate the existing terrain at the cross section location. Therefore, the model can only be constructed to the last hinge point before the tie down location. Field personnel have to use traditional methods to determine the tie down location on the job site. The possibility does exist to incorporate the additional existing conditions data, but the effort it would take to incorporate the existing TIN and program logic within Excel to use the data to tie down would be extensive.

Figure 3.2 is a schematic diagram which documents the steps involved in implementing the spreadsheet method.

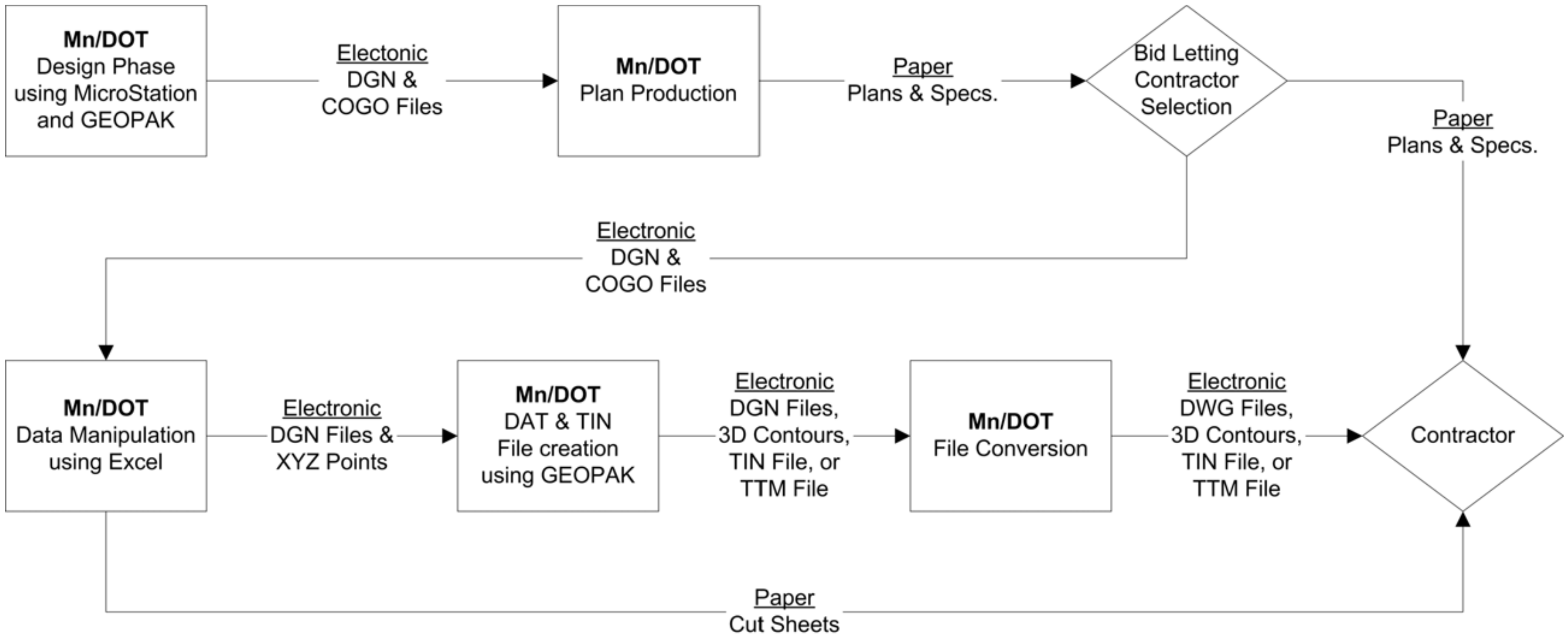


Figure 3.2 - Spreadsheet Method Workflow

Modeling with GEOPAK Site

The GEOPAK software package includes another module called GEOPAK Site. Initially, this module was targeted for engineers working in the land development market. It includes tools for designing sub divisions, residential roadways, and ponds. GEOPAK Site progressed into typical roadway design projects, such as treatment ponds, mass grading areas, and interchange infield areas. The work flow in GEOPAK Site is typically based in a two dimensional design plane. A designer using GEOPAK Site tags an elevation onto a two dimensional element.

There are three major components that a GEOPAK Site model contains. The first, Elements, are typically individual lines and arcs. Elements represent specific features in the field; for instance, a line may represent a length of curb and gutter. The second component, Objects, are comprised of several Elements, and often represent items such as treatment ponds or individual roadways. The final components are Models. Models consist of one or more Objects, and correspond to an entire project, such as a residential development.

This hierarchy is advantageous, as Models are dynamic. Each individual Element in a Model has an associated elevation assigned at the vertices of the Element. A change to an Element's elevation will be reflected in any Objects that the Element belongs to. Objects do not possess a specific elevation, as each Element in the Object may possess differing elevation values. Nevertheless, Objects can be raised or lowered in GEOPAK Site. Raising or lowering an Object changes the elevations of each Element belonging to the Object. Furthermore, Objects can also contain side slopes which are a graphical representation of the elevation at which the Object ties into the overall -model. Side slopes are used to mesh the Object to other Objects or the Model instantaneously. This advantage allows a designer to dynamically change an entire model by making changes at the Element level of hierarchy.

There are many advantages to using GEOPAK Site. The software is often used early in the design process, rather than after design is complete. If appropriate electronic files are available, the software can be used in reverse engineering once the design is complete. The GEOPAK Site software is integrated with other GEOPAK modules, including Road and Drainage. Therefore, the entire design can be created using the same files throughout the project life cycle. Conventional cross sections can be cut through GEOPAK Site Models and Objects; they can be stand alone or part of the GEOPAK Road cross sections. GEOPAK Site offers several ways to view and query the design; typically the user displays contours. The Models and Objects can be exported as a 3D surface model in the form of a GEOPAK TIN file. GEOPAK can convert this TIN file into various formats, depending on the machine control equipment manufacturer's requirements.

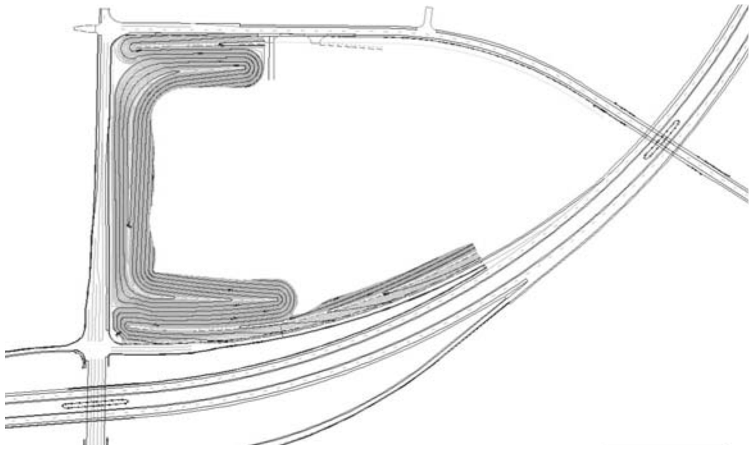


Figure 3.3 – Modeling in GEOPAK Site

GEOPAK Site can be used to model several portions of a design, but is difficult to create a comprehensive design for use in 3D Machine Control. For the most part, GEOPAK Site is capable of generating a finished grade surface model. During construction, it is essential to know the subsurface features and the corresponding elevations and offsets for grading the granular fill and aggregate base. To model subsurface features, a software tool entitled "Quantity Depths" may be used. Unfortunately, this feature is not adequate enough to represent the various granular layers and over sizing that is typical of conventional cross sections. Additionally, the learning curve for users of GEOPAK Site is steeper than using the traditional methods of generating cross sections.

Although the design can occur in two dimensions, it nonetheless requires the user to think in three dimensions. As mentioned earlier, GEOPAK Site software adapted from land development design requirements. These projects do not include the multilane, superelevated projects that are typical on a highway design project. These areas are difficult to model without great effort from the operator. The software includes many dialog boxes and numerous settings that affect the quality of the finished surface model. The complexity of the process is such that instances occur in which a small step, checking a toggle box for instance, can introduce drastic errors into the model. Finally, the ability to accurately perform a quality control check of the surface model is more difficult than in conventional cross sections. This is attributed to the large number of elements included in the model. Rather than just checking the validity of the cross sections, it becomes essential to verify that all of the elements possess the proper elevations at their vertices, a much more laborious task. Whereas in a three dimensional modeling system, the user can alter their viewpoint to look at the model from multiple angles; users of GEOPAK Site usually review numerical data to verify the models accuracy. Although users can verify triangle files or contours, users tend to be much more comfortable checking cross sections.

Figure 3.4 documents the workflow associated with modeling in GEOPAK Site. The figure portrays how an entire project would be modeled. This is an important distinction, as previous projects have used GEOPAK Site to model portions of a project (i.e. pond grading).

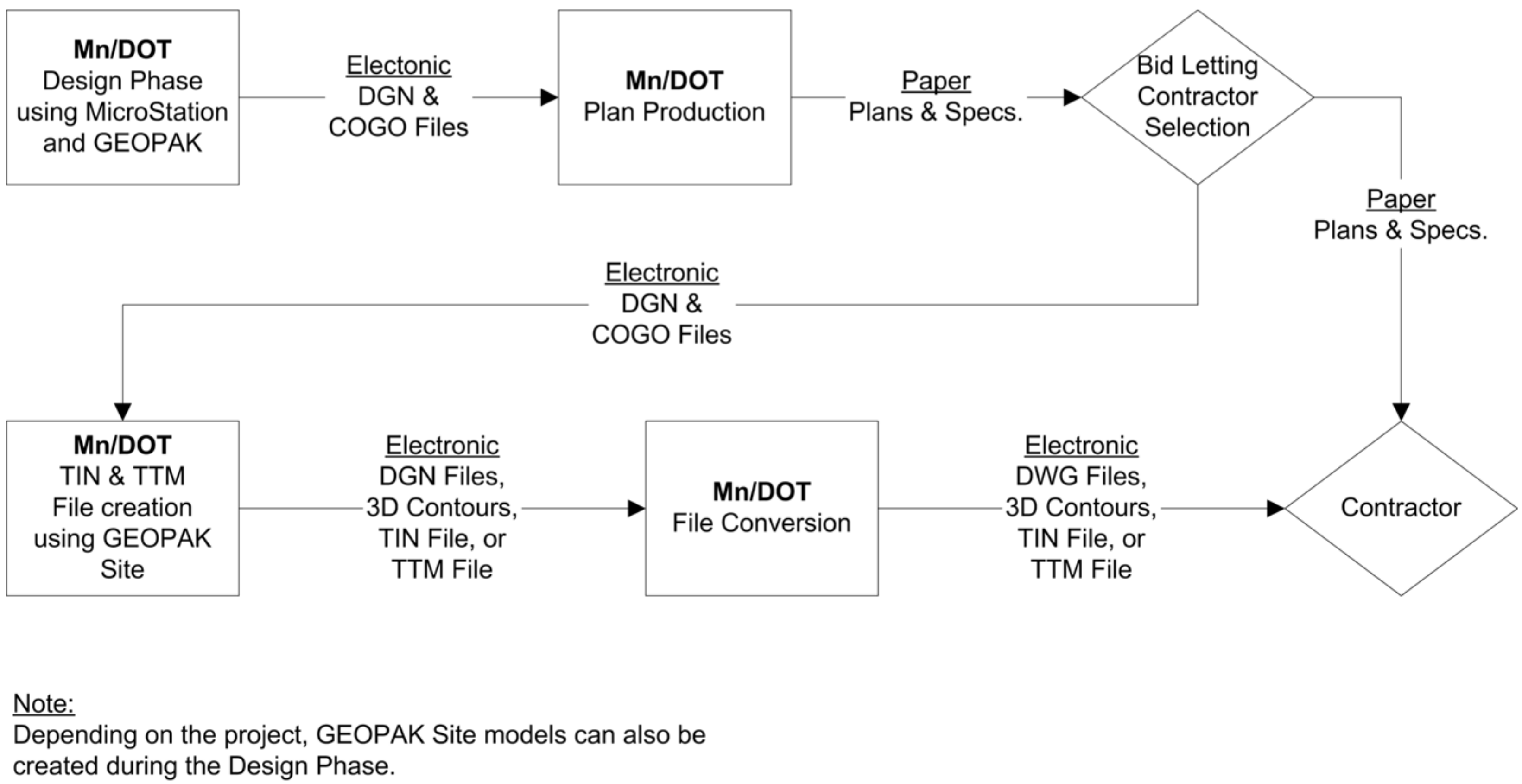


Figure 3.4 – GEOPAK Site Workflow

Post Design Modeling using GEOPAK Modeler

Bentley Systems, Inc. possesses a strong relationship Mn/DOT. As a direct result, Mn/DOT has the ability to offer input into the future software developments and improvements Bentley Systems considers.

Observing the overwhelming demand for 3D models and the inability of GEOPAK Site to meet those demands, Bentley Systems began developing a new design tool for GEOPAK. Bentley Systems released this tool in late 2006 in an attempt to develop three dimensional modeling without changing the existing design workflow. This product, the Roadway Model Builder, builds a three dimensional model of the project using the same traditional cross section development process that Mn/DOT has used for several years.

Mn/DOT had extensive input in developing this design tool. During the P069 Project in 1999 and 2000, Mn/DOT worked closely with Bentley Systems staff in developing the Roadway Model Builder. This cooperation allowed for testing early development versions of the software on Mn/DOT pilot projects.

The tool requires the designer to design in three dimensions rather than in the two dimensional viewpoints that is common today. The Roadway Model Builder automatically determines the appropriate interval for generating cross sections; the interval selected depends on the complexity of the design. Cross section intervals are more frequent in critical areas, such as vertical curves, and in transitional areas, such as turn lanes. In typical cross sections, pattern lines are drawn perpendicular to the roadway alignment. In modeler, the pattern lines are drawn radial to the plan view elements representing the geometry.

In most of Mn/DOT's experiences using the Roadway Model Builder, the model has been constructed after the design and preparation of construction documents has been completed. The reason that this modeling has occurred late in the design process is attributable to the long time frames required for project delivery and not to the function of the Roadway Model Builder.

The biggest benefit of this method is the creation of a complete project model that includes both the finished surface model and individual sub models for each granular layer. A sub model represents the intermediary steps in model creation, such as subsurface layers of granular fill. These models tie into the existing TIN as well as to the surface model. A GEOPAK TIN file can be created from the surface model and its sub models. As with the GEOPAK Site model, TIN files can be converted into the file formats specified by the machine control equipment manufacturers. Additionally, the work flow in this method is very similar to that used in the development of traditional cross sections with GEOPAK Road. The model is created by processing criteria files. Criteria files contain routines capable of performing logic tests and perform all of the drafting of elements in cross sections. Criteria files are used for many different objects in the overall model including roadway design, ditch design, and noise wall design.

The biggest disadvantage of this method results from the location of modeling in the project life cycle. Due to the recent release of the software, models are being created once the final design documents are completed. Considerable rework is introduced by producing the model at this stage in the design process. This creates a duplicate design step, introducing the opportunity for error.

In 2004, Bentley released MicroStation Version 8 (V8) 2004 Edition. The V8 versions of the software created a much more accurate design plane than the previous Version 7 (V7) generation. Projects that were currently underway were converted to V8. As a result of the higher accuracy and precision required by V8, and the fact that files converted from V7 retain their old precision and accuracy, this conversion became a tedious and arduous task. Line work that included overlaps and gaps that resulted from the precision limitations of V7 had to be corrected prior to conversion. Although these issues can still occur in V8, the improved accuracy of the drafting plane has drastically reduced this potential. The GEOPAK Roadway Model Builder requires most of the inaccuracies of V7 be corrected prior to processing the model. This issue has added to the difficulty of using GEOPAK Modeler at the end of the design process. However, as time progresses, fewer projects have any remnants of V7 remaining. Therefore, it is expected that the difficulties attributed to the conversion will diminish with time.

The fact that this method requires the designer to work in a three dimensional design file creates another large disadvantage as a steep learning curve is associated with users who are unaccustomed to navigating these designs. Although the GEOPAK Roadway Model Builder is a huge improvement over previous design tools, the tool contains glitches attributable to the product's recent release; these issues are currently being addressed. The GEOPAK Roadway Model Builder is very demanding of a user's computer. Widespread use of the tool requires a high performance computer at the operator's workstation. At Mn/DOT, CAD workstations are purchased at the central office. 3D modeling is used as the benchmark for processing speed and capability in purchasing these machines. Mn/DOT has a process in which new workstations are purchased every three years for staff members who work on 3D modeling, with the older machines being filtered down in the agency to user's whose tasks are less demanding on the workstation's capabilities.

Figure 3.5 illustrates the workflow associated with post design modeling using GEOPAK Modeler.

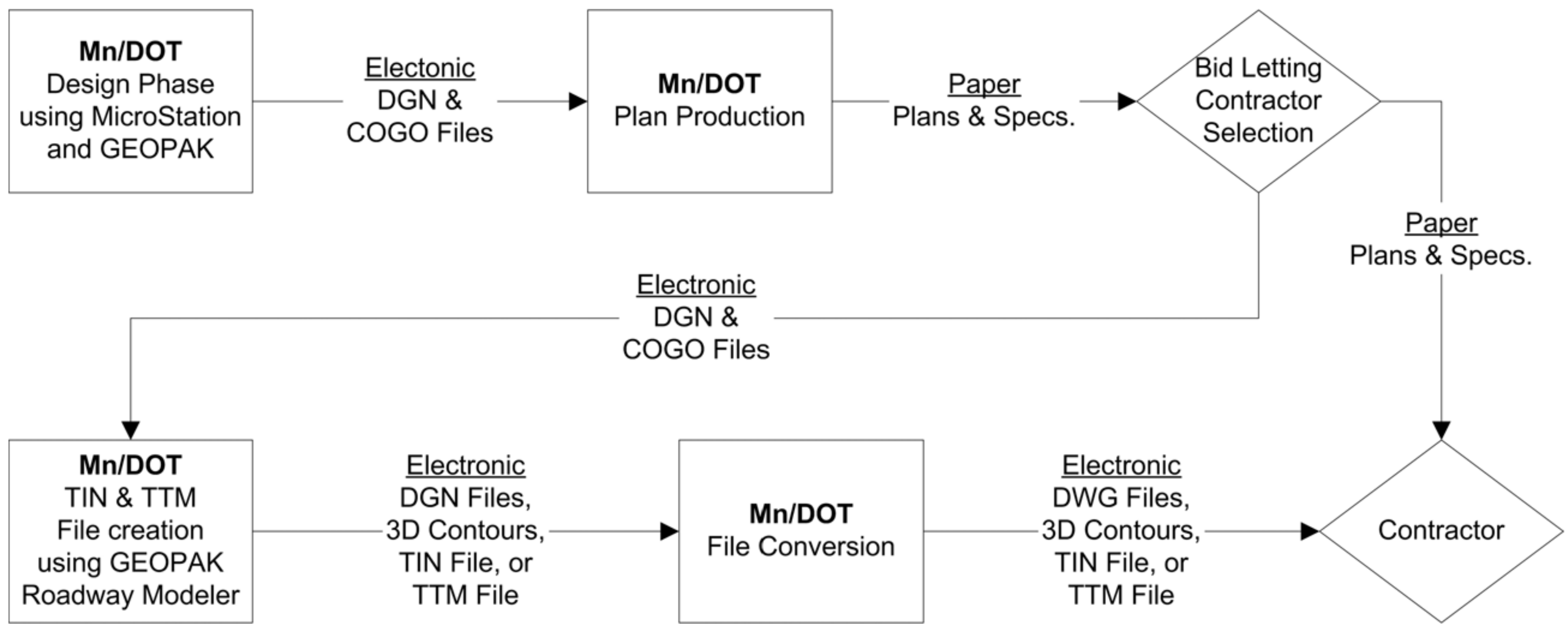


Figure 3.5 – Post Design GEOPAK Modeler Workflow

Concurrent Modeling using GEOPAK Modeler during Design

This process is exactly the same as that of the previous, with one exception. In this method, the modeling is done as a part of the normal design process. In the previous method, modeling is performed after the design and construction plans were completed.

It is expected that this process will replace the previous one as new projects enter Mn/DOT's project delivery cycle. The benefit of this process is that it reduces the need for duplicate design procedures. Consequently, the risk of errors entering into the design after plan preparation is eliminated. By incorporating the GEOPAK Roadway Model Builder early in the design process, it becomes a design tool rather than a construction tool. In each of the previous processes, preparation of the models is a required step necessary in supporting 3D Machine Control or construction stakeout. By incorporating three dimensional modeling early in the design process, it is expected that design quality will improve. In allowing designers to address and correct conflicts in the design prior to construction, both Mn/DOT and the public benefit from improved design efficiency.

Familiarizing and training users in the modeling concept proves to be the largest hurdle in implementing this method. Owing to the civil engineering industry's long tradition of preparing two dimensional plans, a mindset change must occur in order to move to three dimensional modeling. With adequate training, this obstacle is surmountable. Additional short term disadvantages include the increased time needed during design to prepare and troubleshoot models. The time spent in design correlates to a reduction in the number of problems addressed in the field. Nonetheless, the initial time investment will be substantial. The first projects employing this method should expect an extended design period. Over time, as more individuals become experienced, the efficiency of this method will become evident.

Figure 3.6 schematically diagrams the workflow associated with concurrent modeling using GEOPAK Modeler.

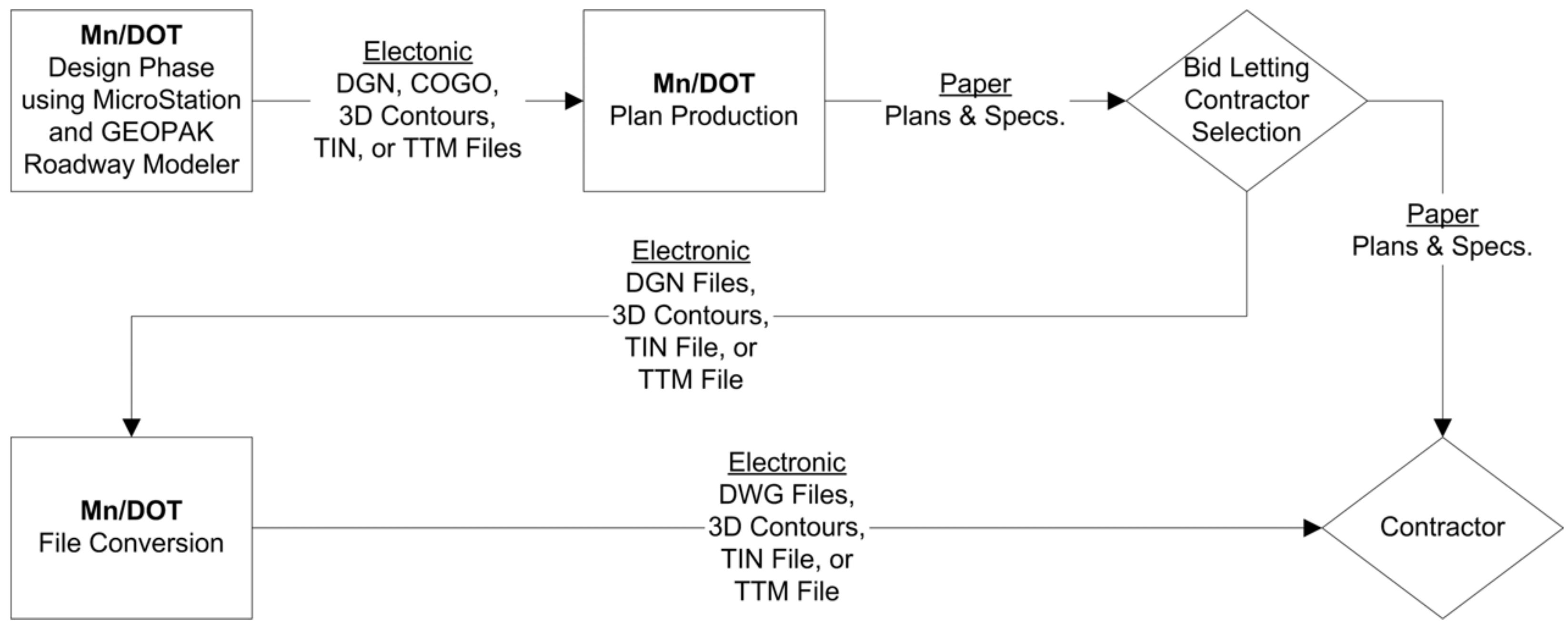


Figure 3.6 – Concurrent Design GEOPAK Modeler Workflow

Modeling Efforts External to Mn/DOT

In addition to the four processes above, there are two processes that exist in the industry that are external to Mn/DOT. These external processes result when Mn/DOT determines that they will allow 3D Machine Control on a project, but will not be directly involved in the creation of the models. Rather, Mn/DOT agrees to provide electronic base files. These additional processes are:

- Contractor Generated Process
- Third Party Industry Process

The processes are detailed below in no specific order.

Contractor Generated Process

This process can vary greatly depending on the contractor and the amount of experience the contractor has using 3D Machine Control systems. The process typically starts with the contractor receiving the contract documents consisting of the plan, specifications, and special provisions. The contractor is then responsible for "reverse engineering" the paper contract documents into electronic CAD files. These CAD files are then used to generate the three dimensional models needed for machine control.

In the instances where the contractor is relatively large and has experience with the technology, employees are dedicated to the reverse engineering process and creation of models. In slightly smaller companies, this responsibility will be assigned in addition to the employee's typical job responsibilities. Small companies with little to no experience will typically hire a consultant to create the models for them. Of all the contractor stakeholders providing input for this project, only one indicated they did not have at least one staff member with some degree of modeling responsibilities.

The conversion process consists of two separate steps, both of which allow substantial opportunity for error. The first step is the conversion of a two dimension representation of the project on paper to the electronic CAD files. This phase of the conversion is facilitated if the contractor successfully acquires electronic files from the agency letting the project. Departments of Transportation throughout the country have varying views regarding the release of files. Fortunately, Mn/DOT is more willing than other agencies to release files if they are available.

The second conversion phase occurs between CAD platforms. 3D Machine Control System software on the market supports various file formats. AutoCAD software file formats and applications are supported more robustly than other CAD platforms. However, 47 out of 50 state DOTs, and the Federal Highway Administration, use the competing MicroStation software CAD platform. AutoCAD and MicroStation are both capable of three dimensional design and modeling, and both platforms utilize various add on products to assist in the geometric design of civil projects. Contractors typically input the surface models they receive from either MicroStation or AutoCAD formats into Terramodel. Terramodel is a software package from Trimble that assists contractors in automating construction calculations, producing stakeout data, and generating 3D Machine Control models. The Terramodel output can be uploaded into the 3D Machine Control System computer for use in the field. SiteVision is the corresponding software from Trimble which is used to prepare and transfer the electronic files for use in the field.

One of the current drawbacks of both Terramodel and SiteVision is the inability to input MicroStation V8 files. At this time, both of these software programs do support MicroStation V7 files. As a workaround, most contractors or third party consultants convert the delivered MicroStation files to AutoCAD files in order to create models. In part, this also has to do with the contractors' greater familiarity with AutoCAD. Terramodel also enables the contractor to create the 3D models from the construction documents should Mn/DOT not provide them with a model or any electronic information.

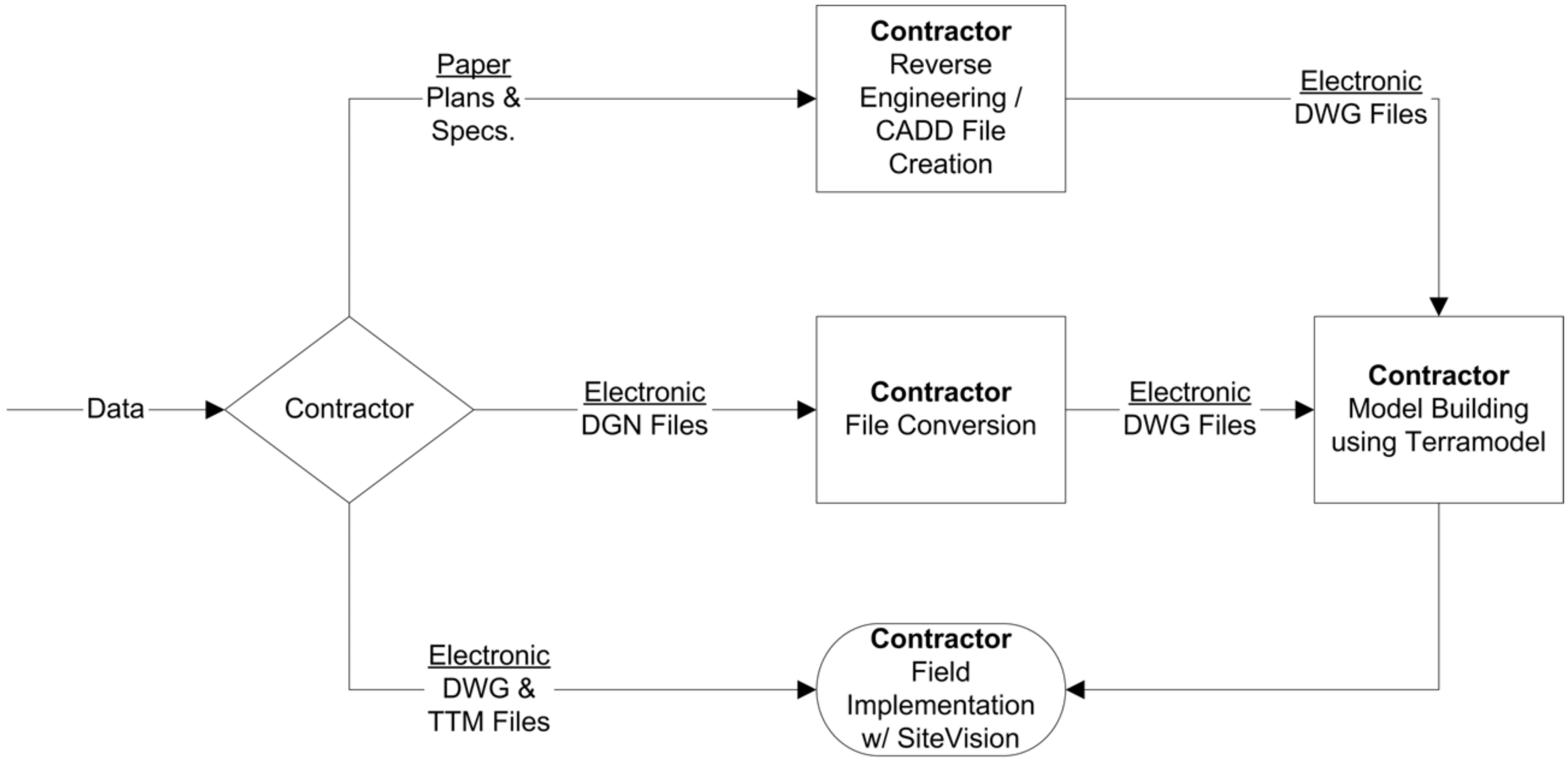
The Contractor Generated Process takes more time and reduces efficiency in the overall project process. Conversions are a high risk process in that errors may enter the design, and adversely affect its quality. The risk is elevated further since the employees dedicated to this task are not as familiar as the designers in regards to mastery of the software programs and engineering methodologies used to create the contract documents. J. Parker, from Keller Construction summarizes the difficulties contractors can face.

> "Taking it from the design file to machine file is one of the most tedious things we're faced with. If the company doesn't have a technical person like myself on staff, someone who knows computers and has experience with CAD files, it can be a problem. There's a lot of technical know-how that goes with this, from an engineering perspective to a surveying perspective to coding everything properly. You have to have an employee for doing all of that, maybe even an entire staff, which means you have to have a certain amount of momentum behind you." [7]

This disadvantage is further compounded when errors or omissions are discovered in the contract documents which may potentially increase the opportunity of claims against the agency. Similar to the disadvantages of the Spreadsheet Method, contractor employees have short time frames between contract award and the beginning of construction in order to prepare the models which further increase opportunities for error.

One of the largest benefits of this process is that the information is generated by the end user of that information and should therefore be the most beneficial to the contractor. The contractor can tailor the output based on their immediate needs and this process can be dynamic as the project progresses. This is unlike the Mn/DOT processes or the Third Party Industry Process, where the contractor receives the information in bulk and it may be too much or too little information for the immediate need.

Figure 3.7 schematically diagrams the workflow associated with modeling using the Contractor Generated Process.



Contractor may receive data in on of three formats:

1. Paper Construction Documents Only
2. Paper Construction Documents supplemented with MicroStation files
3. Paper Construction Documents supplemented with AutoCAD files

Figure 3.7 – Contractor Generated Process Workflow

Third Party Industry Process

A new industry has recently developed that attempts to bridge the gap between engineers producing the plans and the contractors responsible for building them. This industry consists of firms specializing in the process of "reverse engineering" paper plan sets. Contractors hire these firms and ship them hard copies of the contract documents (plan, specifications, and special provisions); the firm takes the information and generates electronic CAD files. These CAD files are then used to generate the three dimensional models needed for machine control. This process follows the same two step conversion process used in the Contractor Generated Process and shares many of the advantages and disadvantages of that process.

Using third party industries usually takes more time due to the additional parties involved. The extra time required for model creation by the third party can be appropriately mitigated with proper planning. Conversions are a high risk process in that errors may enter the design and adversely affect its quality, especially in instances where the schedule requires a prompt turnaround. As a result of the conversion and additional parties involved, liability is an issue with this process. The companies specializing in this process typically require contractors to sign a waiver releasing the model creating company from any claims. As a result, the contractor is ultimately responsible for any errors or omissions in the model. This may explain the increasing trend of contractors hiring or training their own staff to prepare models. The introduction of a separate entity to the project can also benefit the quality of the project by providing a fresh look on the plans from an independent source. Regardless of who is ultimately responsible for the accuracy of the model, it is critical for proper quality control and assurance measures to be in place so that all parties involved have faith in the deliverable product.

Figure 3.8 schematically diagrams the workflow associated with modeling using the Third Party Industry Process.

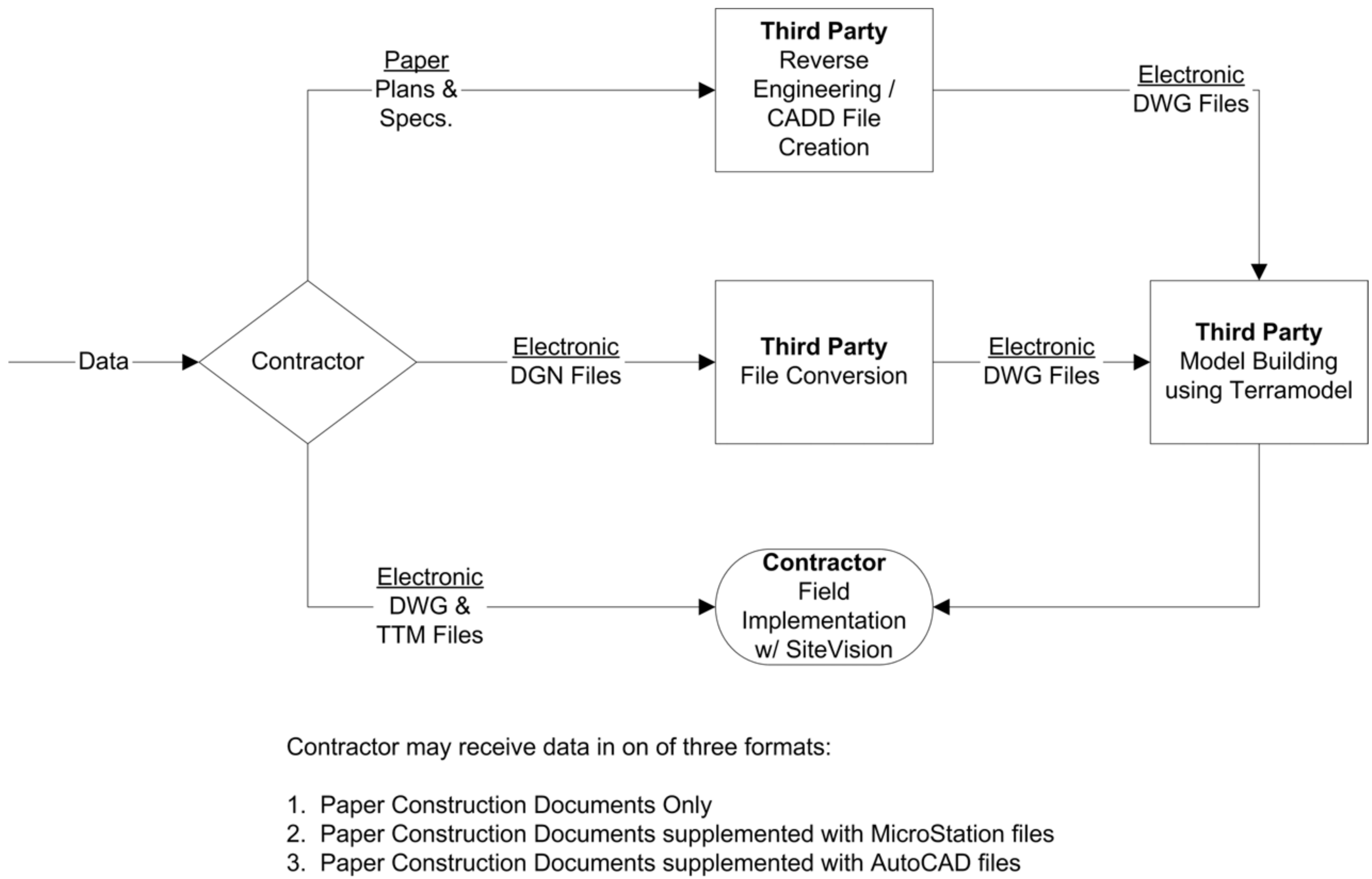


Figure 3.8 – Third Party Industry Process Workflow

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Chapter 4
Stakeholder Input

Input from stakeholders on 3D Machine Control technology was gained through two distinct efforts. The first effort sought to gain very definitive answers to specific questions on machine control topics. This input was received through responses to a survey prepared and distributed to the stakeholders. The responses were then analyzed and formulated into graphs and figures representing actual numbers or percentages of the responses.

The second process involved in-person meetings and telephone discussions with stakeholders. These meetings were often used to discuss the survey questions in greater detail. These meetings often uncovered the heart of the issues in regards to machine control, but the responses cannot be tabulated into charts or figures.

As a result, the Alliant Engineering team did not attempt to categorize the in-person meeting results into the figures featured in this chapter. To do so would discredit the nature of those meetings and in some instances double count stakeholders' responses, since several stakeholders participated in both efforts.

Nevertheless, results from both processes are detailed below and trends were extrapolated from the stakeholder input received. Trends 1-7 were formulated based solely upon the responses to the surveys while trends 8-12 are a result of the in-person meetings. However, some trends highlighted by the survey were also a focus of discussion in the in-person meetings.

Stakeholder Identification

In order to accomplish the second phase of the project, Alliant prepared and distributed a survey on 3D Machine Control to the various project stakeholders. Two stakeholder groups were identified, Contractors and State Engineering/Construction staff.

Alliant used several sources to identify candidates to receive the survey. Mn/DOT maintains a list of Machine Control Champions on the CAES Unit's Machine Control Initiative web site. (http://www.dot.state.mn.us/tecsup/caes/machine.html). These people received the *Machine Control Survey for Engineering Staff.* In addition, Mn/DOT Project Managers suggested additional contacts not found on the Machine Control Champions list.

Alliant contacted four major vendors, local to the area, that supply 3D Machine Control Systems and survey equipment to contractors. Ziegler, Inc. is the vendor for Trimble Machine Control systems in the upper Midwest while Laser Control, Inc. is the vendor for TopCon systems in Minnesota. Sokkia USA and Leica Geosystems were also contacted, however these companies neither offer 3D Machine Control equipment, nor have a large enough presence in Minnesota to provide any contacts. Ziegler, Inc. and Laser Control, Inc. provided names of contractors in Minnesota that use their respective machine control systems. Alliant selected contractors to receive the survey based upon the following criteria:

- Company Size
- Geographic location within the state
- Type of services provided by their company
- Mn/DOT Project Experience
- Brand of equipment used
- Number of pieces of equipment in possession

All selected contractors received the *Machine Control Survey for Contractors*.

Survey Administration

As stated above, two distinct surveys were prepared, one for each large stakeholder group. Many questions were similar on both surveys, which allows for comparison of responses between the two groups. The Contractor specific survey asked more questions regarding their company's investment in machine control equipment; the Engineering and Construction Staff survey asked more questions regarding contract administration on machine control projects. The surveys were prepared in Microsoft Word™, and were electronically distributed to the recipients. The *Machine Control Survey for Contractors* and the *Machine Control Survey for Engineering Staff* are included in Appendix F and Appendix G, respectively.

In an attempt to attain honest and useful responses from the participants, Alliant promised responses would be kept confidential. This was deemed necessary to prevent responders from fearing retribution if their replies were critical of the current Machine Control Initiative or Mn/DOT in general. Therefore, Alliant has summarized all results. Table 4.1 lists all of those contacted for input on this part of the project.

Public Agencies	Private Companies
Mn/DOT	AGC
District 1	Bauerly Brothers
District 2	Belair Excavating, Inc.
District 3	Bentley Civil (GEOPAK)
District 4	Blombeck Construction, Inc.
District 6	Borneke Construction, Inc.
District 7	C.S. McCrossan, Inc.
District 8	Central Specialties, Inc.
Metro	Dennis Fehn Gravel & Excavating
Metro Surveys	Enebak Construction Company
Office of Construction	Frattalone Companies
	Frontier Construction Company, Inc.
State DOTs	Joe's Excavating, Inc.
Maine DOT	Laser Control, Inc.
New York DOT	Louis Leustek & Sons, Inc.
Oregon DOT	Mathiowetz Construction
Washington DOT	Max Steininger Inc.
Wyoming DOT	Midwest Contracting LLC
	Niles Weise Construction Company
Other Regional Agencies	Progressive Contractors, Inc.
Anoka County	R & G Construction Company
	R.L. Larson Excavating, Inc.
	R.J. Zavoral & Sons
	Riley Brothers Construction, Inc.
	S.R. Weidema, Inc.
	Shafer Contracting Company, Inc.
	Sorenson Brothers Inc.
	Ulland Brothers
	Ziegler, Inc.
	Zumbro River Constructors

Table 4.1 – List of Survey Contacts

Survey Distribution and Response Rates

Surveys were distributed to individuals affiliated with the organizations and companies listed above. After an initial contact, individuals were asked if they would be willing to complete the survey. Surveys were distributed once this approval was granted. The goal in distribution was to reach as many individuals as possible that are either aware of 3D Machine Control processes or have worked with machine control systems. With more input, stronger and more applicable recommendations can be formed. An ancillary goal of the distribution was an attempt to balance the number of surveys sent to both public agencies and private contractors. This balance would provide input that was unbiased – both stakeholder groups could provide an equal amount of input into the future polices of 3D Machine Control project administration. Table 4.2 documents the distribution of the surveys.

	Number of Surveys Distributed	Percent of Total
Engineering and Construction Staff	19	43%
Contractors	25	57%
Total	44	100%

Table 4.2 – Survey Distribution

A total of forty-four surveys were circulated to the project contacts. Approximately half of the surveys went to each stakeholder group. This distribution split testifies to the effort of unbiased sampling. Nonetheless, the distribution was not split exactly in half. This results from the numerous variables that could impact the contractor's responses – company size, experience, investment, location, etc. In order to accurately survey the breadth of these variables, it was necessary to distribute more surveys to contractors.

The number of survey responses from each stakeholder group, as well as the response rates, has an impact on the conclusions drawn from the survey results. Table 4.3 documents the number of responses received from each group, and what proportion of the total they make up.

	Number of Surveys Returned	Percent of Total
Engineering and Construction Staff	11	38%
Contractors	18	62%
Total	29	100%

Table 4.3 – Surveys Returned

The data indicates that approximately three quarters of all responses were generated by contractors and private industry. It was determined to report both the overall response and the individual stakeholder's responses because of this imbalance. Reporting solely the overall result would have greatly overshadowed the responses of half of the stakeholders. Table 4.4 documents the response rates for each stakeholder group. Overall, 66% of all surveys distributed were returned.

	Number of Surveys Distributed	Number of Surveys Returned	Response Rate
Engineering and Construction Staff	19	11	58%
Contractors	25	18	72%
Total	44	29	66%

Table 4.4 – Survey Distribution and Response Rates

The response rates indicate that Contractors were more likely to respond as Engineering and Construction Staff. This data is skewed as a result of network security settings at Mn/DOT and other agencies. The survey was designed to take advantage of current trends in surveying technology. Due to the high security of Mn/DOT's computer server, many Mn/DOT staff either did not receive the survey or had a difficult time returning the survey through electronic means. Second, as a direct result of this situation, Alliant chose to meet individually or teleconference with many Mn/DOT staff members. Those individuals that were met often chose not to fill out a survey; the interviews covered many of the same topics as the survey.

Survey Response Demographics

In order to fully understand the results of the survey, it is helpful to know the overall makeup of the survey responders. Responders were asked whether they had any experience with machine control technology. Figure 4.1 depicts the results to that question with Figures 4.2 and 4.3 showing the results by Contractor Responses and DOT Responses respectively.

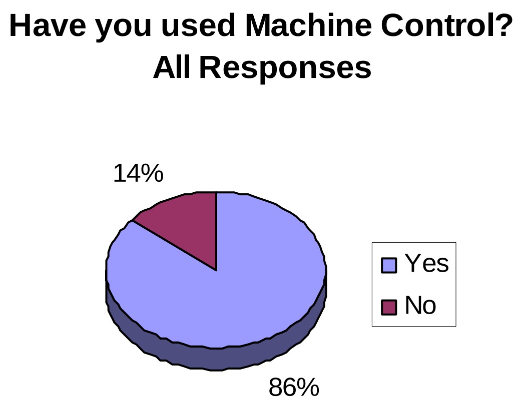

Figure 4.1 – Experience with Machine Control (All Responses)

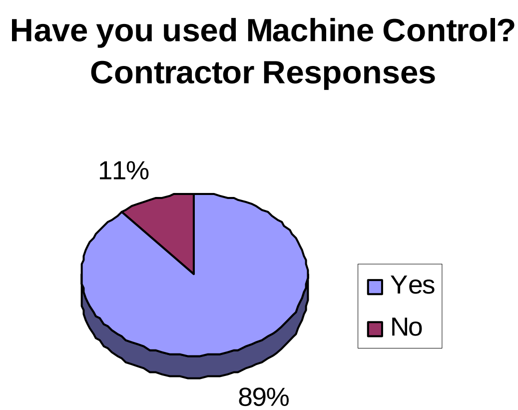

Figure 4.2 – Experience with Machine Control (Contractor Responses)

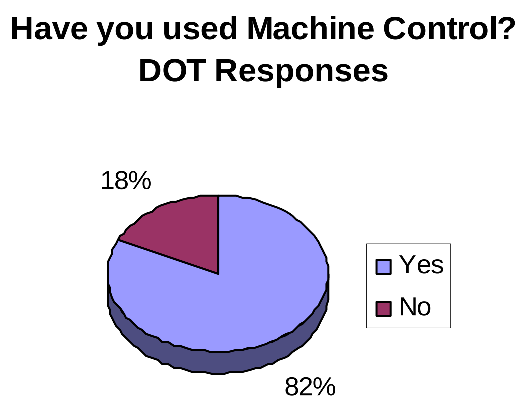

Figure 4.3 – Experience with Machine Control (DOT Responses)

A large percentage of the survey responders indicated that they have experience in machine control technology. When comparing between the two stakeholder groups, contractors have a slightly higher percentage of responders indicating experience with machine control technology. These results show that most of the results and trends discussed later in this chapter are based on users with some level of exposure to the technology.

Although an overwhelming number of responders indicated that they have experience with machine control technology, the level of this experience varies greatly. Responders with machine control experience were asked to provide both the total number of projects completed in the last construction season and the number of those projects that utilized machine control technology. With regard to DOT responses, the percentage reflects the ratio of projects using machine control to the total number of projects completed in the responder's district. Figure 4.4 shows the results for all responses with Figure 4.5 and 4.6 showing the results by stakeholder group.

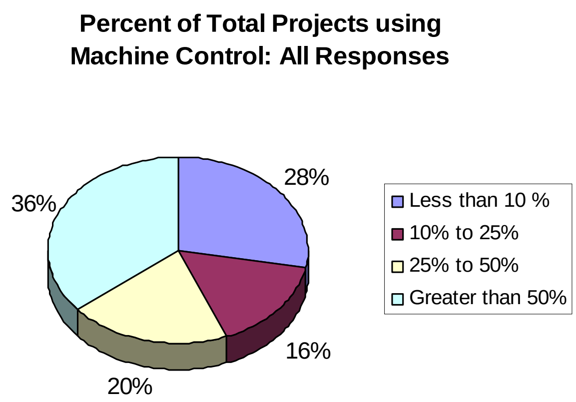

Figure 4.4 – Percent of Total Projects using Machine Control (All Responses)

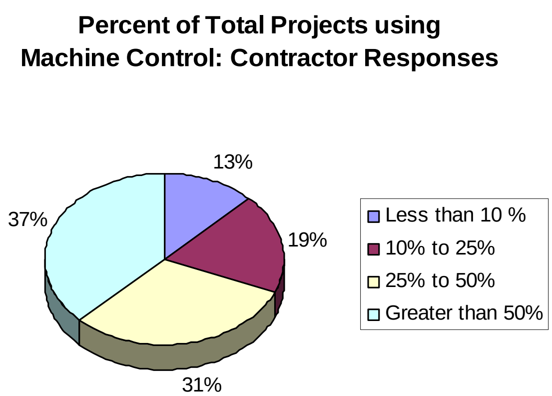

Figure 4.5 – Percent of Total Projects using Machine Control (Contractor Responses)

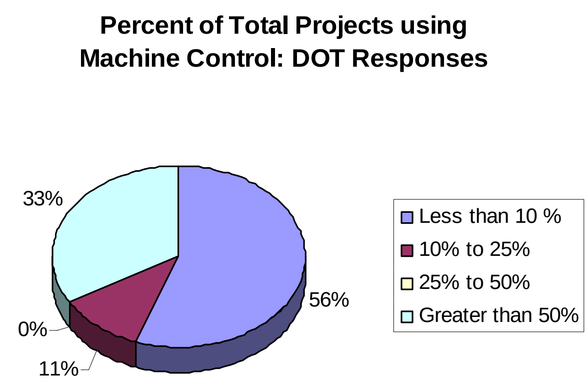

Figure 4.6 – Percent of Total Projects using Machine Control (DOT Responses)

Contractors as a whole are using 3D Machine Control on a greater percentage of their projects during the last construction season. In 37% of the contractor responses, they indicated they were using the technology on over half of the projects constructed. Of the large contractors, 3D Machine Control Experience tends to be either greater than 50% of projects or between 10% and 25% of projects. This indicates that large contractors have the luxury of choosing to utilize the equipment widespread, or opt to use traditional methods, depending on the nature of the project.. The majority of smaller contractors (75%) indicate that greater than 25% of their projects utilize machine control. This implies that small contractors who invest in the equipment are more likely to use it on more projects, or seek to bid on projects where the equipment is suitable for use. Although DOT responses indicated a high response in the same category, there were a large number of responders that stated machine control was used on less than 10% of the projects last construction season.

Funding issues and the type of construction projects at Mn/DOT may impact these results. As funding has grown stagnant for transportation projects in the state, the total number and type of construction projects Mn/DOT releases for bids has changed. More projects are being let in recent years that focus on preserving the existing infrastructure. A smaller number of projects have been let that involve earthwork grading where the technology would be beneficial. Contractors have flexibility to pursue other projects, apart from Mn/DOT, in order to utilize the technology to a greater extent.

Of the contractor responses indicating that they have previous machine control experience, the majority of them, 81%, indicated they use systems from Trimble or a combination Trimble and other brands.

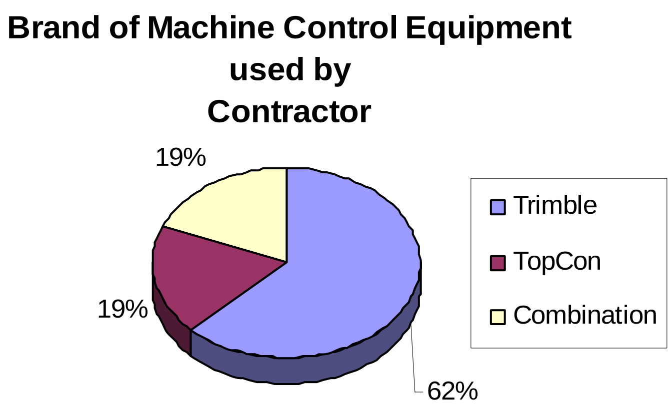

Figure 4.7 – Brand of Machine Control Equipment

As mentioned previously in this report, Mn/DOT special provisions only allow systems from Trimble and TopCon for machine control operations. Therefore, it is not surprising to see a lack of other brands in these results. However, these results show that of all the contractors that responded to the survey, most are experienced with 3D Machine Control systems from Trimble. This is especially the case for small contractors, where 75% indicated they use Trimble systems. Seldom did small contractors choose to use a combination of the equipment; this is logical as the cost of a 3D Machine Control system may make it prohibitive for a small contractor to own two distinct systems. Large contractors, in contrast, are as likely to use a combination of equipment as to pick a vendor, as 50% indicated they use a combination of equipment. Not a single contractor indicated use equipment brands other than TopCon or Trimble.. The fact that Trimble systems are overrepresented in the results can be attributed to several factors. First, many contractors use Caterpillar equipment. Caterpillar has made an extensive commitment to 3D Machine Control. On all new Caterpillar models, the wiring and interfaces required to support machine control are standard options. Second, Ziegler, Inc. is a major regional supplier of Caterpillar and Trimble equipment, headquartered here in Minnesota. The easy access to both an equipment supplier and integrator of machine control technology, all within one location, is attractive to contractors.

For further survey analysis, responses from contractors were categorized into two sub groups based on contractor size. The groups are referred to as large contractors and small contractors within the analysis. This categorization was necessary to determine whether the size of the contracting firm altered the trends observed in contractor responses. Of the 18 responses received from contractors, 5 were categorized as large contractors and the remaining 13 were categorized as small contractors.

Survey Analysis

Further analysis of the survey results focused on trends that were helpful in understanding the key issues regarding 3D Machine Control projects. Each question was analyzed based on returned survey responses. The data was analyzed as total responses, and then independently by stakeholder group. The total responses are not weighted; the charts indicate the raw percentage of responses from the total number of surveys returned. Seven trends were isolated from the responses and are presented in the following sections.

Trend #1 – Model Creation

A question found on both the Engineering Staff and Contractor surveys was, “In a perfect world, who would your district or agency prefer to create the 3D models?” Just over half of the respondents said it should be the contractors’ responsibility to prepare the three dimensional model. The remaining percentage indicated this responsibility should rest with the owner. Figure 4.8 documents the response results. The results were further broken down into stakeholder groups (Figures 4.9 and 4.10). The results between these two groups were identical.

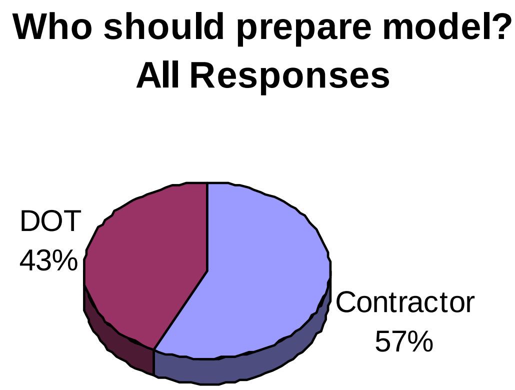

Figure 4.8 – Model Preparation (All Responses)

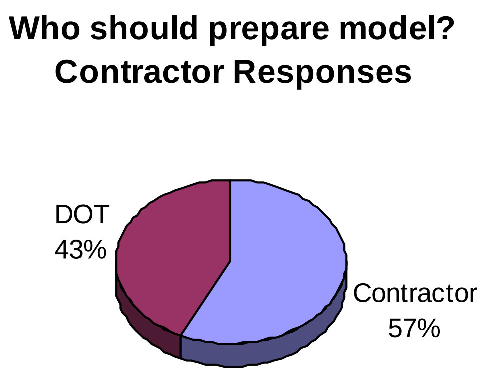

Figure 4.9 – Model Preparation (Contractor Responses)

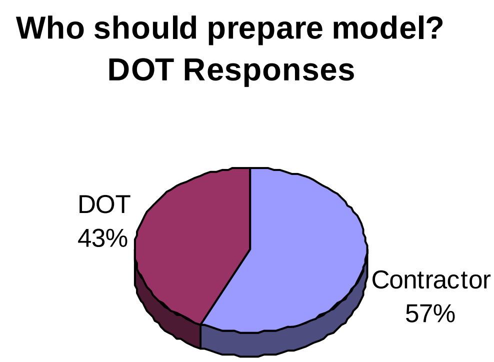

Figure 4.10 – Model Preparation (DOT Responses)

Overall, both owner representatives and contractors favor the model preparation be done by the contractor. The owner representatives favor contractor preparation as it puts less strain on the District staff. The state can instead allocate staff to inspection and oversight, rather than detailed model creation. Furthermore, the time currently spent by agency staff preparing the model can instead be spent on preparing the construction documents and ensuring their accuracy.

The majority of contractors indicated their preference to create the models. The responses were the same for both small contractors and large contractors. This choice is likely made to expedite preparation of the models. If the contractor is responsible for preparing the models, they will not have to wait for the model to be completely prepared by the state prior to beginning their work. As the model creator, contractors can begin grading prior to the completion of the entire model, especially if the proposed project is large. The contractor can also use the model in their project management software to calculate material volumes and stage the construction. Staging can occur as the model is developed, rather than after receiving the completed model, further streamlining the process.

Trend #2 – Model Liability

In regard to which party is responsible for potential errors in the model, 57% of responders answered the contractor. In separating the two stakeholder groups, agency Engineers strongly felt that the contractor takes full responsibility, while the Contractors were split evenly on the liability issue.

Summarizing the above results, the majority of respondents prefer the contractor prepare the model and be liable for its accuracy. Figures 4.11, 4.12 and 4.13, document these results.

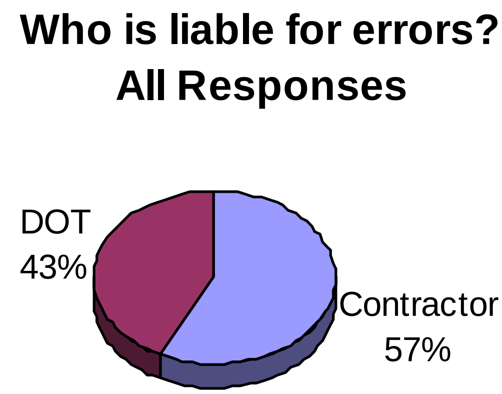

Figure 4.11 – Error Liability (All Responses)

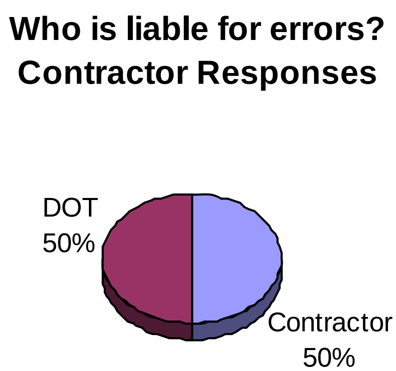

Figure 4.12 – Error Liability (Contractor Responses)

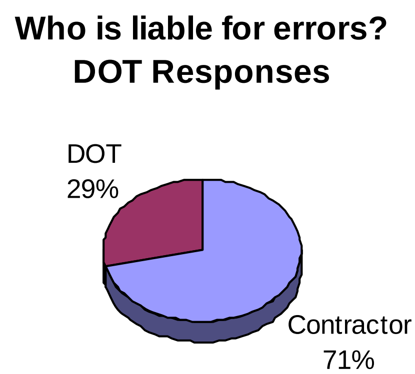

Figure 4.13 – Error Liability (DOT Responses)

There is a difference of opinion regarding error liability in the 3D models created. As far as the owner is concerned, the responsibility for an accurate model lies with the contractor. Because most agencies provide a disclaimer on their electronic files absolving them of the liability for the files' accuracy, it is logical that most owner representatives feel that the contractor should take full responsibility for the model's correctness. Contractors, however, are split on who assumes this liability.

The contractors' responses toward this question rest in the relationship they have with individuals representing the owner. When the relationship is trusting, it is not uncommon for both parties to accept a share of the responsibility in the model's precision. A distrusting relationship, however, will likely lead to a situation where each party is likely to blame the other for errors and omissions to the model. Contractors who have worked with data prepared by a particular agency and have faith in the data's correctness, will likely assume liability for the model. Although a disclaimer is provided, the responsible owner will provide a highly accurate set of data. Likewise, the responsible contractor will check the data and ensure its quality.

There is also a difference in opinion with regard to the size of the contractor's firm. Large firms were of the opinion that the contractor is liable for errors (67%). This is attributable to the fact that larger contractors have in-house modeling staff and the resources to verify the model accuracy. Smaller contractors were more indecisive, with 45% stating liability rests with the contractor, and 55% stating it lies with the owner. This may be ascribed to the likelihood that these firms do not have the resources to create the models in-house. These firms frequently use third party agencies to create the models, while still being liable. It is for this reason that small contractors feel that the DOT is responsible for errors.

Trend #3 – Machine Control Advantages

Stakeholders were queried about the advantages and disadvantages of using 3D Machine Control on projects. The overall response yielded similar results to the responses made by agency Engineers and Contractors. Furthermore, both large and small contractors responded similarly. Time savings, cost savings, and greater quality were documented as the greatest advantages, with each issue receiving approximately 25% of the total response. Since the successful completion of a project is defined by these variables, it appears increased use of 3D Machine Control benefits the industry as a whole. Subsidiary advantages included flexibility, (13% of responders) and a reduced learning curve (LC) (6% of responders). Figures 4.14, 4.15, and 4.16 document the advantages and their corresponding results.

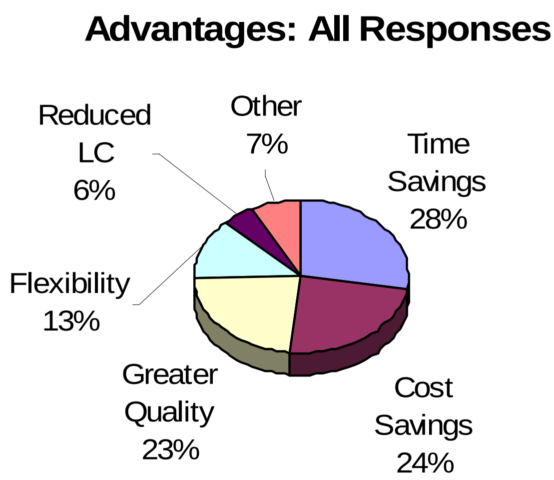

Figure 4.14 – Advantages (All Responses)

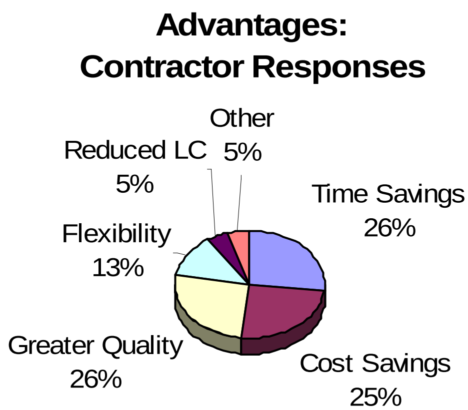

Figure 4.15 – Advantages (Contractor Responses)

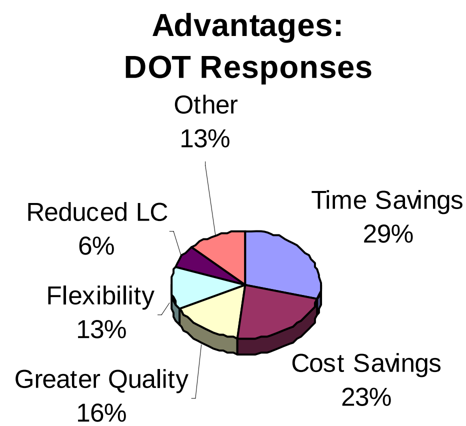

Figure 4.16 – Advantages (DOT Responses)

In general, both stakeholder groups overwhelmingly value the improvement in quality and decrease in time and cost that 3D Machine Control brings to a project. Both groups valued the time savings, but for different reasons. From the owner's perspective, the overall time line of the project is reduced, enabling a quicker completion of a project for the public. Contractors are able to complete their tasks quicker, enabling them to bid more competitive and take on more projects than previously. Cost savings are beneficial to both stakeholder groups; increased efficiency enables lower bid prices benefiting the owner and lower operating prices benefiting the contractor. Rather than using hubs staked at intervals, grading operators benefit from a 3D model which provides continuous grade information. This results in a higher quality since the surface is likely to have much smoother grades with no unintended variations, which benefits the public.

Trend #4 – Machine Control Disadvantages

Responders indicate three major disadvantages in using 3D Machine Control: initial investment, training, and frequently changing technology. Since these three concerns involve significant investments in both time and money, it may prove to be a difficult obstacle for smaller companies and businesses to overcome to begin using this technology. Figures 4.17, 4.18, and 4.19 illustrate the disadvantages that responders have encountered in using 3D Machine Control.

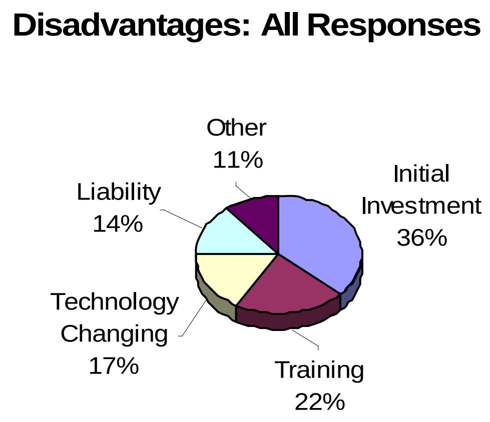

Figure 4.17 – Disadvantages (All Responses)

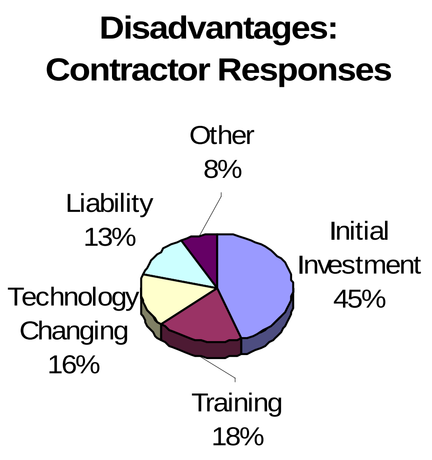

Figure 4.18 – Disadvantages (Contractor Responses)

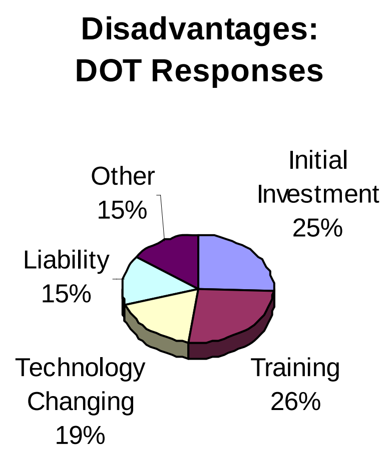

Figure 4.19 – Disadvantages (DOT Responses)

Of all the respondents, greater than three-quarters isolated three disadvantages of 3D Machine Control: initial investment, training, and the rapid change in technology. Initial investment was a huge concern for contractors. With the cost of outfitting a machine being approximately $100,000, the initial investment is high. Contractors that lack the resources to make this investment are at a disadvantage as opposed to those with sufficient resources to outfit multiple vehicles. In order to invest in the equipment, a contractor must be convinced that the investment will be profitable. The DOT responders have two issues with initial investment. The DOT invests time and resources in training its model creators. There is an opportunity cost in training staff. Although the in-class training is only a two-day commitment, it is important to realize that an individual is not expected to become proficient with class room training alone. By training existing staff, the agency is electing to change the responsibilities of a staff member, removing them from a position at which they are presently proficient at to one where they must build new proficiency. Due to this initial investment in training, it is in the DOT's best interest for contractors to use the technology on jobs. If the investment for contractors is insurmountable, all of the efforts in training DOT staff will go to waste as contractors will use traditional methods to construct projects.

The level of training needed to establish a proficient individual in using these systems is also large. With untrained staff, efficiency will be minimal, resulting in time expenditures and resulting opportunity costs. Training is important in both 3D model creation and in equipment operation. Training tends to be advanced for model creation, and requires substantial experience with the methods mentioned in Chapter 3. The DOT staff highlighted training as a concern as it relates to an opportunity cost; time spent training is time not spent on daily work tasks. With all departments within Mn/DOT contending for resources, DOT staff has some concerns with the costs of training. These are legitimate concerns given that an under trained model designer creates liability for the DOT. Training costs are also a concern for contractors. Their costs are associated with model creation, in addition to the training needed for equipment operators.

The third concern both parties indicated was the frequency with which technology changed in the industry. Contractors are concerned with staying competitive in their industry. Therefore, the need to have the most efficient and state-of-the-art equipment is necessary for them to remain profitable. With the frequent changes in equipment, this correlates to frequent equipment upgrade purchases. The DOT also needs to have a complement of equipment to verify the accuracy of the contractors work. Furthermore, software upgrades and changes need to be made to ensure the most accurate models are being created. Once again, when allocating resources to the many departments within Mn/DOT, project managers need to balance machine control equipment needs with other needs.

Of interesting note is the lesser importance both groups placed on liability. It was assumed that most groups would be highly concerned with whom liability rests with. Although it is a concern, it is not one of the most important disadvantages of using the technology. Both shareholder groups are more concerned with the initial costs of using the technology, and are less concerned with using the technology and coordinating with each other.

Trend #5 – Type of Projects where Machine Control is Currently Used

Stakeholder feedback indicated there were four primary projects where 3D Machine Control is commonly used. These include site grading, roadway embankments, pond grading, and granular placement. This result comes as no surprise given that current GPS technology has a tolerance of approximately a tenth of a foot. Only a very small percentage of machine control projects have higher tolerances and thus require more advanced technology. The size of the contracting firm has no effect on the type of work completed; percentages for both large and small firms were nearly equal. The results of this question are found in Figures 4.20, 4.21, and 4.22.

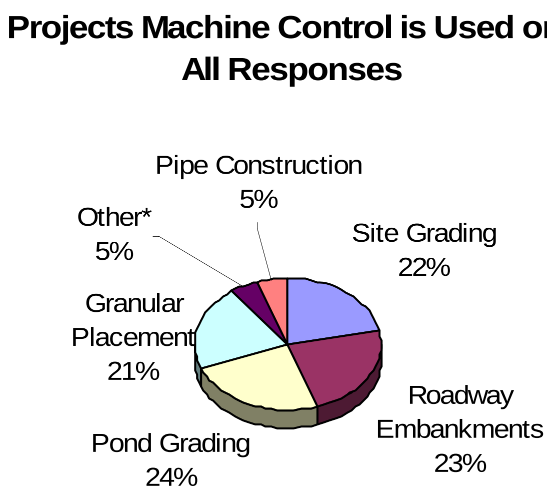

Figure 4.20 – Project Types (All Responses)

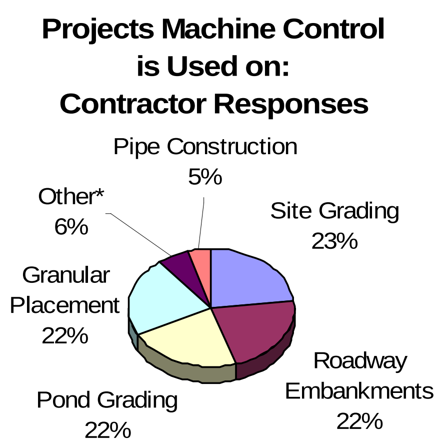

Figure 4.21 – Project Types (Contractor Responses)

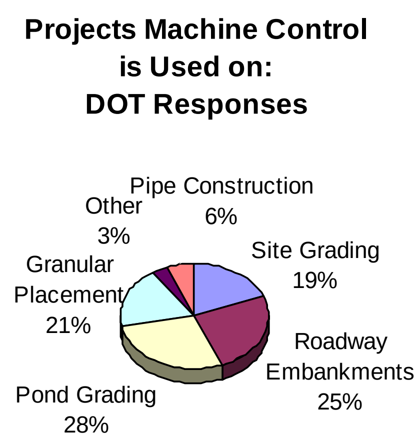

Figure 4.22 – Project Types (DOT Responses)

*Other refers to curb paving, bituminous paving, concrete paving, and bridge construction.

Intuitively, both the DOT responses and the contractor responses should be very similar, as the contractors frequently do machine control work for the DOT. Therefore, it is of little surprise that the results indicate that both groups had very similar responses. The majority of all machine control work consists of grading ponds, embankments, and granular placement. This indicates that both stakeholder groups have a diverse experience with 3D Machine Control, and that their experiences are compatible. This is the first step in ensuring the seamless implementation of 3D Machine Control technology statewide.

A small percentage of responders indicated that their experience included activities requiring higher precision such as pipe construction, paving, or bridge construction. Responders were not obligated to further define this experience, but it is highly unlikely that these activities are completed solely through the use of Machine Control. The technology has not yet matured to a point where it can be used accurately for these construction activities. Rather, it is more realistic that the construction of these items is staged. Machine Control may be used for rough cutting and then a supplemental method, such as an automatic total station, laser augmentation, or traditional survey methods, is used for the final placement of these materials. Regardless, the fact that some responders are using the technology in these applications proves the flexibility of Machine Control on the construction site.

Trend #6 – Controlling Factors for the Use of Machine Control

Since higher tolerances are required for projects such as curbing, concrete paving, bituminous paving, and bridge construction, there is reason to suspect that the type of work is a controlling factor when an organization is deciding to use machine control or not. This is illustrated by the response to the survey. Figures 4.23, 4.24, and 4.25 show that some of controlling factors of machine control use include type of work, physical size of project, mandated by contract, and electronic information availability. Type of work had the highest percentage of 27%, then electronic information availability with 24%, and physical size of project had 19% of the answers. The availability of formatted electronic information could be a factor why some contractors do not choose to use machine control. They may not have the resources to create a model but would be able to use a model created for them and machine control to complete a project.

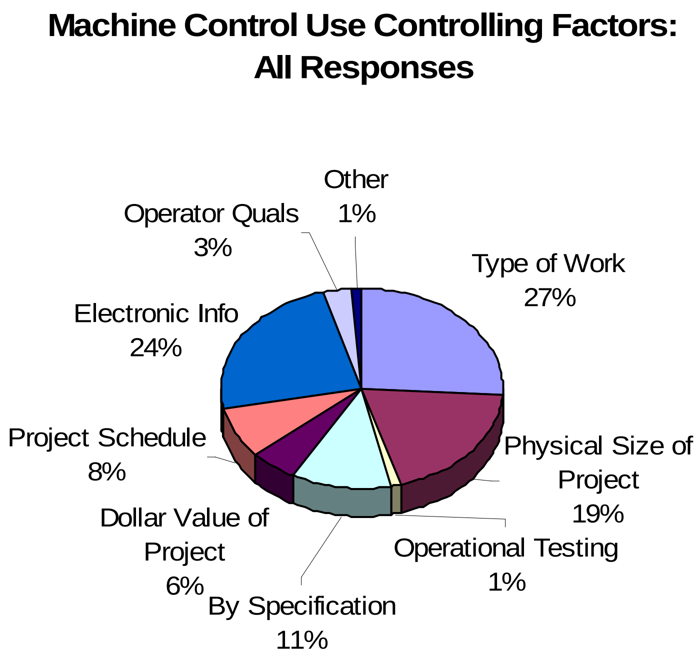

Figure 4.23 – Controlling Factors (All Responses)

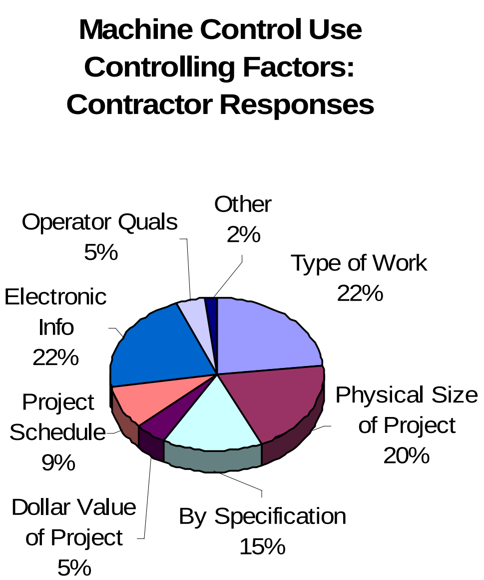

Figure 4.24 – Controlling Factors (Contractor Responses)

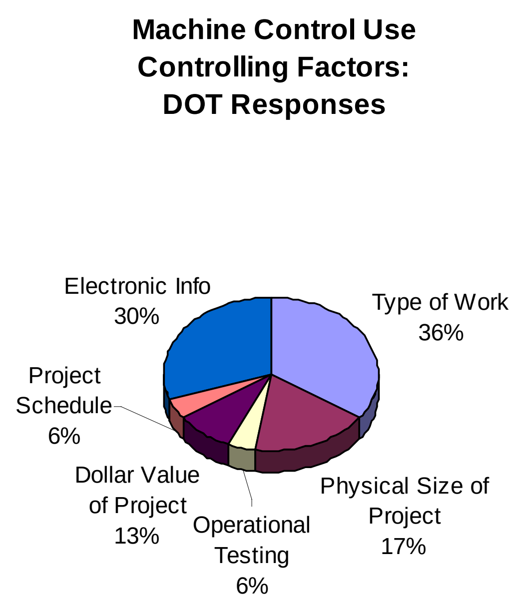

Figure 4.25 – Controlling Factors (DOT Responses)

Once again, contractors, both large and small, and owners cite similar reasons for using 3D Machine Control on a project. The type of work, availability of formatted electronic data, and physical size of a project are the three biggest contributors for contractors opting to use the technology and for the DOT to make a project eligible for machine control. Operational testing, or using the equipment to validate the technology is effective, dollar value of the project, and project schedule were less important as controlling factors.

The type of work was the number one controlling factor for the DOT. Projects must be of a type suitable for machine control. Furthermore, the DOT will not support a project of a type that has not yet been performed. Likewise, contractors will use machine control on the types of projects that they have the equipment and experience to complete.

Electronic information is a contributing factor that was cited in approximately a quarter of the surveys received. The DOT would much rather choose to use machine control on a project where a model already exists, or where sufficient electronic data has been collected to easily make the model. Contractors will choose to use machine control when sufficiently formatted electronic data is provided by the DOT. If models already exist, the contractor is much more likely to use the technology because the time needed to generate the model in house is eliminated. Likewise, the contractor will choose to use machine control if sufficient electronic data is available such that the construction of the model will be both quick and simple.

The physical size of a project is another factor that contributes to both owners and contractors choosing to use 3D Machine Control. Larger projects are best suited for machine control as they are able to offset the cost of preparing the 3D models. Likewise, larger job sites enable contractors to more effectively stage their grading to produce the most efficient result. Equipment can also be moved to other areas if GPS signals are poor. Larger projects enable longer grading runs, which results in greater grading quality.

Trend #7 – Machine Control Bidding

How districts and agencies handle bidding was another survey question that was answered by contractors and owners (Figure 4.26). This was a question with significantly different responses from contractors and owners. The two figures below, Figure 4.27 and Figure 4.28, show the difference in percentages between contractors and owners. The two main differences were between the "Specific Pay Item" and the "N/A-Machine Control saves time and money" answers. Contractors said that bidding should be handled by a "Specific Pay Item" in 32% of their answers while owners only answered this way 7% of the time. Owners checked the "N/A-Machine Control saves time and money" box 51% of the time while contractors only selected this answer 24% of the time.

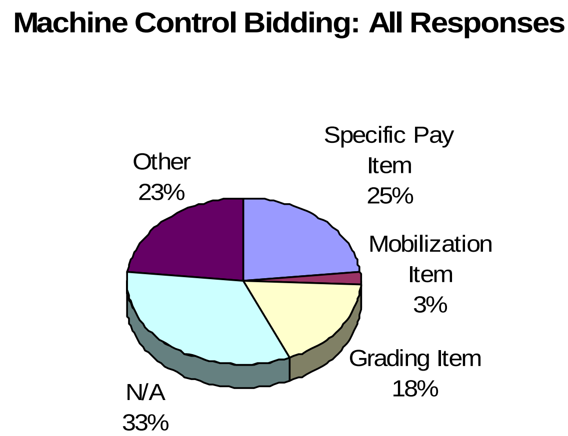

Figure 4.26 – Bidding (All Responses)

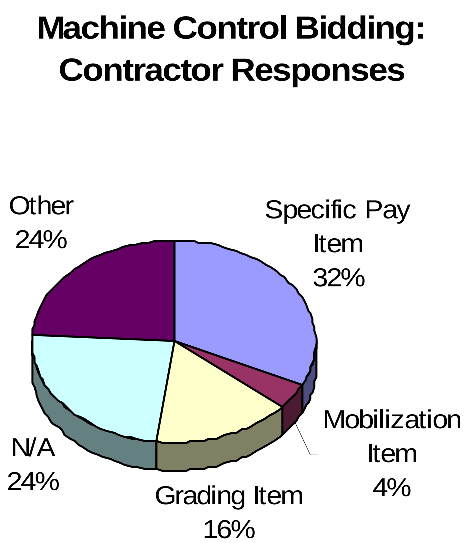

Figure 4.27 – Bidding (Contractor Responses)

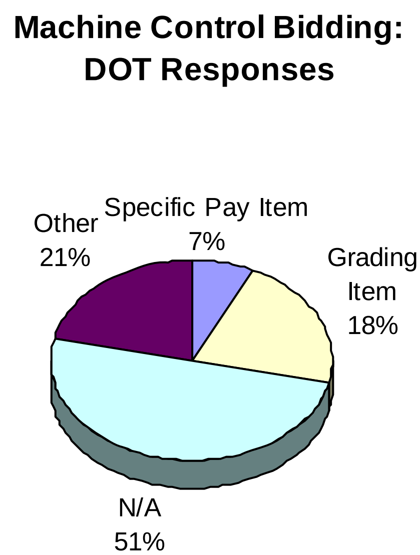

Figure 4.28 – Bidding (DOT Responses)

The results indicate that neither stakeholder group has a defined opinion as to how machine control projects should be bid. The majority of the DOT representatives marked that the bidding mode was irrelevant. As machine control saves both time and money, the bidding method should not matter. The interpretation of this answer could imply that DOT staff view 3D Machine Control work as incidental to the contract. Since the contractor will save money in using the method, there should be no further economic incentive to use 3D Machine Control.

Conversely, contractors feel that there should be a specific pay item for 3D Machine Control work, especially with the larger contractors. Large firms overwhelmingly endorsed specific pay items for 3D Machine Control, as opposed to smaller firms (50% to 29%). This pay item would help offset the cost of the equipment and the labor for model creation. Another portion, approximately a quarter, agreed with the DOT staff that no bidding method should be needed as they will use machine control either way, since it saves both time and cost. Among smaller contractors, bidding as a grading item was preferred by 19%; none of the large firms endorsed this bidding method. Finding a bidding method that pleases both stakeholder groups is one of the bigger challenges in creating a unified 3D Machine Control plan for the State.

Survey Analysis Summary

The survey administration enabled a large portion of the stakeholders to reply anonymously. The results of the survey indicated the general view of both contractors and DOT officials with regard to 3D Machine Control Systems. Furthermore, the results indicated that in general, the size of a contractor's firm is not very relevant in the attitudes contractor's have towards the technology. After analyzing the responses, the above issues were isolated. In addition to soliciting surveys, Alliant met with several individuals and groups to discuss the project in greater detail.

In-Person Meetings

In person meetings were conducted with many of the Mn/DOT Districts, as well as other industry stakeholders, including representatives from the Associated General Contractors (AGC) of Minnesota, engineering software developers, and other state DOTs that embrace 3D Machine Control technology. Similar to the administration of the survey, Alliant promised responses would be kept confidential in an attempt to attain honest and useful responses from the participants. Table 4.5, lists all of those contacted for input on this part of the project.

Public Agencies	Private Companies
Mn/DOT District 1 Design	AGC
Mn/DOT District 1 Construction	Bentley Systems, Inc.
Mn/DOT District 3 Design	Ziegler, Inc.
Mn/DOT District 4 Design	
Mn/DOT District 6 Construction	
Mn/DOT District 8 Design	
Mn/DOT District 8 Surveys	
Mn/DOT Metro Surveys	
Wyoming DOT	

Table 4.5 – Meeting Contacts

As with the surveys, additional industry trends were isolated via these meetings. These trends indicate the common concerns that stakeholders had regarding issues that currently hamper the ability to implement 3D Machine Control on future projects. The trends and comments documented below are further explored, in conjunction with the survey results, in Chapter 5, Stakeholder Concerns and Challenges.

Trend #8 – Training

Nearly unanimously, stakeholders mentioned the need for training regardless of the functional group or job description. It is apparent that the lack of training on machine control topics is causing a sense of apprehension in reference to how machine control will change job roles and responsibilities. This trepidation to the technology is most likely creating obstacles towards furthering the Machine Control Initiative within Mn/DOT.

Of utmost importance is the time frame where training is applied. Frequently, individuals are trained during less busy periods. Rather than have staff idle, the DOT encourages individuals to seek training that will make them more productive and knowledgeable. Unfortunately, skill and knowledge retention tends to diminish the longer an individual goes without application. In the case of 3D Machine Control, the amount of training required to ensure proficiency can be extensive. This training goes beyond class time as well. By not providing a modeling project near the completion of a training course, it is likely that staff will begin to lose the skills and knowledge provided in training. This effect can be mitigated with foresight; providing training when a 3D Machine Control project is on the imminent horizon will make staff members more productive when producing their first model. Increased training will lead to greater familiarity with the process, which in turn leads to greater confidence in the technology and its eventual acceptance.

Trend #9 – Liability

Discussions during in-person meetings resulted in two distinct view points regarding liability, particularly when discussing liability for model creation. Both view points seek to protect the agency from further claims and, potentially, reduce the current level of claims.

One viewpoint perceives machine control, particularly the creation of models by the agency, as a potential for an increase in claims from the contractor. In order to protect the agency from this potential threat, this group feels that the agency should not create the models required for machine control systems.

The other viewpoint sees machine control as justification for improving the agency's internal quality efforts. They feel this opinion is justified by the technology's growth within the industry. When 3D Machine Control Systems were first introduced, stakeholders were not sure if the technology would root within the field and become the next innovation in the construction cycle. This generated a "wait and see" approach to determine the longevity of the technology. This group now feels that this period is over and that the technology is here to stay, regardless of whether it is accepted by the agency.

This group believes that the additional modeling efforts required to support machine control improves the overall quality of the contract documents. Many designers expressed that they depend on the agency field crews to help ensure the plan's accuracy when they are computing the stakeout survey information. This verification is the last opportunity for errors to be corrected prior to the start of construction activities. A more defined quality process within the modeling environment would provide this same functionality. The resulting contract documents would be both thorough and of higher quality. Therefore, the agency's liability and claims from the contract should be reduced.

The "wait and see" approach also has some drawbacks. By not taking a proactive stance towards 3D Machine Control, the DOT loses some of its ability to dictate how the technology is applied in the field. Manufacturers and contractors are gaining insightful experience with the technology, and have established a method of using the technology that tailors to their applications. With waiting, the DOT does not have the ability to provide input on the methods that the contractor is establishing. Additionally, the wait and see method does not enable the DOT to take advantage of technology that is already refined. Although some machine control applications, such as paving, are not mature enough to be implemented, others, such as grading, have been successfully employed. If the DOT were to wait to adopt any 3D Machine Control until paving applications were perfected, the DOT would miss the benefits that can be attained with using the technology in grading.

One caveat to this trend is that, regardless of the view point on liability, all stakeholders agreed that the constructed project is of a higher quality using machine control technology. Because of this fact, apprehension towards the liability of creating the model may actually be limiting the overall quality of projects constructed within the state.

Trend #10 – Changing Roles and Responsibilities of Staff

Another trend that appeared often was hesitation regarding who would be responsible for the additional tasks and whether the use of machine control would eliminate the need for some types of personnel. The two stakeholder groups that often expressed these hesitations were surveyors and design engineers.

Design engineers were concerned that the modeling efforts required to support machine control would place an additional work load upon them, and increase the liability of their designs. This additional work would consequently shorten the allowable time to complete projects. The general belief is that 3D Machine Control saves time during construction; design engineers unanimously believe the time savings during construction was at their expense in design time. Many pointed to Mn/DOT's current initiative to do more with less as another reason that liability would be a concern with their changing responsibilities. By adding responsibilities with less time to complete tasks, errors will be propagated.

In order to clarify opinions, most design engineers that participated in the in-person meetings had not personally used the modeling tools during design, but were modeling the project after design had been completed and the project had already been let or would be let soon. In post design modeling efforts, additional effort is required since the project is effectively being modeled twice. If the modeling efforts were included earlier in the design process, it would be expected that the amount of rework would decrease, which may change the views of design engineers.

Survey staff also expressed concerns regarding the increase in the use of machine control technology within the state. Generalizing their comments, it appears the concern is one of self preservation. They fear that their job responsibilities will be scaled back dramatically or even eliminated altogether. This concern is understandable since two of the largest benefits of machine control are the time savings and flexibility that result from no longer requiring hubs in the field prior to grading.

Few of the surveyors that participated in the meetings had actually been involved with a full scale machine control project. The few surveyors that had participated did not share this same self preservation fear expressed by many others. Instead, they stated that the time they typically allocated for placing hubs had been reduced, but not completely eliminated. Machine control equipment still has limitations in complex areas. In these situations, surveyors supplement the GPS equipment and models with traditional hubs. In addition, the time spent establishing control and performing quality control checks on the constructed elements actually increased, compensating for the reduced time placing hubs.

It is important to remember that using 3D Machine Control does not replace the roles of the surveyor or the inspector. As with any other project delivery method, some verification must be provided to ensure that the project is built to plan. With our without 3D Machine Control, grades are verified by surveyors. Inspectors validate that completed work meets the requirements of the contract documents. These two roles will still be necessary to assure accuracy. Both surveyors and inspectors serve as the last line of defense in isolating errors in the plans or construction.

Trend #11 – Accuracy

Accuracy was addressed in every meeting that occurred. Everyone that attended the meetings was aware that GPS has intrinsic errors that are propagated throughout the project. For this reason, many design engineers expressed concerns that the technology was still too new and were unsure if it should be relied upon so heavily for the construction of their plan sets. In contrast, surveyors understood that errors can be mitigated and properly planned for during construction, in a similar manner as in GPS topographic surveys. The use of reference stations and the continual improvement in GPS data accuracy is constantly improving upon the quality of GPS reliant projects.

All stakeholders expressed concerns applying the technology to urban areas, in particular to critical slope areas such as low grade gutter profiles. Urban construction projects were raised several times as areas where the stakeholders would probably choose not to use machine control technologies. It appeared that machine control is either used on the whole project or not on the project at all. There seemed to be a reluctance of contractors to use a collection of technologies such as combining traditional survey methods and automatic total stations to improve reception and accuracy.

Many of those who had direct experience with machine control during construction shared how they were initially skeptical of the accuracy of the GPS system and the resulting product from the contractor. In order to gain confidence in the system, they developed an in-field quality procedure where they used a separate means, other than GPS, to verify the accuracy of the GPS control and constructed product. In all of these experiences, after a few weeks into the project, the GPS systems had routinely checked in accurately and the parties became confident in the results.

Trend #12 – Acceptance

If one trend became apparent in the in-person meetings, it was the lack of acceptance as a whole of machine control technology. All of the previous trends can be inferred by this trend. Several responders expressed numerous hesitations and objections as to whether machine control technology should continue to be emphasized by the agency. These responders often mentioned that the technology should not be an agency issue, but rather determined by the contractor, arguing that 3D Machine Control is both a means and method. Agency staff in several meetings admitted that their support of machine control efforts was mainly because of the direction of upper management and therefore did not appear to have personal belief, or acceptance of the technology.

A portion of those that participated in the meetings did not have first hand experience in machine control. Those without experience stated that the direction of upper management was why they support machine control. Although these responders may have lacked first hand experience with machine control, they still expressed concerns with the technology. These same responders also were very careful in the selection of the words in their statements, clarifying that their concerns should not be interpreted as resistance to upper management's decision. It appeared as though they were fearful of personally being labeled as unsupportive of the initiative. Some district staff also mentioned the possibility of resistance to the machine control initiative being used negatively in district performance measures.

Those that were enthusiastic regarding machine control had been personally involved in a machine control project as a project manager, surveyor, or 3D model creator. When asked what changed their perception, it was the "seeing is believing" argument. Once they had seen the efficiencies and time savings the contractor gained, and having access to the models for as-built surveys and inspection, they were convinced that the technology should be a focus for the future.

It is important for the DOT to emphasize the opinions of those who do share an enthusiasm for 3D Machine Control technology. The best means of promoting acceptance of this application is through sharing the experiences of those who have participated. Once individuals have proof from their peers that this delivery method saves both money and time, they will become much more willing to adopt it on future projects. The key to acceptance is to spread the word; a fervent supporter of the technology will convert more people to acceptance than a department wide mandate.

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Chapter 5
Stakeholder Concerns and Challenges

Through interviewing stakeholders, analyzing survey results, and researching other state DOTs, seven key issues were isolated that warrant further discussion. Thoroughly addressing these issues leads to the formation of recommendations. These recommendations form the 3D Machine Control Strategy, a comprehensive approach to implementing the technology statewide. The 3D Machine Control Strategy builds upon lessons learned while simultaneously addressing stakeholder concerns. Establishing the concerns of stakeholders involved and a resolution of each concern develops the most robust strategy. The core topics are Acceptance, Accuracy, Cost, GPS Coverage, Changing Roles and Responsibilities of Staff, Liability, and Training.

Acceptance

Gaining acceptance of 3D Machine Control as a viable project delivery method is key to the technology's future success. At present, agency staff is more reluctant to accept 3D Machine Control than contractors. With the understanding that the process of preparing a project for the use of this technology differs from the conventional method, emphasizing the benefits that 3D Machine Control brings to both Mn/DOT staff and the public is important.

Any change in methodology requires the "buy-in" of all project team members. Therefore, implementing 3D Machine Control on a statewide scale requires all relevant stakeholders to understand the benefits and importance of this delivery method. Educating and demonstrating the advantages of this technology to agency staff, surveyors, and designers, as well as private contractors, will help gain acceptance for 3D Machine Control. Until doubting stakeholders actually observe the equipment in operation, it is expected that skepticism will hinder a greater deployment.

With a unified group of stakeholders, projects will be able to pursue more aggressive schedules. This correlates to greater efficiency resulting in financial gains for contractors. Contractors using this equipment will be able to competitively bid, as the overall cost of grading work will decrease with increased efficiency.

Accuracy

Agency staff indicated concern regarding the accuracy of 3D Machine Control Systems presently in use. Staff attitudes ranged from confidence to uneasiness in using these systems on grading projects. Previous machine control experiences revolved around rough grading and grading of structures that do not require precise tolerances. Some responders indicated that the traditional methods of survey stake-out are the most accurate method of grading, as human judgment provides higher quality results than automated processes.

Unlike other industries, the construction industry seldom mass produces a product. Whereas automation is essential to productive manufacturing, efficiency in construction is based upon human outputs – design quality and knowledge of existing conditions. The process of grading always depends upon the characteristics of the site, its topography, soil type, etc. As a result no two grading projects are identical. This unique nature of construction projects makes many individuals wary of automated processes; too many variables exist for the precise execution of a design without the input of human judgment.

By establishing quality control protocols for both 3D model evaluation and post-construction inspection, the confidence of agency staff in machine control technology will grow. Furthermore, demonstrating the equipments' abilities and documenting its limitations enables the state to determine what projects are best suited for 3D Machine Control. Lastly, it is important to monitor the changes occurring in the industry with regard to equipment advances, technique improvements, and software upgrades. This familiarity with the industry will facilitate Mn/DOT in modifying and updating its policies as technology progresses.

Cost

Cost is a topic of concern in every industry with every project. Managing cost and schedule are the two most critical tasks in project management. The financial costs of using 3D Machine Control varies from very high for small company, first time users to relatively low for machine control veterans. The primary cost issues in 3D Machine Control include equipment, model creation, and project management.

Because 3D Machine Control requires specialized, and highly calibrated, electronic equipment, the initial investment for a contractor can be substantial. Beyond purchasing specific tools, the installation of equipment and the training of operators may make machine control extremely difficult for small businesses. As more projects become 3D Machine Control eligible, the ability to break into the industry becomes more difficult; a firm knows that in must purchase expensive equipment and spend large amounts of overhead in training operators and maintenance staff. This condition leads to an unfair advantage for corporations that have already made investments into equipment.

Furthermore, as time progresses, new technology is developed that provides a competitive edge for those who purchase it. As Mn/DOT has an obligation to not discriminate against firms of any size, an innovative method must be considered to provide firms with the opportunity to gain experience in using this technology. Unique bidding techniques or state supplied equipment/training may help all firms, regardless of size, to bid and participate in 3D Machine Control projects statewide.

Beyond the cost of equipment, additional expenditures are incurred in preparing the 3D models used by machine control systems. These costs are present regardless of whether the agency, contractor, or third party generates the design. One way to alleviate these is to standardize the method for creating models. Once a standard method is established, efficiency can be improved via education, training, and experience. Once the learning curve has been surmounted, it is expected that the costs of this task would reduce.

These two cost factors substantially contribute to the overall expense of managing a 3D Machine Control project. This overall cost needs to be compared to the equivalent cost of traditional methods of construction. As with all new emerging technologies, the initial outlays are high relative to those of established methods. This is a result of stakeholders being unfamiliar with the new processes and delivery means. Over time, these costs decrease as individuals find more efficient processes and design improved equipment. In 3D Machine Control, establishing firms into the industry is a costly venture. Fortunately, in this stage of the technology's implementation, a portion of this task has been completed. Many contractors have already invested in the equipment and familiarized themselves with the processes of designing models and grading with the equipment. However, a method must be designed to provide access of this technology to all firms.

As such, it would be expected that in the relative future, the costs of these projects should begin to fall. Further study of the cost trends and a comparison of 3D Machine Control costs to traditional methods of construction should be completed. This will enable the industry to project the return on investment and opportunity costs of further pursuing 3D Machine Control.

GPS Coverage

The lack of GPS coverage in a project location is a major concern among both agency staff and contractors. These concerns are especially critical when bidding on a project. Both stakeholder groups have acknowledged the benefits that 3D Machine Control brings in efficiency and speed of design. This efficiency is limited, however, by the level of GPS coverage present on a site. Coverage is affected by both natural and manmade obstructions. Topography – hills, gullies, as well as tree cover – can adversely affect the number of satellites that a GPS receiver obtains signals from. The quality and reliability of data is directly related to the number of satellites that the receiver tracks. In urban areas, buildings can cause the same effect as topography, blocking out and refracting satellite signals.

GPS coverage is also limited by the absence of reference stations in the project vicinity. Reference stations provide correction factors that compensate for the lag in time it takes for a signal to arrive from a GPS satellite. The State of Minnesota currently operates a network of reference stations that emit corrected readings to the GPS rover device. However, this network does not extend statewide; projects in portions of Mn/DOT Districts 1 and 2 do not have access to this network as the required reference stations have yet to be constructed.

The issue of GPS coverage concerns stakeholders as it has an adverse impact on the schedule and cost of construction. If GPS reception does not meet a minimum threshold, the quality and ability to operate 3D Machine Control Systems is compromised. If work cannot be completed due to a lack of signal, the potential exists that machines may run idle and the project falls behind schedule. Mn/DOT Special Provisions specify that no adjustment in payment or schedule will be made due to satellite reception issues. This phenomenon severely hinders operations and may negate all of the efficiency benefits that 3D Machine Control would normally bring.

Mn/DOT currently requires that hubs be placed using traditional survey methods regardless of whether machine control will be used on a project or not. This requirement does provide an excellent backup plan in cases where signal reception might be intermittent, mitigating the potential for idle machinery on a job. This requirement should nonetheless be evaluated to determine a compromise of having a backup plan for loss of satellite signal and capturing the most savings from using 3D Machine Control.

In order to compensate for the potential lack of GPS coverage on a project, contractors need to diversify their equipment. Their 3D Machine Control systems should not rely solely on GPS guided devices, but include laser and total station guided devices as well. These technologies enable contractors to utilize machine control in situations where coverage is poor or non existent. Additionally, both agency staff and contractors should test the GPS coverage in an area prior to committing to machine control. Stakeholders must realize that there are situations where GPS guided equipment is not an appropriate choice for grading. Increasing both the number of reference stations and the coverage of reference stations throughout the state would help to increase the range in which GPS guided equipment is applicable.

Changing Roles and Responsibilities of Staff

The introduction of 3D Machine Control as a delivery method necessitates changes to the tasks that agency staff must perform on a project. Specifically, the roles of both designers and surveyors are altered. Designers are asked to generate their proposed plans using three dimensional techniques – a process differing from traditional two dimensional engineering and drafting. Contractors would not require the same amount of stakeout and hub placement from surveyors. Rather, surveyors need to verify that work is being completed on the correct datum and that project tolerances are met.

As the process for constructing projects with 3D Machine Control has become better defined, the required tasks and responsibilities of the project team have been identified. New tasks, such as verifying the accuracy of three dimensional models, are created. Key agency members, especially those with many years of experience, are crucial in implementing this new delivery method. It is important for the agency itself to emphasize this point. It is common for team members to become concerned that their positions will be eliminated with the introduction of a new system. 3D Machine Control creates new tasks and responsibilities, and redefines previous roles, eliminating this concern.

It is imperative that the agency contacts its most experienced and veteran employees and ensures their acceptance of 3D Machine Control. These members are needed as leaders to convert the traditional methods and tasks to the new process of 3D Machine Control. New methods to verify completed construction need to be developed by agency surveyors. Design staff needs to become familiar with the common techniques of modeling, as well as the processes ensuring the correctness of models. A quality control procedure needs to be designed, implemented, and maintained to guarantee the entire methodology of 3D Machine Control is completed to the tolerances and desires of Mn/DOT.

This movement to reassign the roles of project management will be accomplished with technical training and education of all stakeholders. Familiarity with the process, roles, equipment, and software will lead to an efficient transition to 3D Machine Control.

It is important to highlight that each task and role in project delivery is essential to the success of the project. It is of high importance to begin a dialog with laborers in both the private and public sectors regarding the implementation of this technology. Many laborers such as technicians, field personnel, and operators may be represented by trade unions. The unions representing these people will undoubtedly have concerns about changing roles and responsibilities, especially with the perception of this technology reducing the work force. Research conducted for this project does not validate that the technology has reduced the workforce, but rather has strengthened it.

In order to ensure success, every project team member's role is crucial. Educating staff regarding what jobs have changed, and why they changed, leads to better acceptance of the responsibilities in 3D Machine Control.

Liability

The issue of liability arises in any discussion of project delivery – no matter the industry. It is of little surprise that this issue also occurs in discussing 3D Machine Control. Both major groups of stakeholders, contractors and agency staff, have concerns regarding which party should be held responsible for the quality and accuracy of work. Additionally, both groups have differing opinions as to who bears this responsibility.

Liability in 3D Machine Control lies predominantly in the accuracy of the three dimensional model. Computer users have realized that a high quality output is highly dependent on the quality of the inputs. This is magnified with the issue of model creation. The models are very dependent on high quality topographic surveys and existing ground surface models. To clarify, the required accuracy of the existing ground surface model is no greater than those used in typical cross section development. But rather, the generation of typical cross sections effectively limits the awareness of the designer to errors that may be inherent to the existing ground surface model. Traditional cross sections are effectively a snap shot of the existing ground surface model as some predetermined interval. Conversely, a 3D model is a true surface to surface comparison and errors in the existing ground surface model should be magnified.

Additional liability rests in the correct implementation of that model in the field. The latter issue is the contractor's responsibility, as establishing a proper guidance system for their equipment is critical in constructing the project. The liable party is much more difficult to establish when it comes to model accuracy. This is a direct result of the multiple ways in which this model can be created.

Liability is the driving force behind project quality, cost, and schedule. Projects with high owner accountability tend to be of low cost and quick to construct; quality is lowest when owner liability is high, as the constructer is not held accountable for the work produced. Likewise, with high contractor liability, quality tends to be exceptional, at the detriment of high cost and slower schedule. The ideal situation is one in which both parties share the responsibility of the project's outcome.

The production of the three-dimensional model places this responsibility with the model creator. If the agency constructs the model, they must be confident that it is precisely what the agency wants built. Errors and omissions in the model will not be the contractor's responsibility – the agency has provided precise instructions for how they want the project constructed. When the agency provides electronic data with a disclaimer, the contractor assumes responsibility for the model's creation and the validity of the electronic data received. This mandates a quality control process that requires verification of the existing data and detailed analysis of the proposed model – a costly responsibility.

In order for both stakeholder groups to benefit from using 3D Machine Control, this liability must be shared. If the agency guarantees the quality of the initial electronic data, the contractor could assume full responsibility for the model's creation. This would ensure that the resulting model would be of high quality, without the agency having to pay for verification of the existing data. Another option includes placing the liability on a third-party model designer. This stakeholder would verify the electronic data and construct the model using the construction documents. Although this alternative results in an increased cost resulting from the introduction of a third-party, it enables an expedited construction as the contractor need only follow the model provided; the agency assumes no additional liability. By establishing guidelines for model quality control, the agency can govern the quality of the model.

Training

Of paramount importance in implementing 3D Machine Control systems is the training of project team members. Both contractors and agency staff indicated that training was their highest priority in moving forward with machine control. Both stakeholder groups indicate that additional training would help them better understand the protocol in administering a project and increase the efficiency of the project. Training could be provided from a number of sources including software designers, equipment manufacturers, industry leaders, and educational institutions.

The amount of training provided directly correlates to project success. A number of variables important in project management are affiliated with training. Training defines distinct processes in the project life cycle. Project team members are assigned responsibility by thoroughly educating them in the correct tasks needed to complete an individual process. Training also provides individuals with a glimpse of how their process fits into the entire project life cycle; team members comprehend how the effective execution of their procedure directly impacts the productivity and quality of the total process.

Efficiency is continually improved with on-going training. As stakeholders are educated, they begin to improve their speed, accuracy, and ability to troubleshoot errors in their tasks. As a result, quality improves. Training also provides a means of standardizing tasks. Once a procedure is standardized, a consistent quality product can be expected. Each member of the project team – designers, surveyors, inspectors, and operators – need to obtain a proper understanding of their role in the project cycle and how to act together to deliver the best possible product.

It is important to establish a system to educate all of these individuals in a relevant time frame. By contacting those firms with the most experience in working on 3D Machine Control projects, a curriculum can be created to train and educate stakeholders. As with any successful training, the trainee must implement the lessons learned within a short time of being trained for the best retention on the subject matter. The longer the time lapse between the training and the implementation, the greater the depreciation training has as a benefit.

Beyond experienced contractors, software and equipment vendors need to be accessible to agency and contractor staff. This accessibility is in the best interest of these providers, as an educated group of stakeholders will likely continue to use the same product line and purchase next generation software and equipment. Further, established coursework at local institutions of higher learning will further serve to instruct project team members. A comprehensive training plan will serve the best interest of all stakeholders involved in 3D Machine Control Systems.

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Chapter 6
Recommendations

The recommendations that follow below are suggestions for the department to consider with the goal of encouraging further use of machine control in the State of Minnesota. The recommendations usually result from one of two scenarios. A recommendation may support or enhance mechanisms already in place that are advantages to machine control use in the state. Other recommendations may overcome or address an obstacle for the use of machine control technology in the state. In either case, the recommendation will include a description of the advantage or disadvantage the recommendation is targeting. Table 6.1 provides an overview of the challenges each recommendation is intended to mitigate.

Specific costs are difficult to quantify for all the recommendations. In some cases, the costs could be shared with other departments within Mn/DOT or other agencies through cost sharing agreements. As a result, the recommendations include a relative cost scale of Low, Moderate, and High.

Categories were used for describing the overall timeline for implementing the specific recommendation. The categories are 3 Months, 6 Months, On-Going, or Phased. These criteria will help Mn/DOT in planning and implementing the recommendations presented in this chapter. Figure 6.1 illustrates the proposed implementation flow for each of these.

Number	Recommendation	Timeline	Issues Addressed						
			Acceptance	Accuracy	Cost	GPS Coverage	Changing Roles and Responsibilities of Staff	Liability	Training
1	Outreach to other departments internal to Mn/DOT	3 Months	●				●		
2	Outreach to other agencies and organizations external to Mn/DOT	3 Months	●				●		
3	Provide Training to all Stakeholders	6 Months	●	●	●		●	●	●
4	Develop and Implement a Quality Control and Assurance Process	6 Months	●	●			●	●	●
5	Develop Innovative Contract Bidding Techniques	6 Months			●			●	
6	Equip Field Staff with Required Equipment	Phased	●	●			●	●	
7	Convince Engineers of the Benefits of Modeling during the Design Process	6 Months to On-going	●	●			●	●	
8	Modify the Responsibilities of the Construction Stakeout Surveyor	6 Months to On-going	●	●			●	●	
9	Support and Expand the Mn/DOT CORS Network	On-going	●	●		●			
10	Create a Pre-Qualified or Certified List for Machine Control Model Creation	6 Months	●	●					
11	Consider New Partnering Opportunities	On-going	●	●	●			●	●
12	Develop a Work Flow for Machine Control Delivery	On-going	●	●	●			●	●

Table 6.1 – Summary of Recommendations

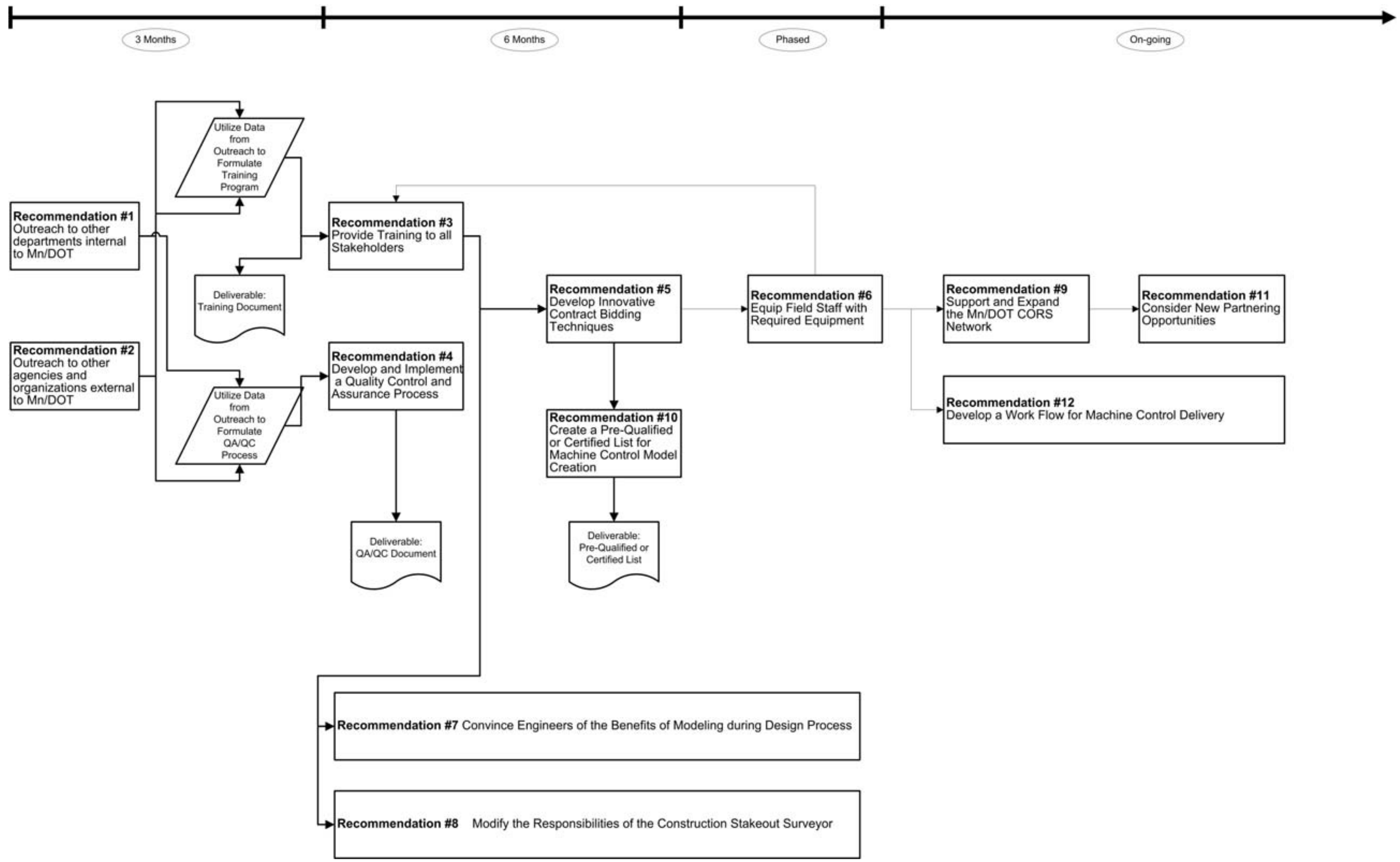

Figure 6.1 – Recommendation Timeline

Recommendation #1: Outreach to other departments internal to Mn/DOT
Addresses Issues: Acceptance and Changing Roles and Responsibilities
Cost: Low
Timeline: 3 Months

Mn/DOT has been an advocate for 3D Machine Control technology shortly after the technology was introduced in the industry. However, many of those advocating efforts have been confined within the department and specifically, within the CAES Unit.

At this present date, this has created challenges for the technology by creating political differences between departments and functional groups within Mn/DOT. There may be several factors that have contributed to these political challenges, but they must be resolved before moving forward.

The CAES Unit has done an extensive amount of work to get the Machine Control Initiative to be as successful as it has been in Minnesota. This work has come with the consequence of alienating some functional groups within Mn/DOT that will be critical in the acceptance of the technology. The success of the technology is dependent upon acceptance by planners, engineers, technicians, construction managers, inspectors, and surveyors.

The acceptance of the initiative is further fragmented by Mn/DOT's decentralized organizational structure. There is some resistance to the initiative due to the autonomy the Districts desire from the Central Office. Since the Machine Control Initiative is currently spearheaded by the CAES Unit, it is being met with resistance at several districts. Furthermore, each district has a locally designated Machine Control Champion, but few are experts on the subject matter or have had first hand experience with the technology. There is the general lack of personal buy in among several District level employees. To clarify, they are not in opposition of the Machine Control Initiative, but they appear to support because of decisions by upper management. The resistance is not across the board, the issue came up enough in discussion that it should be addressed. The easiest way to address these issues is through dialog and education.

This recommendation suggests that Mn/DOT form taskforces that are committed to the success of machine control. These taskforces should be composed of at least one member from each of the functional groups affected by the use of the technology. This ensures that all functional groups and department's needs will be met. The taskforces should be large enough to accurately represent all the functional groups and departments involved, but should be kept to a manageable size. A taskforce with 8-12 members would be ideal.

The taskforces would ideally be organized such that it would be formed at the District level, but would have reporting and decision making channels through a centralized body. This would ensure that local needs are being met while providing a common implementation throughout the state. If the taskforces are geared too much towards District level independence, machine control implementation will be fragmented throughout the state with different standards in each District. If the task force is geared too much towards a centralized body, machine control will lack the acceptance by those in the field responsible for implementation.

Recommendation #2: Outreach to other agencies and organizations external to Mn/DOT
Addresses Issues: Acceptance and Changing Roles and Responsibilities
Cost: Moderate
Timeline: 3 Months

Similar to Recommendation #1, the machine control initiative has been confined primarily within the CAES Unit. At times, this has created challenges for the technology by creating political differences as to which department within Mn/DOT should lead the effort.

The success of 3D Machine Control technology in the state will be highly dependent upon Mn/DOT's ability to convince all stakeholders, both internal and external to the department, that the technology is a benefit to the industry.

Recommendation # 3: Provide Training to all Stakeholders
Addresses Issues: Acceptance, Accuracy, Cost, Changing Roles and Responsibilities, Liability, and Training
Cost: Low-Medium
Timeline: 6 Months

Perhaps more so than any other recommendation, this recommendation addresses nearly every major issue exposed during the evaluation. Almost unanimously, stakeholders requested more training when it came to using machine control technology. Designers expressed interest in more training for preparing and modifying the models. Surveyors and construction staff expressed interest in training for making field revisions to the models. Contractors would benefit from training on the agency's policies and procedures regarding machine control use and model creation.

The need for training is immediate and as already mentioned, crosses all user groups. Training to date has primarily focused on creating the models from a post production plan set. The CAES Unit has taken the primary responsibility for providing this training. The effort by the CAES Unit has been successful given the limited resources and staff available.

In order to improve the delivery timeline of training and tailor the training to all stakeholders, the training responsibility will have to expand dramatically and will likely outgrow the capabilities of the CAES Unit alone. In addition, the focus of the training material will have to expand beyond just model creation. Therefore, Mn/DOT should assemble a multidisciplinary taskforce dedicated to developing and executing a training program. This taskforce should be coordinated with the outreach taskforce (Recommendation #1). The outreach taskforce could be charged with the responsibility of implementing the training program, or could allow for the formation of a subgroup to focus directly on training.

Ideally, the training would be developed as a mobile training program that would visit each district within the state. Several comments were gathered during the in-person meetings that current training opportunities are hard to attend, mainly due to travel requirements and limited class offerings. The training should be modular in format such that it addresses all user groups such as designers, surveyors, construction and inspection staff, contract administrators, etc.

The cost associated with training can vary greatly. If the training is to be provided by Mn/DOT staff, then the cost associated with this effort can be kept to a minimum. If the resources do not allow Mn/DOT to adequately perform this training, the agency should contract for these services. In this situation, the cost would likely grow to a moderate level. Cost alone should not be the determining factor for the provision of training. It is true that training has an associated cost, but the benefits can far outweigh the investment.

Recommendation # 4: Develop and Implement a Quality Control and Assurance Process
Addresses Issues: Acceptance, Accuracy, Changing Roles and Responsibilities, Liability and Training
Cost: Low
Timeline: 6 Months

Acceptance of this technology by the industry will be highly dependent upon the quality of the models regardless of who prepares them and subsequent changes to the models through field revisions. This issue is particularly magnified for Mn/DOT if the agency continues to prepare models in house, either as part of the design process or post plan production.

Any time a new process or deliverable is added within the industry, the initial introduction will likely have some errors in the deliverable itself or the process. If these errors occur repeatedly for an emerging technology such as machine control, it can degrade the trust in the technology and the technology is never accepted as an industry standard.

In order to remove this potential obstacle from machine control, a rigorous and defined Quality Control and Quality Assurance plan must be developed and implemented within Mn/DOT and followed by all stakeholders.

The plan should address not only preparing and modifying the models themselves, but have standards in place for establishing control on the construction site, procedures and documentation requirements for checking in and adjusting the machine control equipment to the established control, and a plan to address field modifications to the models when needed.

Furthermore, the quality control and assurance process will help the agency and all stakeholders involved identify the errors in the delivery method and take corrective actions to limit the potential for those errors on future projects. A well defined and executed process will help define and correct issues before claims are made, therefore reducing the liability to the model creators.

Recommendation # 5: Develop Innovative Contract Bidding Techniques
Addresses Issues: Cost and Liability
Cost: Low
Timeline: 6 Months

Overwhelmingly, contractors stated one of the largest disadvantages to the use of machine control was the initial investment for the equipment. Early in the operational testing phase of the technology, Mn/DOT helped subsidize a portion of the equipment for a few contractors.

Today, many contractors, especially most large companies, have already invested in machine control technology. Several small and midsize companies are presently considering the investment. Through many of the in-person meetings, Mn/DOT staff repeatedly stated that a contractor's decision to invest in machine control is a market force and suggested Mn/DOT let the market forces work on their own without direct intervention from the department.

This recommendation attempts to level the playing field for all bidders, regardless of whether they currently own machine control equipment or not. This recommendation is considered a short term recommendation and would eventually be replaced by a different bidding process once machine control equipment is owned and operational by most contractors bidding on Mn/DOT projects.

The concept is similar to the way Alternative Technical Concepts (ATC) are handled in the Design-Build bidding process. In Mn/DOT's current Design-Build RFP process, Mn/DOT defines a Base Configuration (BC) for a project. The Base Configuration is the bench mark to compare all responders on equal criteria. There are no alternates that are a part of this process. Only after all responders are graded or selected on the Base Configuration are the ATC's considered. These ATC's can either add to or subtract from the price established on the Base Configuration.

The process could be modified to allow all contractors a competitive chance to successfully win the project, based on their bid price for the Base Configuration. After Mn/DOT has successfully scored or selected a contractor from the Base Configuration bid, they could review the ATC's submitted by the contractor and choose to approve or deny each one independently.

The process would require the bid schedule to be structured so that the Base Configuration is well established for all bidders. The bid schedule and special provisions should state whether the department will provide construction surveying or if the contractor will be required to provide those services. The bid schedule and special provisions should state that machine control shall not be considered as part of the Base Configuration and instruct the bidder to submit an ATC for the use of that technology.

Responding bidders would submit their bids in similar format as they currently are submitted. The only change in the current bidding process is that ATC's would be submitted in a separate, sealed envelope with the associated costs. The ATC's would be submitted at the same time as the bid for the Base Configuration. This requires the contractor to bid more competitively on the ATC's since they do not know if they will be the successful bidder at that time.

Recommendation #6: Equip Field Staff with Required Equipment
Addresses Issues: Acceptance, Accuracy, Changing Roles and Responsibilities, and Liability
Cost: High
Timeline: Phased

Partly due to the technology changing and evolving rapidly, some districts are inadequately equipped to support machine control technology. Some districts have leveraged various contracting requirements to rent the necessary equipment in order to equip their surveyors. Other districts may have enough pieces of equipment, but due to various updates in both software and hardware, the equipment doesn't have the full functionality or communication abilities to consistently deliver on machine control projects.

Managing hardware and software upgrades is not a new problem, but will likely be compounded in the next few years as new satellites become available and receiver technology changes. It would be advantageous to define a replacement and upgrade method at this time to be prepared for those upcoming changes.

Each district should complete a full inventory of their current equipment and software. This would include firmware versions on the hardware itself, as well as any software on laptops and desktop workstations used in processing that equipment.

The inventoried equipment should then be compared to a list of minimum requirements compiled by the equipment vendors to meet current applications, including machine control. An upgrade plan should be enacted that ensures, at a minimum, that each particular hardware component has the latest firmware or software version loaded.

In some cases, hardware components will need to be upgraded or replaced. Replacement of these units will obviously cost more than software upgrades, but will likely be needed within the next five years due to improvements in the technology. There are various revenue streams that can be identified to cover the costs of upgrading and replacing equipment. In the event of workstations, there is already a program for replacement that is managed by the central office. A similar program is in place for survey equipment. Additionally, the costs associated for this recommendation should be kept separate from the ongoing efforts of the Mn/DOT CORS network mentioned in Recommendation #9. All of these programs may need to plan for increased spending in order to take advantage of new advancements in technology. So each particular model series should be evaluated for replacement considering the timeline for GPS enhancements.

Recommendation #7: Convince Engineers of the Benefits of Modeling during the Design Process
Addresses Issues: Acceptance, Accuracy, Changing Roles and Responsibilities, and Liability
Cost: Moderate
Timeline: 6 Months to on-going

Although the timeline for this recommendation will likely take several years to complete, the need is immediate. Not one responder to the survey or in-person meeting attendee disputed the benefits of machine control. Nearly unanimously, all stakeholders agree that the use of machine control on a project saves the contractor time, saves the contractor money, and results in a higher quality finished product.

Because of these benefits, most employees at Mn/DOT question the need for Mn/DOT to promote the technology. In their opinions, machine control is a market driven issue and is to be dealt with by normal market forces. They are quick to take the "Means and Methods" approach and leave it up to the contractor to determine the best method. When some designers were questioned specifically about the value of three dimensional models in design, most dismissed any potential benefits from the added information. Of those who held this opinion, many considered the plans they produce to be of high quality and contained little or no errors.

Mn/DOT should evolve to concurrently design the three dimensional model with the project design on all grading projects. This ensures a higher quality product and makes for good design practice, regardless of whether 3D Machine Control is utilized on the project. In the short term, these models will provide experience and familiarity with the techniques used in their generation. In time, designers will become proficient in this model created, further streamlining the project delivery process.

Recommendation #8: Modify the Responsibilities of the Construction Stakeout Surveyor
Addresses Issues: Acceptance, Accuracy, Changing Roles and Responsibilities, and Liability
Cost: Low
Timeline: 6 Months to on-going

Although adoption of machine control technology will likely change every aspect of the industry, perhaps no role will change more significantly than those surveyors currently responsible for construction stakeout.

Many of the benefits listed by both agency and contractor staff is that less time and staff is needed for construction stakeout and the result is more flexibility to move around on the project.

In many circumstances, resistance to change is a self preservation mechanism. There appears to be some resistance by surveyors to embrace this technology for fear that their services will no longer be required and therefore their positions will be reduced or eliminated.

To address these concerns, it is important to educate surveyors that although their responsibilities may change, their skills and services are necessary and critical to the success of the technology.

First and foremost, surveyors will be ultimately responsible for establishing control on each machine control project. Many contractors and vendors of machine control equipment noted that this is sometimes the most difficult task they encounter when using machine control on a site.

Increased use of machine control creates a significant opportunity for surveyors to become more involved in the quality processes on a project. Although less time will be spent staking the placement of certain materials, this time will likely be backfilled with more verification surveying and inspection type of activities.

Several engineers and designers stated that they have additional confidence knowing surveyors and inspectors will find and correct any errors in the plan. In essence, field staff is the last line of defense for the overall quality of the construction documents. This issue was most often raised in Districts where Mn/DOT provides most, if not all, of the construction staking and inspection services to the contractor. In the current design processes within most Districts, field staff members are the only truly independent reviewers of the design. Perhaps this task has not been formalized.

In order to still provide this important quality control function, surveyors could ultimately be responsible for model creation. To date, most training on model creation within Mn/DOT has focused on design staff. Surveyors would need a lot of training in order to assume this responsibility, but it would also help in implementing the previous recommendation for a defined Quality Control and Assurance program. One potential disadvantage of adding these responsibilities to surveyors is that design personnel would still be allowed to work in a two dimensional world and may not benefit from the added quality a model can provide during the design process. Furthermore, the 3D model would not benefit other design groups since it would be created after the construction documents were prepared. On projects where the surveyors are supplied by the contractor, Mn/DOT feels that it is unlikely they will receive a copy of the model for later use.

As a result, the change in the job responsibilities of construction stakeout surveyors is likely inevitable; the change will occur over several years and allow ample time for training and education. With the current technology available, the accuracy is not to the point where machine control equipment can be used in paving and curbing operations, utilities, or bridge work. For the immediate future, surveyors will still be relied upon to provide construction staking support in these tasks.

Recommendation #9: Support and Expand the Mn/DOT CORS network
Addresses Issues: Acceptance, Accuracy, and GPS Coverage
Cost: Moderate
Timeline: On-going

Mn/DOT's Office of Land Management has been building a network of Continuously Operating Reference Stations (CORS) throughout the south and central regions of the state. The system currently extends as far north as a line connecting the cities of Duluth and Moorhead.

The system can increase the accuracy of GPS data to approximately 0.04 ft in both horizontal and vertical datums. This accuracy is obtained by continuously monitoring the GPS coordinates at each reference station. The elevation and location are well established at each reference station. At any given moment, a GPS reading at the same location will provide a slightly different location and elevation than the known values due to errors inherent to GPS.

By comparing the current reading to the known reading, the user can determine the exact amount of error and a correction can be calculated to compensate for the error. The greater the number of reference stations providing data for the correction calculation, the greater the confidence the user can have in the GPS location and elevation. All of the data from the reference stations are fed to a server in Mn/DOT's Central Office that calculates and provides the corrections. Currently, the software being used in this process is Trimble's® VRS software.

Acceptance of any new technology is gained after continuous, accurate results. By expanding the CORS network throughout the state and purchasing equipment capable of using all the new satellite technologies, all GPS technologies including machine control will gain more acceptance.

According to representatives for the Office of Land Management, the initial cost of each reference station is estimated at approximately $30,000. Each site requires power and an internet connection in addition to the equipment and hardware costs. The system is currently used by several agencies throughout the state and cost sharing is common due to the many potential users and benefits the system offers.

The system does require users to have access to the internet, typically through the use of a cellular phone, to receive the correction from the VRS software. Therefore, use of the system is restricted by cellular provider and their respective coverage area within the state.

A targeted implementation plan for the expansion of the CORS network should be developed. The plan should identify expansion sites and categorized their implementation similar to other planning initiatives at Mn/DOT. Potential timeline for categorization could include sites to be implemented within the next 5 years, 5 to 10 years, and greater than 10 years. Additionally, expansion should take into consideration the types of roadways and their importance to regional economy. The expansion of the CORS network should be prioritized along high priority roadways first, then branch out to cover roadways of medium priority, ultimately covering all roadways within the expansion area. This strategy will be useful as it likely that future construction efforts will follow a similar funding pattern with high priority roadways starting construction projects sooner than low priority roadways.

Recommendation #10: Create a Pre-Qualified or Certified list for Machine Control Model Creation
Addresses Issues: Acceptance and Accuracy
Cost: Low
Timeline: 6 Months

Mn/DOT has already established a defined selection system through the use of the Pre-Qualified lists for various engineering, surveying, and construction activities. By creating this process, Mn/DOT recognizes that certain project tasks require specialized skills or experiences to complete that task successfully. 3D Machine Control definitely requires expertise and familiarity with the process. Certain members of the consulting industry, in addition to contractors with their own modeling staff, have already attained this experience.

The prequalification list would serve many purposes that are advantageous to both the department and the local industry. For those contractors that need additional help on larger or more complex projects, they could seek the help of these Pre-Qualified list members. Mn/DOT benefits by setting the selection criteria for placement on the list and dictates a renewal schedule that ensures all firms on the list stay current on the changes in the technology. Creation of the list and actions of those members seeking placement on the list acts will create a market awareness of the technology and the benefits gained from its use.

Recommendation #11: Consider New Partnering Opportunities
Addresses Issues: Acceptance, Accuracy, Cost, Liability, and Training
Cost: Moderate
Timeline: On-going

An important connection was made during the literature search for this project. One of the largest promoters of 3D Machine Control technology in the country is located in West Des Moines, Iowa. This company, McAninch Corporation, is a leading highway and site-development contractor that completes approximately $200 million of construction annually, boasts one of the largest Caterpillar equipment fleets in the Midwest, and recently completed a North Carolina DOT project nearly a year ahead of schedule attributed to the use of 3D Machine Control. The company, and its founder, was instrumental in the formulation of the joint venture Caterpillar Trimble Control Technologies, LLC.

McAninch Corporation has formulated several strong partnerships, including one with Iowa State University's Center for Transportation Research and Education (CTRE). Through the partnership, new classes have been developed at the University that teach graduates the benefits of the technology and how to harness it in their careers. The company also creates and distributes several publications and training materials on the use of GPS technology and partakes in numerous speaking engagements to disseminate information to others within the construction industry. The company is a strong advocate for improving the construction industry through the use of technology.

This recommendation encourages Mn/DOT to consider partnering with McAninch Corporation and their partners. The department should attempt to arrange for a meeting with those individuals, perhaps tour the CTRE labs and visit the contractor's facility to absorb as much knowledge as possible from the pioneers in 3D Machine Control.

Company representatives may be willing to be part of Mn/DOT outreach efforts to stakeholders within Minnesota, offering a unique viewpoint from a voice outside of the department. Additionally, CTRE possesses a mobile geotechnical laboratory that demonstrates several applications of innovative construction technology. Mn/DOT should inquire into the use of this mobile laboratory, or create their own concept of this trailer to tour the state promoting the technology to stakeholders.

Recommendation #12: Develop a Work Flow for Machine Control Delivery
Addresses Issues: Acceptance, Accuracy, Cost, Liability, and Training
Cost: Moderate
Timeline: On-going

As mentioned earlier in this report, there are several methods that exist both internal to Mn/DOT and within the private industry to support machine control and particularly, model creation. This recommendation encourages Mn/DOT to create models for most grading projects. The decision to model nearly all grading projects should be made regardless of whether machine control will be used during construction of the project.

The modeling effort should occur concurrent to project design in a standardized manner, as this allows for the most reuse of the data and the resulting model throughout the project lifecycle. Modeling in preliminary engineering phases will allow better transfer of concepts at public information meetings, allowing design staff to convey engineering principles to the public. Modeling during design of the highway would help facilitate water resource engineering, noise abatement, utility design, and quantity generation.

The ability to use machine control during construction is only one of the numerous benefits concurrent modeling during design brings to a project.

This further aligns Mn/DOT to be in a better position regarding the use of machine control by the contractor. By actively producing 3D models on a large portion of projects, the decision to actually use machine control on a project ultimately lies with the contractor. Mn/DOT would no longer be forced to determine ahead of time which projects are candidates for machine control. The current identification process may be too restrictive, filtering out candidate projects that may benefit from machine control while simultaneously forcing machine control use on a project that a contractor elects not to use. With the increased engineering quality 3D modeling may provide, Mn/DOT can make better design decisions for the project while leaving the construction means and methods up to the contractor.

Mn/DOT should actively focus their efforts on reducing the data interchange and conversion necessary for modeling to transcend functional groups and design phases. From review of current software within the market, most of the electronic files should remain within the MicroStation and GEOPAK formats. Other than greater familiarity on the part of the contractors, the need to convert to AutoCAD formats appears to be unjustified.

As mentioned previously, although a few of the software programs used in machine control systems do support MicroStation file formats, they do not yet support the Version 8 formats Mn/DOT currently produces. This is expected to be a short term obstacle that the industry will likely resolve in the near future. Mn/DOT can take an active role in lobbying software vendors, to facilitate this change on a shorter time frame.

The process for creating models should be standardized, which all model designers internal and external to Mn/DOT must follow. This process should include the use of standard criteria files for creating the models, the development and implementation of CADD standards specific to 3D modeling, and distribution of the necessary configuration and setup files required during model creation. A training program, such as the one in Recommendation #3 would further benefit all model designers by educating them on the standards.

Figure 6.2 illustrates the proposed work flow for machine control delivery as a result of this recommendation.

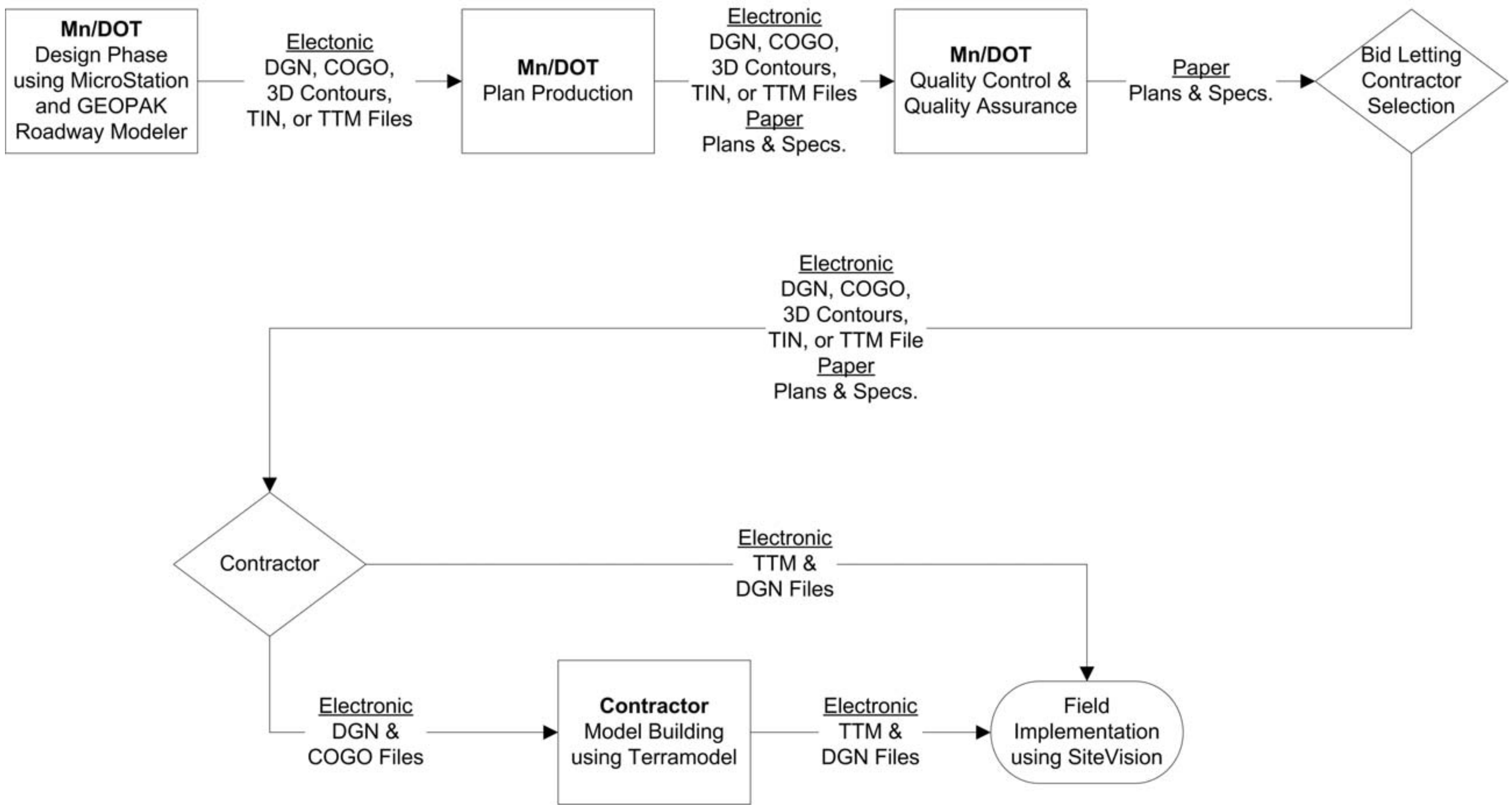

Figure 6.2 – Proposed Work Flow for Machine Control Delivery

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Chapter 7
Conclusions

3D Machine Control and Guidance Systems are rapidly being deployed in the heavy civil construction industry. The deployment of the technology in the field of highway construction lags behind certain private industry markets such as mining and mass grading of large developments due to the complexities and tight tolerances of corridor construction. Mn/DOT has been a leader in the implementation of 3D Machine Control in this domain. In order to take the next step, the industry needs to implement changes in the way it manages, designs, surveys, and constructs roadways.

The overwhelming opinions of the industry, both public and private sector, is that the use of 3D Machine Control technology increases quality, improves efficiency, and provides greater safety in the work zone. Manufacturers of heavy equipment are building the wiring apparatus, mounting details, hydraulic sensors, and control stations into their standard products, with full knowledge that the technology will be installed within the life cycle of the machinery. Large contractors are employing staff with expertise in the use of the technology. Private industry rarely expends significant resources on technology that is seen as short term.

In order to fully utilize the advantages of technology in the construction industry, the industry must continually evaluate and challenge existing business processes. Each industry member's specific role and the methods used to accomplish tasks should evolve accordingly. Through the continual refinement of these processes, the public can be assured that stakeholders are delivering high quality projects with the best use of resources.

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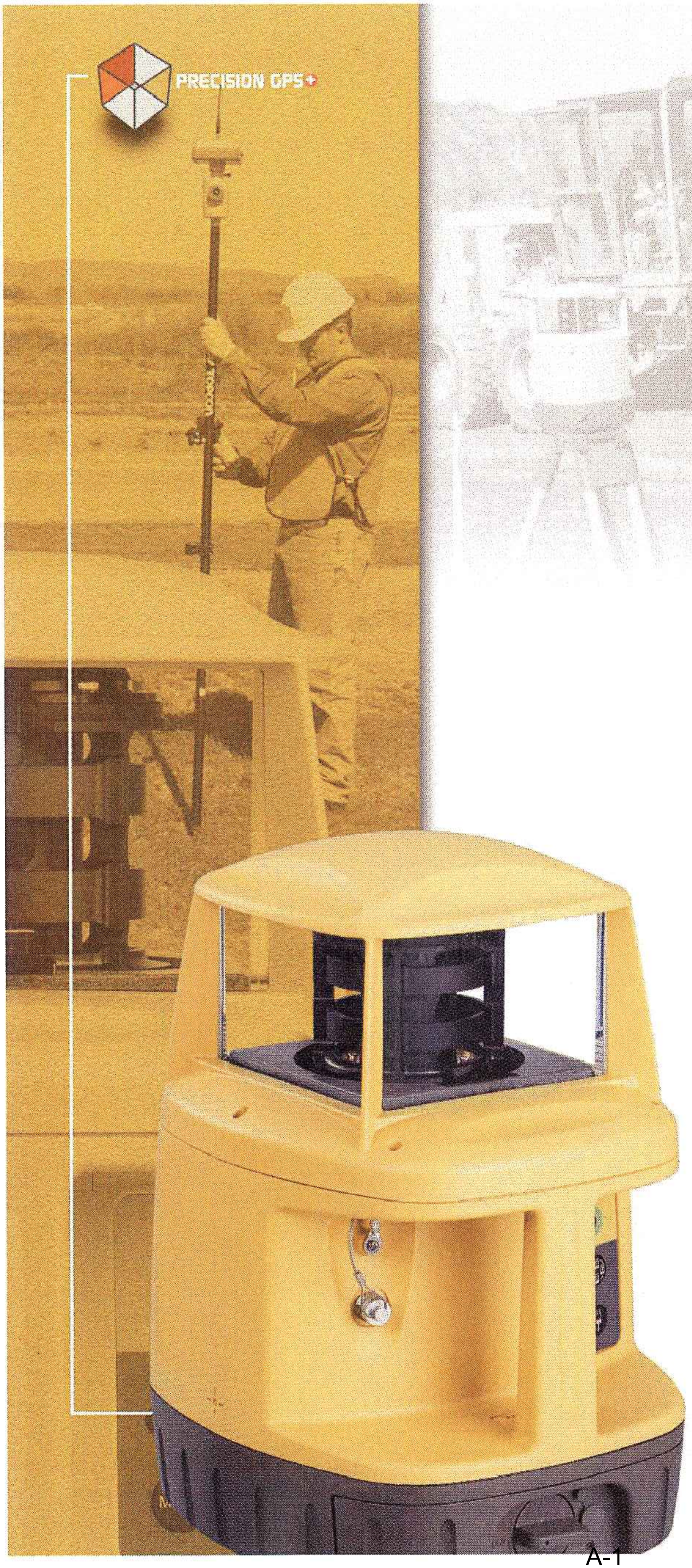
Appendix A

3D Machine Control System Brochures



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EQUIPMENT AUTOMATION: 3D-MC

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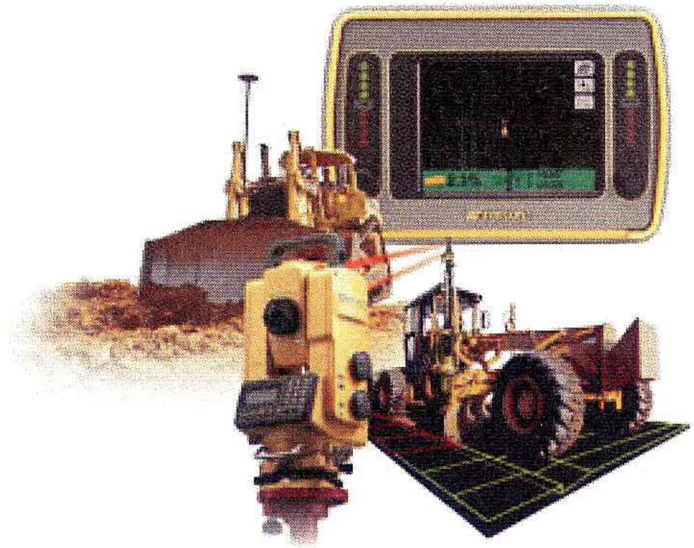


3D-MC

Automatic, Stakeless Grading

With over 70 years in the precision measuring business, Topcon knows what contractors expect from the equipment they purchase: Performance - will it do the job, Reliability - will it survive, Simplicity - can my operators use it, and Compatibility - will it be obsolete tomorrow. Topcon leaves the competition behind in each of these areas.

performance

- GPS+ (GPS + GLONASS): More satellites keep you working when other GPS only systems cannot
- Paradigm chip: allows receiver to track up to 20 satellites when the competition can only track 9
- Co-op tracking: grade in and around trees where others can't
- Laser communication for LPS is faster and more accurate than radio
- Continue to work when waiting for a 3D model or change orders by instantly switching to sonic, laser or slope control

simplicity

- Color "touch screen" control box that can be used by any operator
- Smart Knobs provide full control to the operator right at his fingertips
- Completely automatic to eliminate guesswork

reliability

- A history of over a quarter century providing equipment automation to contractors
- Slope sensors and connectors are filled with epoxy to keep out dust, moisture and vibration
- Extra heavy duty cables and simple rugged bracket design

compatibility

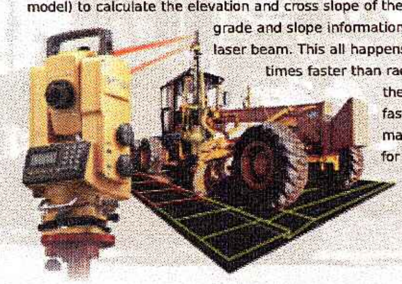
- System Five-3D control box will run Laser, Sonic, Slope, 3D-GPS+ and 3D-LPS "Plug n Play"
- Modular "building block" design: Add options as your business grows
- Digital technology allows for forward and backward compatibility from 1989

3D-MC

3D-LPS

Topcon's 3D-LPS (Local Positioning System) is the World's first and only laser based 3D machine control system. Instead of adding more stakes to finish to those tighter tolerances, you can now significantly reduce or eliminate the stakes all together with Topcon's patented 3D-LPS system.

How does it work? As the equipment moves across the site, a robotic total station tracks the LPS receiver to determine its location (X, Y). The system then looks to the DTM (digital terrian model) to calculate the elevation and cross slope of the cutting edge at that exact point. This grade and slope information is sent to the machine through a fan laser beam. This all happens 50 times per second! That's almost 10 times faster than radio based systems. More information to the machine allows the operator to finish faster and make fewer passes while still maintaining tight tolerances. It's the ideal system for high accuracy and expensive material projects.



- Laser communication vs radio provides more information which results in higher finish speeds
- Laser communicating w/LS-2000 Receiver means fewer passes to get to final grade

System Five-3D

The new System Five-3D Control Box reduces the clutter of the operator's compartment by combining Operator controls and a powerful field computer in one small package. System Five-3D displays grade indication, machine set-up, system status, and provides job site position information. And it's touch sensitive for easy operation.

Use System Five-3D for your Topcon 3D-LPS or 3D-GPS+. Zoom in on the site, make grade changes, or check system status at the touch of a finger. And it's fully compatible with your current Topcon 2D system.

3D-GPS+

Forget about waiting for stakes to begin grading. With Topcon's 3D-GPS+ machine control system, an operator knows where he is on the jobsite and how far away the cutting edge of his machine is from final grade. By triangulating distance measurements to satellites orbiting 12,000 miles in the sky, we can locate any point on the earth. Add a base station to correct for errors and GPS can accurately control the grading on your jobsite to within 1/10' or less. Imagine cutting or placing material within spec over your entire site without stakes. With Topcon's 3D-GPS+ not only do you move the material quicker and with less stakes, but also eliminate the costly process of moving material twice.

A distinct advantage of Topcon 3D machine control is our ability to track more satellites than anyone else. 3D-GPS+ (GPS + GLONASS) insures you will not have equipment downtime due to too few satellites found in GPS only systems. No one can deny when using GPS, "the more satellites the greater the solution quality and integrity."

Another unique feature available only from Topcon is our "Co-op Tracking". This technological advancement allows you to stay locked on satellites while grading in or around trees. The ability to track satellites in these adverse conditions guarantees your grading production will stay on or ahead of schedule.

If you are looking for a way to be more competitive and improve your profits, Topcon's 3D-GPS+ for your equipment is all the control you need.

- Increase production by making fewer passes with fewer machines
- Increase production by eliminating downtime waiting for surveyors and cutting out rework
- Control materials to your advantage and reduce overages
- Significantly decrease surveying cost by reducing staking on base and sub-base

General Construction, Surveying, Earthmoving, Mapping. No matter what type of work you do, Topcon has a tool that will help you get the job done right, the first time.

Pocket 3D

Topcon has combined its Pocket 3D field software with its HiPer® receivers to offer a compact, yet powerful jobsite management tool for contractors. This lightweight and cable-free system is perfect for:

- Quickly checking cuts/fills anywhere on the jobsite
- Topoing existing ground to verify accuracy of plans prior to moving dirt
- Monthly, weekly or daily topos to check work progress
- Topoing stockpiles for instant and accurate quantities
- Mark manholes, utilities or lot corners to locate after grading or paving
- Stakeout roadways and top or toe of slopes

Pocket 3D will cut out delays waiting for surveyors and grade stakes providing you more control of your jobsite and profits. Best of all it is so simple, any of your grade foreman or checkers will be able to use it.

System Five-3D

- Windows CE® based operating system
- 300 MHz computing speed
- Simple touch screen operation: the industry's easiest-to-use, operator friendly alternative
- High-resolution, high-visibility display: System Five-3D makes it easy to see information all day long, from bright mornings to dusk. Automatically changes for light conditions
- Select from multiple views of your job, anytime: choose from plan, cross-section, or profile view or a combination of the two
- USB and Compact Flash ports: Updating control box software or project files can be completed in the field
- Built in light bars for grade and steering indication
- Projects stored in the computer and not on the flashcard. Update multiple machines from one card

For more info on this or any other Topcon product log onto:

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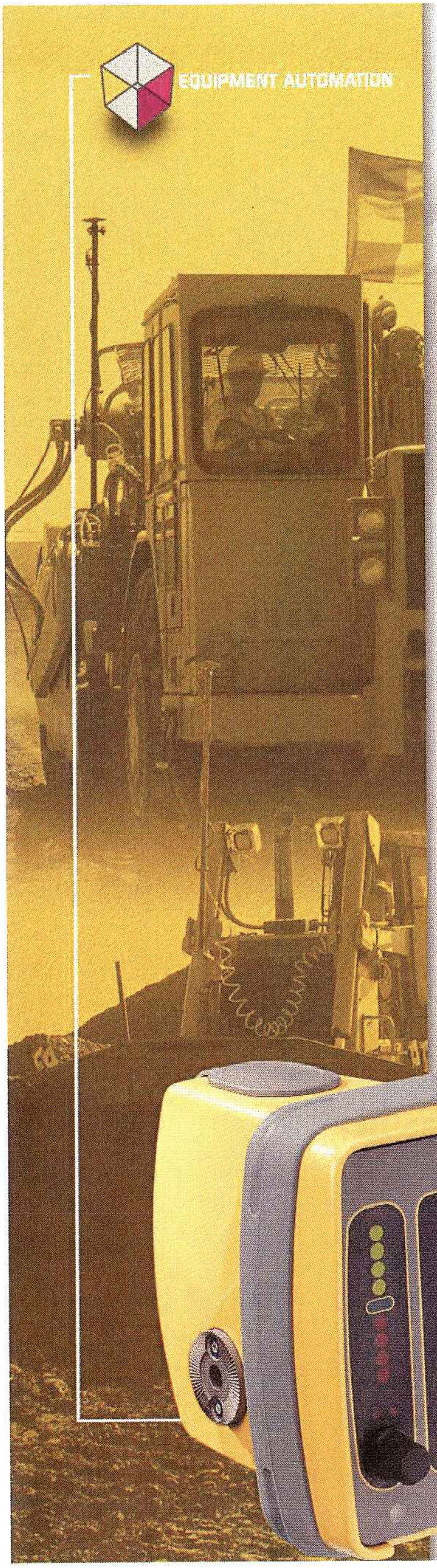

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Experience the productivity of Topcon GPS+ machine control at a much lower initial investment with the new 3Di-GPS+ Indicate Control System from Topcon. Now your bulk earth moving equipment can take advantage of GPS+ technology to dramatically increase your rough grading productivity. One of the most important aspects of grading is balancing your material. Utilizing 3Di on your scapers, compactors and large dozers will insure you move the right amount of material the first time.

High visibility display lets you zoom out for a whole job perspective, or...

zoom in, add cross section perspective and many other options depending on the operators preference

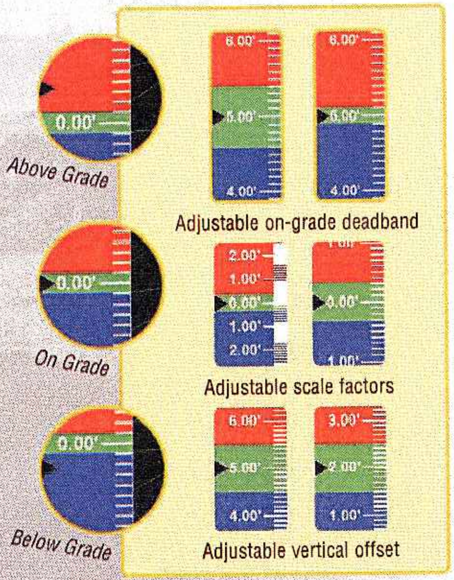
Earthmoving efficiency has never been higher! 3D control has never been easier!

- **Low initial investment / easy upgrade path to fully automatic, GPS+ system!**
- **Simple user interface**
- **New easy to use Grade Indicator for cut/fill operations!**
- **New Benchmark feature makes it easy to check position!**
- **New Machine Builder specific for Scrapers!**
- **Real time pictures of the jobsite allows an operator to mark clearing limits without the need of a surveyor, allowing you to start and finish ahead of schedule**

3D Made Easy

From its quick "follow-the-numbers" setup to its versatile, all-in-one display/control panel, 3Di-GPS+ is an operators dream.

- **Simple, color-coded "scrolling tape" cut/fill indication**
- **Adjust green on-grade deadband to match job tolerance**
- **Turn the grade knob to easily enter vertical offsets for large cuts or fills**
- **User adjustable scale factors**
- **Multiple job views—plan, profile, cross sections**



Topcon brings the future of machine control to you today with the affordable 3Di-GPS+ for bulk earthmoving and compacting.

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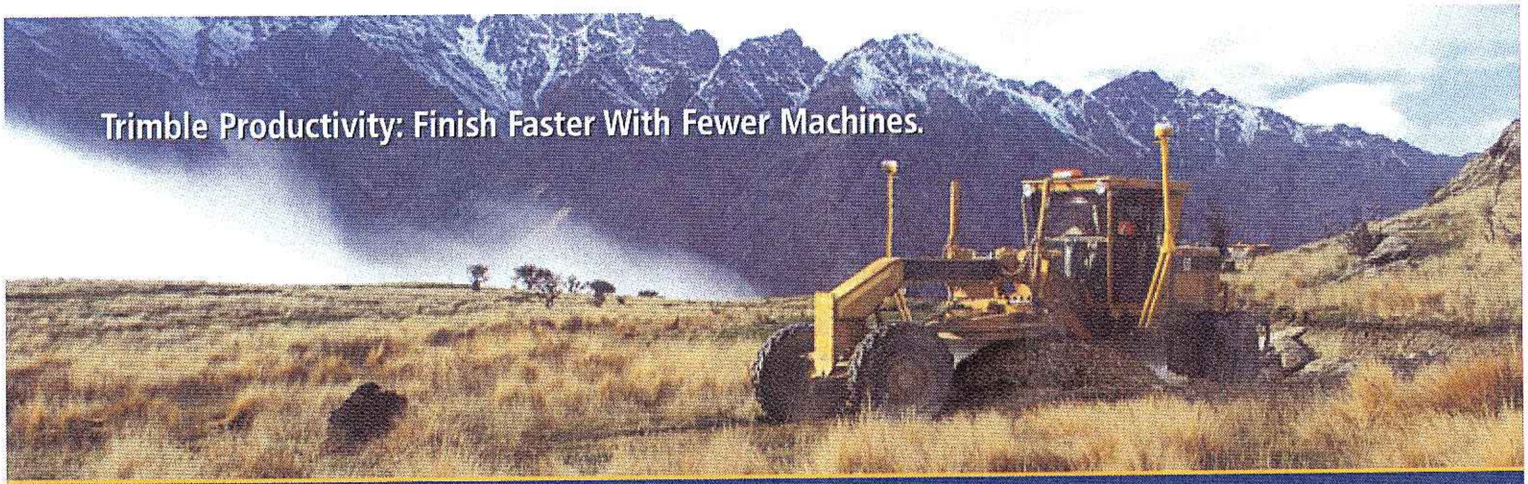


GRADE CONTROL SYSTEMS

Trimble

TAKING THE GUESSWORK OUT OF EARTHWORKS IMPROVES YOUR PRODUCTIVITY AND PROFITABILITY

Performing earthworks smarter, faster and more profitably is critical to success in today's highly competitive construction industry. Today, you need to be able to perform all parts of the job faster and more accurately than ever before. From estimating to completion, Trimble's next-generation Grade Control Systems are truly revolutionizing the total construction process.

Trimble offers you the most complete line of Grade Control Systems. From laser or sonic-based through to 3D, these rugged systems are easy to use, fully upgradeable and flexible enough to meet a wide range of application and jobsite requirements. Additionally, each system can be used as a full control system or as a guidance system.

Quite simply, there is no better solution to meet the challenges of today's schedules and budgets. Gain a competitive edge and streamline your operations with the next generation of grade control systems from Trimble, the company that invented grade control systems.

FULLY UPGRADEABLE

We've developed our next-generation Grade Control Systems to be fully upgradeable. Our systems can be installed on machines from any vendor and use the industry-standard Controller Area Network (CAN) to meet your needs today, as well as in the future. The CAN environment lets you easily add sensors and upgraded software to meet specific machine and application requirements. The upgradeable wiring harness is the "backbone" of the system and is designed for plug-and-play flexibility allowing you to upgrade the system from a single sensor control to a multi-functional GPS 3D solution. Additionally, you can very easily move the system from one machine to another.

EQUIP YOUR ENTIRE FLEET

Whether you are using excavators for mass excavation, dozers or scrapers for bulk earthworks, or motor graders for finished grading - the Trimble Grade Control Systems family has a solution to meet your needs. Our flexible and upgradeable GCS family can be installed on a wide range of machines—dozers, motor graders, scrapers, excavators and more. You can use a common platform across your entire fleet , while at the same time choose the best option for the machine and the application. Select from laser, GPS, total station, sonics, angle sensors and rotation sensors.

FASTER JOB CYCLES

Spend more time being productive and less time waiting for surveying and grade checking. With site plan and grade information displayed in the cab, operators can finish jobs faster with minimal supervision—even in dusty, windy or dark conditions.

FLEXIBLE

Perform a wide range of work, from mass excavation through to finished grade, on both large and small jobs. Trimble machine control products are designed to adapt to a variety of machines and jobsite applications.

LOWER OPERATING COSTS

Getting the job done right the first time eliminates rework. With design information at your fingertips, the need for stakes, hubs or stringlines is reduced. Through improved productivity, personnel and machine costs are also reduced. Plus, accurate grading helps you carefully control material usage.

RETURN ON INVESTMENT

Grade Control Systems quickly pay for themselves—often on the first project! Faster completion, less rework, less staking, less checking, lower costs, and improved material yields all add up to a stronger bottomline for your company.

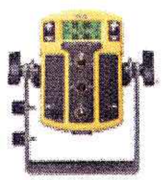
AFFORDABLE

TRIMBLE GCS300 GRADE CONTROL SYSTEM: SINGLE ELEVATION

The Trimble GCS300 Grade Control System is a single control system that uses the LR410 laser receiver to control the lift of the machine blade. Very easy to set up, learn and use, the system is designed primarily for use on dozers; however, it can also be set up on other machines. It is an ideal solution for smaller construction projects such as housing pads in smaller subdivisions and sports fields. The GCS300 is an excellent first investment. It provides a low cost of entry into Grade Control Systems along with the ability to easily upgrade as your needs grow.

TRIMBLE GCS300 APPLICATIONS:

- Small Housing Pads
- Small Building Sites
- Tennis Courts
- Finish Grading



TRIMBLE CB420 CONTROL BOX: THE CONTROL YOU NEED FOR IMPROVED PRODUCTIVITY!

Featuring dual LED grade displays, a graphical backlit LCD display, easy-to-operate switches and pushbuttons, the Trimble CB420 control box is upgradeable from the Trimble GCS300 through GCS600 Grade Control Systems.

When used with the GCS300 and GCS400, the software provides the operator with a range of powerful features specifically designed for lift and/or tilt control on dozers and motor graders. These include:

Pushbutton Benching for fast daily setups.

Cut/Fill Mode provides accurate numerical information as the operator cuts or fills to grade for jobsites with very tight tolerances.

Customizable Menus to configure the system speed, control bandwidths and control box parameters to adjust the system to changing material— gravel, rock, sand and treated bases for the best finish.

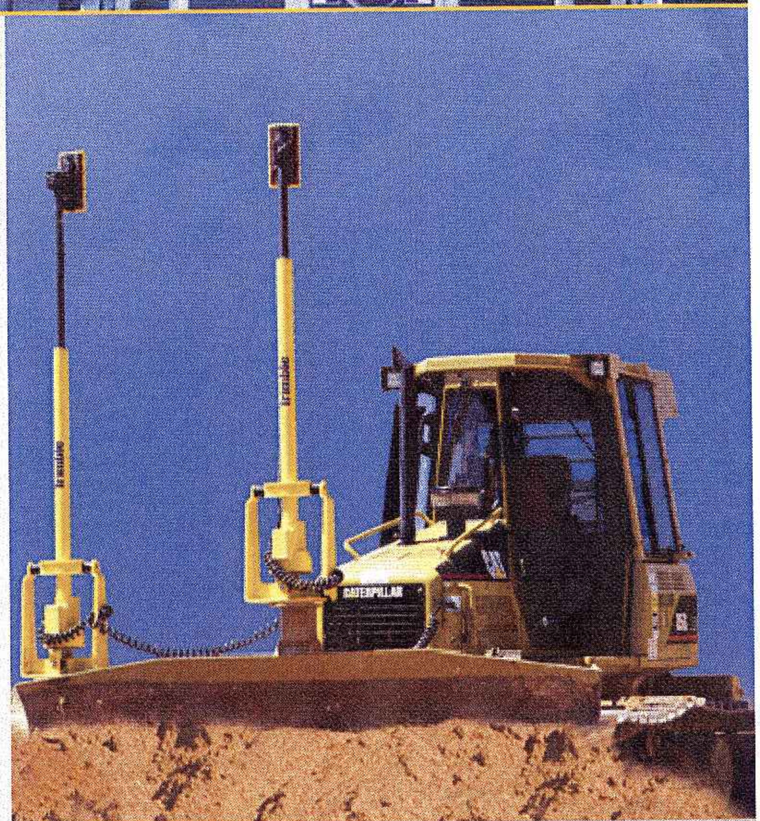
Selectable Accuracies lets the operator adjust the system for the best productivity on jobs with different accuracy specifications.

Elevation Offset provides the ability to enter an elevation offset at the push of a button so the operator can move from one elevation to the next level without resetting up the laser transmitter.

TRIMBLE GCS400 GRADE CONTROL SYSTEM:
DUAL ELEVATION, OR ELEVATION AND BLADE SLOPE CONTROL

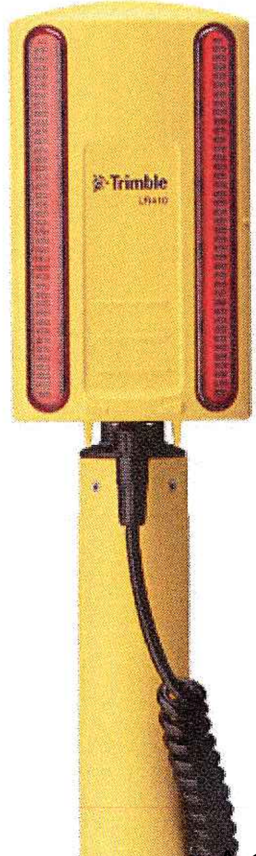
The Trimble GCS400 Grade Control System is a dual-control system that controls both the lift and tilt of the machine blade. This is done by connecting two LR410 laser receivers or one LR410 and an AS400 slope sensor to the system. Contractors can select to purchase the GCS400 or start with the GCS300 and later upgrade to the GCS400. The system is designed primarily for use on dozers; however, you can also use it on other machines. By controlling both functions, the GCS400 allows the operator to control the material more accurately, especially across larger jobsites.

Linked Mode:
For even greater speed and accuracy, the Trimble GCS400 system features a unique Linked Mode, which ties lift and tilt together and displays them as a single control. Using Linked Mode, the operator can easily, accurately and consistently benchmark and adjust the system.



TRIMBLE LR410 LASER RECEIVER

The Trimble LR410 laser receiver is fully linear and has smooth corrections the full length of the receiver. It is mounted to a mast on the blade and connected to the machine hydraulics to control lift to an accuracy of 3-6 millimeters (0.01 to 0.02 feet). In auto mode, the system uses the LR410 grade information to automatically move the blade up or down to the on grade position. The same LR410 laser receiver is used with each of the GCS300, GCS400 and GCS600 Grade Control Systems.

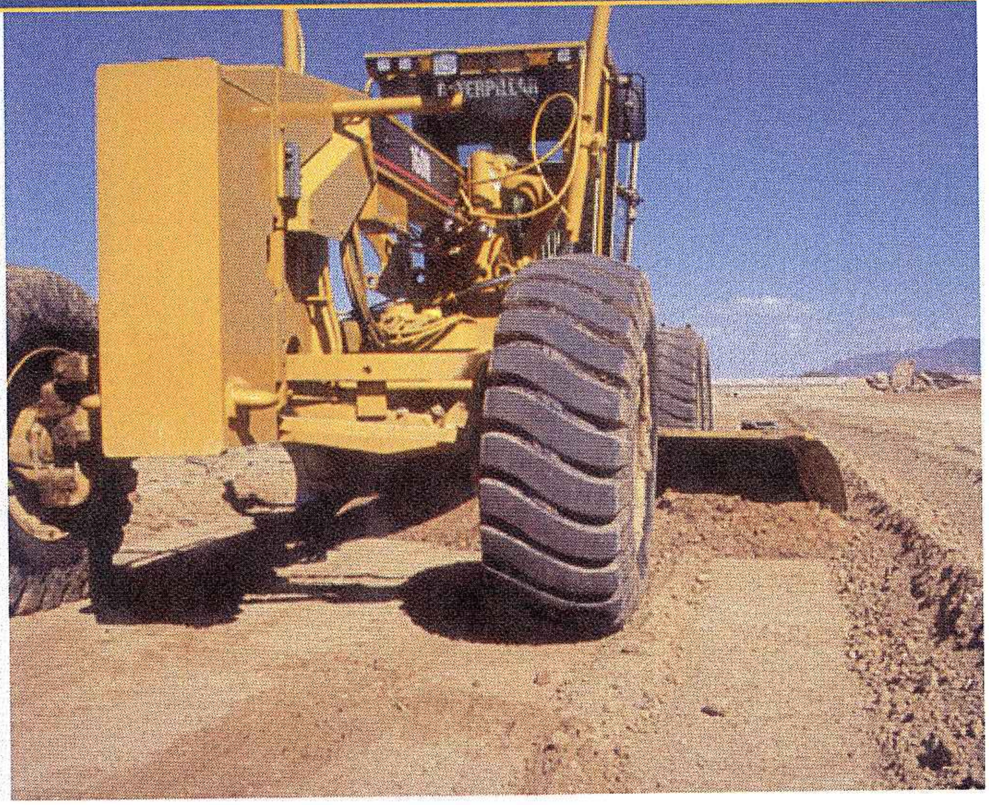


TRIMBLE GCS400 APPLICATIONS:

- Medium/Large Housing Pads
- Medium/Large Commercial Building Sites
- Road Construction
- Sports Fields
- Finish Grading
- Material Balancing
- Rough Grading

...FULLY UPGRADEABLE TO 3D:

FLEXIBLE



TRIMBLE GCS500 GRADE CONTROL SYSTEM: CROSS-SLOPE CONTROL

The Trimble GCS500 Grade Control System is a cross-slope control system designed to be used on motor graders for fine grading work. The system uses two AS400 angle sensors and an RS400 rotational sensor to calculate the cross-slope of the blade. The system allows the operator to select which side of the blade is controlled and switch sides on the return pass. Providing a high degree of flexibility, the AS400 has 100% slope capability making the system ideal for a wide range of applications, including cutting road slopes, ditches and embankments.

TRIMBLE GCS500 APPLICATIONS:

- Road Maintenance
- Road Construction
- Sports Fields
- Embankments
- Road Ditches

TRIMBLE CB420 CONTROL BOX: THE CONTROL YOU NEED FOR IMPROVED PRODUCTIVITY!

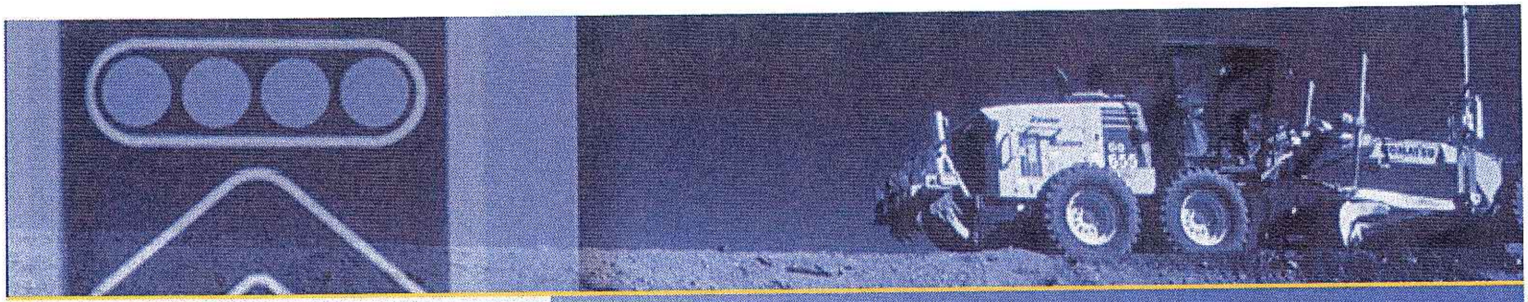
Featuring dual LED grade displays, a graphical backlit LCD display, easy-to-operate switches and pushbuttons, and the CB420 control box is upgradeable from the Trimble GCS300, through to the GCS600. Grade Control Systems. When used with the GCS500 and GCS600, the software provides the operator with a range of powerful features specifically designed for cross slope and blade elevation on motor graders. These include:

Steep Slope is no problem, the GCS500 and GCS600 systems allow operation up to 100%.

Swap Slope direction with the push of a button allowing the operator to make passes in both directions without readjusting numbers.

Adjustable Slope: Easily set or adjust slope for new construction or match slope for existing surfaces.

Laser Receiver: Elevation control maintains the blade elevation to the tightest tolerances.



TRIMBLE GCS600 APPLICATIONS:

- Small-to-Large Housing and Building Site Pads
- Road Construction
- Highway Construction and Maintenance
- Runways
- Embankments
- Road Ditches

TRIMBLE GCS600 GRADE CONTROL SYSTEM: CROSS-SLOPE AND ELEVATION CONTROL

The Trimble GCS600 Grade Control System is a highly flexible cross-slope and elevation control system designed to be used on motor graders for fine grading work. As with the GCS500, the GCS600 uses two AS400 angle sensors and an RS400 rotational sensor to calculate the cross-slope of either side of the blade; the GCS600 additionally uses an LR410 laser receiver or an ST300 sonic tracer to provide elevation control. Using the ST300, the system allows for stringline, previous pass, or curb and gutter tracing. Using one or two LR410 laser receivers, the system can be used for fine grading of plane surfaces. The GCS600 system is ideal for applications with tight tolerances and finished grade work.

Automatically Control the Blade quickly, smoothly and consistently when starting a pass, changing gears or operating at the optimum speed for finishing. Trimble's digital technology and "machine tuning" calibration process ensures the best performance for your application.

Trace curb and gutter, stringline or previous passes with the sonic tracer maintaining the desired elevation.

Customizable Menus configure the system speed, control bandwidths and control box parameters to adjust the system to changing material – gravel, rock, sand and treated bases – for the best finish.

Selectable Accuracies lets the operator adjust the system for the best productivity on jobs with different accuracy specifications.

TRIMBLE ST300 SONIC TRACER

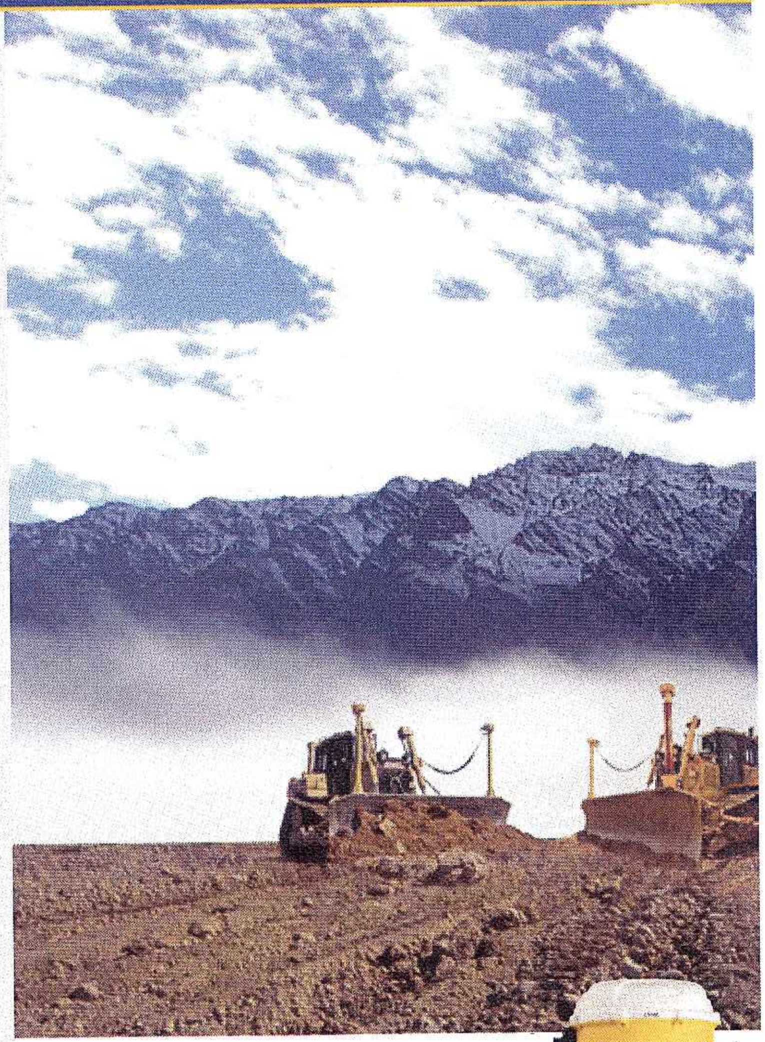
The Trimble ST300 sonic tracer mounted to the blade of the motor grader uses a physical reference such as curb and gutter, stringline, existing or previous pass as an elevation reference. Using a sonic tracer, the system can match curves and accurately get to grade in fewer passes. This reduces operator fatigue, saves material and reduces the need for grade checkers.

LR410 LASER RECEIVER

The Trimble GCS600 system uses the same Trimble LR410 laser receiver as the Trimble GCS300 and GCS400 systems.

...FULLY UPGRADEABLE TO 3D:

INNOVATIVE



TRIMBLE GCS900 GRADE CONTROL SYSTEM: 3D AUTOMATIC CONTROL

One of the most revolutionary changes in the way earthworks are performed has been the introduction of 3D systems originally by Trimble in 1995. The Trimble GCS900 Grade Control System represents the next-generation 3D system from the company that invented 3D grade control.

The GCS900 Grade Control System is a cutting-edge earthmoving grade control system that puts design surfaces, grades and alignments inside the cab. The system uses GPS, GPS and laser, or advanced total station technology to accurately position the blade or bucket in real time, significantly reducing material overages and dramatically improving the contractor's productivity and profitability.

The Trimble GCS900 is extremely flexible and can be used on excavators, dozers, motor graders and scrapers. You may purchase the GSC900 outright or as an upgrade from a Trimble GCS300 through GCS600 Grade Control System. And with its CAN-based design, the GCS900 can be easily moved from machine to machine, as needed.

GCS900: HOW DOES IT DO THAT?

The positioning sensors are used to compute exact position of the blade or bucket many times per second. The on-board computer uses this position information, and compares it to the design elevation to compute cut or fill to grade. This information displays on the SV170 screen— in plan, profile, cross-section view, or text. The cut/fill data is also used to drive the valves for automatic blade control.

Additionally, the cut/fill data is passed to the GCS900 lightbars, providing additional visual guidance to the operator for up/down to grade and right/left to a defined alignment. The light bars are separate from the display so that the operator can focus on safely operating the machine by having the light bar in the field of view.

The MS980 GPS Smart Antenna, the SR300 laser receiver and the ATS Construction Total Station all connect to the same cable harness. This allows the contractor to easily switch between sensors; the contractor has the flexibility to use their system for all phases of earthmoving---from mass excavation through to finished grading.

TRIMBLE GCS900 APPLICATIONS:

Large Residential and Commercial Sites	Golf Courses
Complex Designs	Major Road Projects

TRIMBLE MS980 SMART GPS ANTENNA

The MS980 Smart GPS Antenna is an integrated GPS receiver and antenna designed to provide maximum portability and flexibility. It has been specifically designed for machine installation in the harsh construction environment, and has extensive field-proven performance in mining and construction applications. The dual antenna configuration is unique to Trimble GPS-based Grade Control Systems. Using GPS, the exact position, very accurate cross slope, and heading of the blade or bucket are measured. This is especially advantageous for complex design surfaces such as super-elevation grading tasks. The MS980 can also be used in a single antenna configuration on scrapers and motor graders. Ideal for a wide range of machines, you can use the MS980 Smart GPS Antenna for GCS900 blade control to 20-30 millimeters (0.1 foot).

TRIMBLE SR300
LASER RECEIVER

The Trimble SR300 Laser Receiver is available as an option for use with a GPS-based GCS900 system to provide improved vertical accuracy. This laser receiver is ideal for GPS operations with tight tolerances. The SR300 features 360 degree receiving and works with a standard laser transmitter such as the Trimble GL700 series of grade lasers or the LL500 Laser Level. And with intelligent rejection of invalid laser beams the SR300 is designed to work on jobsites where other lasers maybe present. You can use the SR300 with the GL700 series of Grade Lasers for GCS900 blade control to 3-6 millimeters (0.01 to 0.02 feet).

TRIMBLE ATS
CONSTRUCTION TOTAL STATION

The Trimble ATS Construction Total Station includes a total station, a license-free radio link and an active target mounted to the motor grader blade. The ATS uses active target technology to reliably lock onto and track the target. This unique feature eliminates false lock-ons, ensuring that the correct machine is being tracked. Additionally it has built-in "search intelligence" to quickly search for and find the target when lock is lost. The high up-date rate, low latency and synchronized angles and distance measurements capabilities make it perfect for dynamic applications. Ideal for motor graders performing fine or finished grade, you can use the ATS Construction Total Station for GCS900 blade guidance to 2-5 millimeters (0.007 to 0.016 feet).

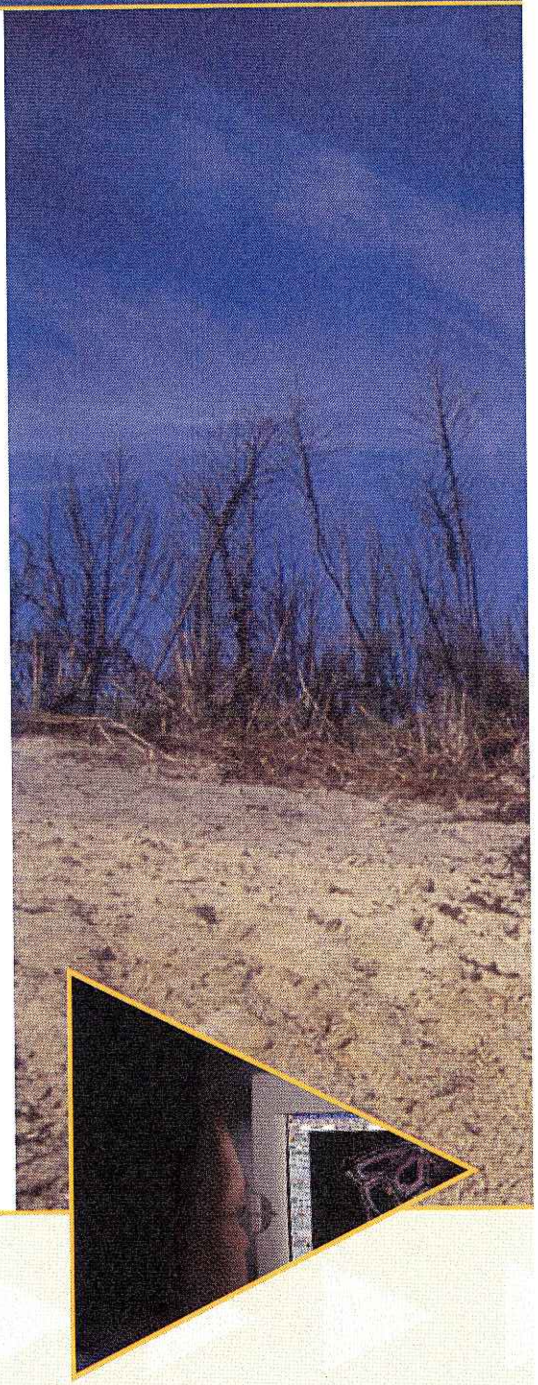
CLOSING THE GAP BETWEEN THE SITE AND OFFICE

Stakeless grade control systems represent one of the most significant changes in the way construction earthmoving is done. Contractors are able to realize many benefits in the grading phase. However, a tremendous amount of work is completed well before the heavy machines and crews show up at the site on the first day…site surveys, designs and engineering plans… and even once construction begins, there are typically regular change orders and revisions to the design and grade checking.

The key to fully realizing the benefits lies in the ability to move data seamlessly through the design and data preparation phases to the field for grading and site positioning.

Traditionally marked by manual process and frequent rework, the survey, design and construction phases have been treated as separate processes. This has resulted in significant rework and design changes which were slow to be communicated and implemented. With Trimble's Integrated Construction solutions, site positioning systems and grade control systems work together using the same digital 3D design data to provide efficiency gains, improved workflow and integrated data processes.

Design data is seamlessly imported from a wide range of leading design and CAD packages and prepared for use in the field by both grade control systems and site positioning systems. The Trimble Terramodel® Visualizer and SiteVision® Office construction data prep software allow you to visualize, check and analyze the site before you put a blade in the ground.



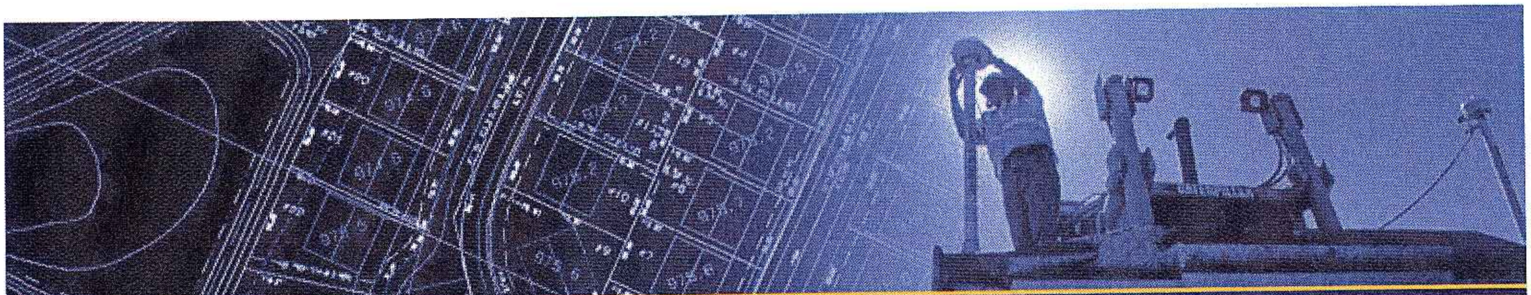
TWO-WAY DATA

TRIMBLE CONTINUES TO CLOSE THE GAP BETWEEN THE CONSTRUCTION SITE AND THE OFFICE WITH TWO-WAY DATA FLOW BETWEEN THE OFFICE AND FIELD.

Trimble's two-way data solution allows you to get updated design data to the field now – not later today, tomorrow or next week. Once design changes are made and approved, getting the information out to the machines is as easy. Two-way data improves turnaround time for design changes and problem solving, allowing contractors to realize productivity gains throughout all phases of the job.

Office

In the office, design changes and updates are made, and then imported into Trimble's data preparation software. The design data is prepared for use in the field by both Trimble's Grade Control Systems and Site Positioning Systems. 3D data visualization allows the engineer to quality check the design before uploading it to the machine.



Base On-site Trailer

At the jobsite trailer, the GPS radio network is connected to the Internet and receives the uploaded data. The base radio wirelessly sends it to machines using the Trimble GCS900 Grade Control System on the jobsite.

In-Cab

On the machine, the GCS900 in-cab computer receives the updated data and the site supervisor or design engineer communicates to the machine operator that a new design file is now available. The operator selects the new information and the design change is implemented in the field in minutes rather than in days.

Additionally the site office can ask yes or no questions that appear on the screen of the in-cab computer. With the press of a button the operator can respond allowing for efficient and safe communications between the office and operator.

Trimble

PRODUCTIVITY IS...

Design
software that helps you prepare data for use on the construction job site.

Grade
control that is faster, more accurate and minimizes rework.

Check
site measurement and stakeout for non surveyors on the job site.

Manage
your assets to improve efficiency, safety, and theft recovery.

Build
with precise laser and positioning for faster layout, leveling and alignment.

Productivity is the key to profitability...getting the job done faster with less machine time and personnel. Only one company can support your productivity with the broadest, deepest and most advanced construction solutions in the industry. Productivity is... Trimble.

YOUR LOCAL TRIMBLE OFFICE OR REPRESENTATIVE

NORTH AMERICA
Trimble
5475 Kellenburger Road
Dayton, Ohio 45424
U.S.A.
800-538-7800 (Toll Free)
+1-937-245-5154 Phone
+1-937-233-9441 Fax
www.trimble.com

EUROPE
Trimble GmbH
Am Prime Parc 11
65479 Raunheim
GERMANY
+49-6142-2100-0 Phone
+49-6142-2100-550 Fax

LATIN AMERICA
Trimble Navigation Limited
6505 Blue Lagoon Drive
Suite 120
Miami, FL 33126
U.S.A.
+1-305-263-9033 Phone
+1-305-263-8975 Fax

AFRICA & MIDDLE EAST
Trimble Export Middle-East
P.O. Box 17760,
Jebel Ali Free Zone,
Dubai, U.A.E.
+971-4-881-3005 Phone
+971-4-881-3007 Fax

ASIA-PACIFIC
Trimble Navigation Australia
PTY Limited
Level 1/120 Wickham Street
Fortitude Valley, QLD 4006
AUSTRALIA
+61-7-3216-0044 Phone
+61-7-3216-0088 Fax

CHINA
Trimble Beijing
Room 2805-07
Tengda Plaza
No. 168 Xiwai Street
Haidian District, Beijing
CHINA 100044
+86-10-8857-7575 Phone
+86-10-8857-7161 Fax
www.trimble.com.cn

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Appendix B

Mn/DOT Machine Control Special Provision

S-1 <u>(2011) MACHINE CONTROL</u>

This Contractor may make use emerging technologies of machine control of the grading equipment for this Project as described herein;

S-1.1 Mn/DOT will furnish the Contractor MicroStation 2D DWG background file and 3D DWG, or TTM files for (*the designer needs to specify which areas and types of work files will be made available for)*, upon Contract approval. These files are created in MicroStation (CADD software) and GEOPAK (Civil engineering software that runs with MicroStation). It shall be the Contractor's responsibility to do any necessary conversion of the provided files for the Contractor's selected grade control equipment.

S-1.2 Mn/DOT shall be given 72 hours prior to delivering any referenced MicroStation / GEOPAK data to the Contractor. Mn/DOT shall have three (3) working days to update any files after the Department approves any Contractor requested changes. Delays due to satellite reception of signals to operate this system will not result in any adjustment to the "Basis of Payment" for any construction items or to Contract time.

{use the following ONLY if there is GPS}

S-1.3 Systems that have been approved are:

Trimble GPS system (SiteVision Office)
TOPCON GPS system (3D-GPS+)

The Contractor may request approval of another system, but use will only be approved if the Survey Equipment-Machine Control System will work with the data in the form Mn/DOT currently produces.

{use the following ONLY if there is NO GPS and a robotic total station will be required}

S-1.4 The machine control equipment utilized on this Project shall utilize a robotic total station for control. The Contractor shall be required to provide a robotic total station for control for the State’s use during their inspection and record keeping for this Project. This may be the same unit as utilized for the Contractor’s machine control or an additional unit. The actual machine control may also require more than a single unit. The State’s usage shall be coordinated between the Engineer and the Contractor to minimize the number of units required.

S-1.5 Mn/DOT believes the electronic data it will provide is accurate, but does not guarantee it. The documents originally provided with the Contract remain the basis of the Contract, and the electronic data being provided is for informational use only in order to assist the Contractor with the use of machine control. Therefore, if use of this data causes an error, any costs to the Contractor in time or money to make corrections as a result of this error will not be considered "extra work".

S-1.6 The system equipment will remain the property of the Contractor.

S-1.7 All machine control work shall be considered incidental work for which no direct payment will be made.

Use the following if Machine Control will not be supported by Mn/DOT.

S-2 <u>(2011) MACHINE CONTROL</u>

This Contractor may make use emerging technologies of machine control of the grading equipment for this Project. Mn/DOT does not intend to share files or models with the Contractor.

S-3 <u>(2011) MACHINE CONTROL</u>

The Contractor is hereby advised that this Project is located in an area of the State that does not have adequate GPS reception to support the use of GPS technologies

Appendix C

Iowa Department of Transportation Developmental Specification for Global Positioning System Machine Control Grading

Iowa Department of Transportation

DEVELOPMENTAL SPECIFICATIONS

FOR

GLOBAL POSITIONING SYSTEM MACHINE CONTROL GRADING

Effective Date
January 18, 2006

THE STANDARD SPECIFICATIONS, SERIES 2001, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

01073.01 GENERAL.

This specification contains requirements for grading construction utilizing Global Positioning System (GPS) machine control grading techniques and shall be used in conjunction with Section 2526, of the Standard Specifications.

The Contractor shall utilize grading equipment controlled with a GPS machine control system in the construction of the roadway embankment. This requirement includes the finishing of the final subgrade surface.

A Value Engineering Incentive Proposal as described in Article 1105.15 of the Standard Specifications will not be considered for the removal of the GPS Machine Control requirements.

The plans indicate the areas of the project where roadway construction shall be accomplished with GPS machine control techniques and the areas that may be constructed with conventional construction survey techniques unless the Contractor chooses to build the required surface models to facilitate GPS machine control grading for those areas at no additional cost to the Contracting Authority.

The Contractor may use any type of GPS machine control equipment and systems that results in achieving the existing grading requirements. The Contractor shall convert the electronic data provided by the Contracting Authority into the format required by their system.

01073.02 EQUIPMENT.

All equipment required to accomplish GPS machine control grading shall be provided by the Contractor and shall be able to generate end results that meet the Standard Specifications.

01073.03 CONSTRUCTION

A. CONTRACTING AUTHORITY RESPONSIBILITIES.

1. The Engineer will set the initial horizontal and vertical control points in the field for the project as indicated in the contract documents.

2. The Engineer will provide the project specific localized coordinate system. The control information utilized in establishing the localized coordinate system, specifically the rotation, scaling, and translation can be obtain from the Engineer upon request.

3. The Contracting Authority will provide the data listed below in an electronic format with the proposal form.

No guarantee is made that the data systems used by the Engineer will be directly compatible with the systems used by the Contractor.

Article 1105.4 of the Standard Specifications shall apply with the additional clarification that information shown on the plans shall govern over the provided electronic data.

This information shall not be considered a representation of actual conditions to be encountered during construction. Furnishing this information does not relieve the Contractor from the responsibility of making an investigation of conditions to be encountered including, but not limited to site visits, and basing the bid on information obtained from these investigations, and the professional interpretations and judgment of the Contractor. The Contractor shall assume the risk of error if the information is used for any purposes for which the information was not intended.

Any assumptions the Contractor makes from this electronic information shall be at their risk.

The Contracting Authority will develop and provide electronic data to the Contractor for review as part of the contract documents. The Contractor shall independently ensure that the electronic data will function in their machine control grading system.

The files that are provided were originally created with the computer software applications MicroStation (CADD software) and GEOPAK (civil engineering software). The data files will be provided in the native formats and other software formats as described below. The Contractor shall perform necessary conversion of the files for their selected grade control equipment. The Contracting Authority will furnish the Contractor with the following electronic data files:

a. CAD Files:
   - GEOPAK TIN files representing the design surfaces.
   - GEOPAK GPK file containing all horizontal and vertical alignment information.
   - GEOPAK documentation file describing all of the chains and profiles.
   - MicroStation primary design file.
   - MicroStation cross section files.
   - MicroStation ROW data file.
   - MicroStation photogrammetry and text files.

b. Machine Control Surface Model Files:
   - ASCII format.
   - LandXML format.
   - Trimble Terramodel format.

Note: TIN files and surface model files of the proposed finish grade include the topsoil placement where required in the plans.

c. Alignment Data Files:
   - ASCII format.
   - LandXML format.
   - Trimble Terramodel format.

4. The Engineer may perform spot checks of the Contractor's machine control grading results, surveying calculations, records, field procedures, and actual staking. If the Engineer determines that the work is not being performed in a manner that will assure accurate results,

the Engineer may order the Contractor to redo such work, to the requirements of the contract documents, at no additional cost to the Contracting Authority.

B. CONTRACTOR'S RESPONSIBILITIES.

1. The Contractor shall provide the Engineer with a GPS rover for use during the duration of the contract. At the end of the contract, the GPS rover unit will be returned to the Contractor. This unit shall have the same capabilities as units utilized by the Contractor. The Contractor shall provide 8 hours of formal training on the Contractor's GPS machine control systems to the Engineer.
2. The Contractor shall review and apply the data provided by the Contracting Authority to perform GPS machine control grading.
3. The Contractor shall bear all costs, including but not limited to the cost of actual reconstruction of work, that may be incurred due to errors in application of GPS machine control grading techniques. Grade elevation errors and associated quantity adjustments resulting from the Contractor's activities shall be at no cost to the Contracting Authority.
4. The Contractor shall convert the electronic data provided by the Contracting Authority into a format compatible with their system.
5. The Contractor understands that any manipulation of the electronic data provided by the Contracting Authority shall be taken at their own risk.
6. The Contractor shall check and recalibrate, if necessary, their GPS machine control system at the beginning of each work day.
7. The Contractor shall meet the same accuracy requirements as conventional grading construction as detailed in the Standard Specifications.
8. The Contractor shall establish secondary control points at appropriate intervals and at locations along the length of the project and outside the project limits and/or where work is performed beyond the project limits as required at intervals not to exceed 1000 feet (300 m). The horizontal position of these points shall be determined by static GPS sessions or by traverse connection from the original baseline control points. The elevation of these control points shall be established using differential leveling from the project benchmarks, forming closed loops. A copy of all new control point information shall be provided to the Engineer prior to construction activities. The Contractor shall be responsible for all errors resulting from their efforts and shall correct deficiencies to the satisfaction of the Engineer and at no additional cost to the Contracting Authority.
9. The Contractor shall preserve all reference points and monuments that are established by the Engineer within the project limits. If the Contractor fails to preserve these items they shall be reestablished by the Contractor shall reestablished at no additional cost to the Contracting Authority.
10. The Contractor shall set hubs at the top of the finished subgrade at all hinge points on the cross section at 1000 foot (300 m) intervals on mainline and at least two cross sections on the side roads and ramps. These hubs shall be established using conventional survey methods for use by the Engineer to check the accuracy of the construction.
11. The Contractor shall provide controls points and conventional grade stakes at critical points such as, but not limited to, PC's, PT's, super elevation points, and other critical points required for the construction of drainage and roadway structures.
12. The Contractor shall provide the Engineer with electronic as-built construction data for the final roadway TIN surface models in ASCII format.
13. At least one week prior to the preconstruction conference, the Contractor shall submit to the Engineer for review a written machine control grading work plan which shall include the equipment type, control software manufacture and version, and the proposed location of the local GPS base station used for broadcasting differential correction data to rover units.

01073.04 METHOD OF MEASUREMENT

The bid item for GPS Machine Control Grading will be measured and paid for at the lump sum contract price.

01073.05 BASIS OF PAYMENT

The bid item for GPS Machine Control Grading will be paid for at the lump sum contract price. This payment shall be full compensation for all work associated with preparing the electronic data files for use in the Contractor's machine control system, the required system check and needed recalibration, training for the Engineer, and all other items described in the Contractors Responsibilities section of this Developmental Specification.

Delays due to satellite reception of signals to operate the GPS machine control system will not result in adjustment to the "Basis of Payment" for any construction items or be justification for granting contract extensions.

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Appendix D

CAES Check List for Post Design Modeling

District Check List

1. Is GPS coverage on the project:

- good – potential for machine control.
- fair – provide alternate models (minimal work to Mn/DOT) and note in special provisions that it's a potential problem.
- poor or none – list in special provisions that this project is not supported for machine control.

2. Is the existing ground information:

- DTM covers all construction area – potential for machine control.
- DTM only covers partial areas. – may be a candidate but should have exclusions listed in special provisions.
- No DTM information – list in special provisions that this project is not supported for machine control.

Note DTM can be either a TIN file from Photogrammetrics or district field generated. LIDAR only data is not desirable at this time as it does not have the required accuracy.

3. What is the dollar value of grading / amount of earth to be moved?

- More than $?? - Definite candidate as contractor will want to use it.
- Between -
- Less than $?? – Cost benefit to contract and Mn/DOT minimal. Can be listed as contractor option.

4. Who designed the project?

- Consultant – Need to review data on a case by case basis.
- In-house

5. Does the project have cross sections?

- Yes – still a candidate.
- No – difficult to make a non-pavement model.

6. Were the cross sections done using standard criteria? If not, what was used? Cite specifics.

7. What percentage of sections have hand modifications in the top of proposed finish grade?

- 0-5% Average time to create model.
- 5-10% Time to create model increases.
- Above 10% Time to create model increases substantially.

8. What percentage of sections have hand modifications in the subsurface?

- 0-5% Average time to create model.
- 5-10% Time to create model increases.
- Above 10% Time to create model increases substantially.

9. Type of projects/part of projects to be done in GEOPAK Site

- All Ponds, parking lots, trails non adjacent to highways, requires minimal time to create a models.

10. Currently no machine control being done for parts of a projects with grading around approach treatments around Bridges and excavation around walls. These should be listed as exceptions in the special provisions.

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Appendix E

Mn/DOT Standard Electronic Design File Disclaimer

Minnesota Department of Transportation

1. Disclaimer and Limitation of Use

The Minnesota Department of Transportation makes no representation or warranties, express or implied, with respect to the use of the data as described below, regardless of its format or the means of its transmission. There is no guarantee or representation to the user as to the accuracy, currency, suitability, or reliability of this data for any purpose. The user accepts the data "as is", and assumes all risks associated with its use. The user agrees not to transmit this data or provide access to it or any part of it to another party unless the user shall first have obtained the express, written permission of the Minnesota Department of Transportation. The Minnesota Department of Transportation assumes no responsibility for actual or consequential damage incurred as a result of any user's reliance on this data.

2. Description of Data:

SP 2774-07, SP 1004-24, and SP 1004-26 electronic files – alignments, geometrics, etc.

3. Agreement of User

I agree to use the data in accordance with the terms as described above.

Name (print) Title

Company Name Date

Signature

4. Instructions to User

Complete and sign this form, and return it to: Mn/DOT Metro, Fax No. 651-582-1368.

Appendix F

Machine Control Survey for Contractors

Alliant Engineering, Inc.

Machine Control Survey For Contractors

Alliant Engineering is completing a project, at the request of the Minnesota Department of Transportation, to conduct research and prepare recommendations for the use of Machine Control technologies throughout the state.

Several stakeholders have been identified in the use and implementation of Machine Control technologies. These include contractors, design and construction engineering staff, equipment manufacturers and distributors, as well as professional trade organizations.

As part of this project, your company/organization has been selected to provide input for the recommendations. As such, Alliant is requesting that you complete and return the following survey. The goal of the project team is to meet as many responders to this survey in person to discuss the results more in depth.

Please be aware that identifiable information will not be included in the final report. All of the information contained within Section 1.0 of the survey will only be available to the Project Team staff and will not be made available to the public without your consent.

If you have any questions about the survey or project, please feel free to contact Tom Jensen at Alliant Engineering. He can be reached at (612) 767-9345 or at tjensen@alliant-inc.com.

Your response would be appreciated before Wednesday, December 13th, 2006.

1.0 Contact Information

Company/Organization Name

Contact Person's Name

Contact Person's Title

Address

City

State -Select-

Zip Code

Phone Number

Email

Web Site URL

2.0 Machine Control Experience

Do you currently use any type of Machine Control system in the field?

-Select-

3.0 Currently Users of Machine Control

(Only answer question in this section if your company currently uses machine control. Otherwise, skip to Section 4)

What year did your company begin using Machine Control systems?

-Select-

What brands of Machine Control equipment is currently in use at your company?
(check all that apply)

- ☐ Trimble
- ☐ Leica
- ☐ TopCon
- ☐ Other -Please provide brand-

If you checked more than one brand, what led your company to invest in more than one brand?

What brands of Machine Control equipment has your company used in the past, but are no longer in use?
(check all that apply)

- ☐ Trimble
- ☐ Other -Please provide brand-
- ☐ TopCon
- ☐ No Others
- ☐ Leica

(Only answer this question if you checked any boxes in the previous question)
What factored into your decision to quit using any of the brands indicated above?

What is the name of your local equipment vendor?

How was your Machine Control equipment obtained?

-Select-

Why did you choose to obtain you equipment in this way?

What is the range of your company's investment in Machine Control equipment?

-Select-

How many hours, in a typical year, do you allocate for ongoing training for Machine Control equipment and software?

How many projects in the most recent construction season did your company use machine control?

projects out of total projects

What kinds of projects does your company use Machine Control systems on?
(check all that apply)

- ☐ Site Grading
- ☐ Roadway Embankments
- ☐ Pond Grading
- ☐ Granular Placement
- ☐ Curbing
- ☐ Bituminous Paving
- ☐ Concrete Paving
- ☐ Pipe Construction
- ☐ Bridge Construction

What factors determine whether your company will use Machine Control on a project?
(check all that apply)

- ☐ Type of Work
- ☐ Physical Size of Project
- ☐ By Specification
- ☐ Dollar Value of Project
- ☐ Project Schedule
- ☐ Availability of Electronic Information
- ☐ Operator Qualifications

Please list the number of each machine outfitted with Machine Control equipment?

- Bull Dozer
- Motor Grader
- Backhoe
- Curbing Machine
- Paving Machine

What is the single biggest benefit your company attributes to the use of Machine Control systems?

What is the single biggest obstacle your company struggles with in the use of Machine Control systems?

Does your company prepare the 3D models necessary for Machine Control in house?

-Select-

(Only answer this question if you answered yes to previous question)
How many staff members work to create the necessary 3D models?

-Select-

Please estimate the number or hours needed to prepare models?
(i.e. hours/pond, hours/1000 feet of roadway, etc.)

What software application do you use with your Machine Control system?
(check all that apply)

- ☐ Terramodel
- ☐ AutoCAD/LDD
- ☐ Microstation/Geopak
- ☐ Agtek
- ☐ AutoCAD/Civil 3D
- ☐ Microstation/Inroads
- ☐ Other -Please provide name-

What quality control procedures are used to ensure 3D model accuracy?

(Only answer this question if you answered no to previous question)
Who is typically responsible for 3D model preparation?

Designer or Engineer   -Please provide 3rd Party Name-

In a perfect world, who would your company prefer to create the 3D models?

-Select-

In your opinion, who is responsible for any errors and/or omissions in the 3D model?

-Select-

4.0 Not Currently Users of Machine Control

(Only answer questions in this section if you answered no to the question in Section 2)

What are the biggest contributing factors that have kept your company from adding Machine Control equipment to the fleet?

(check all that apply)

- ☐ Initial Cost of Equipment
- ☐ Electronic Data Unavailable
- ☐ Technology changing too rapidly
- ☐ Lack of Vendor Support
- ☐ Unsure of Equipment to Select
- ☐ Cost of Model Creation
- ☐ Signal Reception Concerns
- ☐ Employee Resistance

Does your company currently have plans to add Machine Control equipment to the fleet?

○ Yes ○ No

(Only applies if answered Yes to previous question)

When does your company expect to make the addition of Machine Control equipment?

-Select-

5.0 All Responders

In your opinion, how should agencies handle bidding for projects using Machine Control?

- ☐ Specific Machine Control Pay Item
- ☐ Incorporated into Mobilization Pay Item
- ☐ Incorporated into Grading Pay Items
- ☐ N/A - Machine Control Saves Time & Money
- ☐ Other -Please Describe-

What are the advantages of using Machine Control?

(check all that apply)

- ☐ Time Savings
- ☐ Cost Savings
- ☐ Greater Quality of Finished Product
- ☐ Flexibility
- ☐ Decreased Operator Learning Curve
- ☐ Other -Please Describe-

What are the disadvantages of using Machine Control?

(check all that apply)

- ☐ Initial Investment
- ☐ Training
- ☐ Technology changing too rapidly
- ☐ Lesser Quality of Finished Product
- ☐ Unsure of Equipment to Select
- ☐ Liability
- ☐ Other -Please Describe-

In your opinion, what could agencies do to better facilitate the use of Machine Control of projects?

Please express any concerns you might have about increasing the use of Machine Control in Minnesota

Please feel free to enter any other comments regarding Machine Control

Thank you for taking the time to complete the Machine Control Survey for Contractors.

233 Park Avenue South, Suite 300, Minneapolis Minnesota 55415-1108
Phone 612.758.3080, Fax 612.758.3099

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Appendix G

Machine Control Survey for Engineering Staff

Alliant Engineering, Inc.

Machine Control Survey For Engineering Staff

Alliant Engineering is completing a project, at the request of the Minnesota Department of Transportation, to conduct research and prepare recommendations for the use of Machine Control technologies throughout the state.

Several stakeholders have been identified in the use and implementation of Machine Control technologies. These include contractors, design and construction engineering staff, equipment manufacturers and distributors, as well as professional trade organizations.

As part of this project, you have been selected to provide input for the recommendations. As such, Alliant is requesting that you complete and return the following survey. The goal of the project team is to meet as many responders to this survey in person to discuss the results more in depth.

Please be aware that identifiable information will not be included in the final report. All of the information contained within Section 1.0 of the survey will only be available to the Project Team staff and will not be made available to the public without your consent.

If you have any questions about the survey or project, please feel free to contact Tom Jensen at Alliant Engineering. He can be reached at (612) 767-9345 or at tjensen@alliant-inc.com.

Your response would be appreciated before Wednesday, December 13th, 2006.

1.0 Contact Information

Organization Name

Contact Person's Name

Contact Person's Title

Address

City

State
-Select-

Zip Code

Phone Number

Email

Web Site URL

2.0 Machine Control Experience

Have you personally been involved with any type of Machine Control projects?

-Select-

3.0 Currently Users of Machine Control

(Only answer question in this section if your district or agency currently uses machine control)

What year did your district or agency begin using Machine Control systems?

-Select-

What kinds of projects does your district or agency use Machine Control systems on?
(check all that apply)

- ☐ Site Grading
- ☐ Curbing
- ☐ Pipe Construction
- ☐ Roadway Embankments
- ☐ Bituminous Paving
- ☐ Bridge Construction
- ☐ Pond Grading
- ☐ Concrete Paving
- ☐ Granular Placement

What factors determine whether your district or agency will use Machine Control on a project?
(check all that apply)

- ☐ Type of Work
- ☐ Dollar Value of Project
- ☐ Availability of Electronic Information
- ☐ Physical Size of Project
- ☐ Project Schedule
- ☐ Operator Qualifications
- ☐ Operational Testing

How many projects in the most recent construction season did your district or agency use machine control?

______ projects out of ______ total projects

Please list the projects that have used Machine Control in your district or agency?

Why were the projects listed above chosen for the use of Machine Control equipment?

Who decides which projects are eligible for the use of Machine Control equipment?

What is the single biggest benefit your district or agency attributes to the use of Machine Control systems?

What is the single biggest obstacle your district or agency struggles with in the use of Machine Control systems?

Is the process for administering a Machine Control project different from a non Machine Control project?

-Select- -Please Describe-

Does your district or agency prepare the 3D models necessary for Machine Control in house?

-Select-

(Only answer this question if you answered yes to previous question)
How many staff members work to create the necessary 3D models?

-Select-

Please estimate the number or hours needed to prepare models?
(i.e. hours/pond, hours/1000 feet of roadway, etc.)

What software application do you use with your Machine Control system?
(check all that apply)

- Terramodel
- AutoCAD/LDD
- Microstation/Geopak
- Agtek
- AutoCAD/Civil 3D
- Microstation/Inroads
- Other -Please provide name-

What quality control procedures are used to ensure 3D model accuracy?

(Only answer this question if you answered no to previous question)
Who is typically responsible for 3D model preparation?

Designer or Engineer -Please provide 3rd Party Name-

233 Park Avenue South, Suite 300, Minneapolis Minnesota 55415-1108
Phone 612.758.3080, Fax 612.758.3099

In a perfect world, who would your district or agency prefer to create the 3D models?

-Select-

In your opinion, who is responsible for any errors and/or omissions in the 3D model?

-Select-

4.0 Not Currently Users of Machine Control

(Only answer question in this section if your district or agency does not currently use machine control)

What are the biggest contributing factors that have kept your district or agency from using Machine Control equipment on projects?
(check all that apply)

- ☐ Initial Cost of Equipment
- ☐ Electronic Data Unavailable
- ☐ Technology changing too rapidly
- ☐ Lack of Vendor Support
- ☐ Unsure of Equipment to Select
- ☐ Cost of Model Creation
- ☐ Signal Reception Concerns
- ☐ Employee Resistance

Does your district or agency currently have plans to add Machine Control equipment to the fleet?

○ Yes ○ No

(Only applies if answered Yes to previous question)
When does your district or agency expect to make use of Machine Control equipment?

-Select-

5.0 All Responders

In your opinion, how should districts or agencies handle bidding for projects using Machine Control?

- ☐ Specific Machine Control Pay Item
- ☐ Incorporated into Mobilization Pay Item
- ☐ Incorporated into Grading Pay Items
- ☐ N/A - Machine Control Saves Time & Money
- ☐ Other -Please Describe-

What are the advantages of using Machine Control?
(check all that apply)

- ☐ Time Savings
- ☐ Cost Savings
- ☐ Greater Quality of Finished Product
- ☐ Flexibility
- ☐ Decreased Operator Learning Curve
- ☐ Other -Please Describe-

What are the disadvantages of using Machine Control?
(check all that apply)

- ☐ Initial Investment
- ☐ Training
- ☐ Technology changing too rapidly
- ☐ Lesser Quality of Finished Product
- ☐ Unsure of Equipment to Select
- ☐ Liability
- ☐ Other -Please Describe-

In your opinion, what could districts or agencies do to better facilitate the use of Machine Control of projects?

Please express any concerns you might have about increasing the use of Machine Control in Minnesota

Please feel free to enter any other comments regarding Machine Control

Thank you for taking the time to complete the Machine Control Survey for Engineering Staff.

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