Automated Machine Guidance

A. Concept

Automated machine guidance (AMG) for grading is a process in which grading equipment, such as a motor grader or dozer, utilizes onboard computers and positioning systems to provide horizontal and vertical guidance to the equipment. Automated machine guidance for grading reduces the need for grade stakes and improves the safety of construction personnel.

In addition to automated machine guidance for grading, paving and milling equipment has the ability to utilize “stringless” control to guide the machine both vertically and horizontally. Stringless milling and paving operations eliminate the time of setting and removing the string line along a project. In addition, stringless technology results in fewer traffic disruptions as traffic does not need to be routed around the string line. These benefits result in increased safety for construction personnel and the traveling public.

B. Deliverables and Computer Inputs

Contractors should use the same 3D engineered model for all aspects of construction. This ensures consistency between the grading, trimming, and paving surfaces. For example, if the contractor were to use a grading file that has been manipulated, the unmodified paving surface may not match the ground elevations after grading. Using the same 3D model for all AMG activities reduces the risk of surface elevations that do not match.

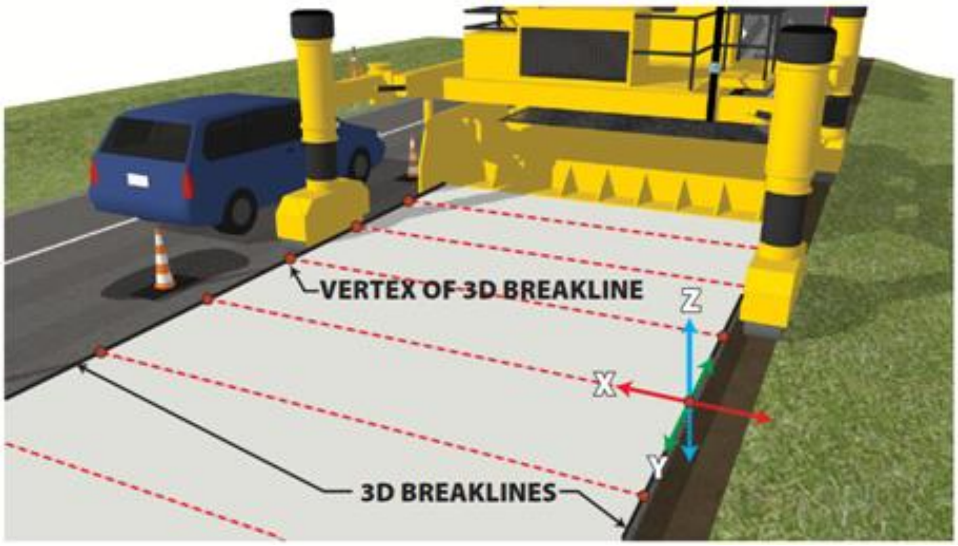
As with all AMG-equipped machinery, the contractor will need to upload the 3D engineered model into the AMG system. AMG systems are only capable of accepting specific file types. Rather than providing 3D file types to contractors in specific formats that are compatible with individual pieces of equipment, it is recommended the designer provide files in generic formats as shown in the table below. LandXML and DXF file formats are generic formats that are compatible with a wide range of CAD and survey software programs.

Information Contained Within File	Recommended File Format
Alignment	Land XML
Surfaces	Land XML
3D Line Strings	DXF

Providing files in a generic format saves time for the designer since they do not need to provide the data in multiple formats. The generic file types will need to be converted by the contractor into a compatible file type prior to uploading it to their system. A fully designed 3D engineered model for AMG grading contains the existing grading surface, proposed grading surface, and proposed features. It is able to guide grading machines and excavators when they are referenced to control points set up on or near the project site.

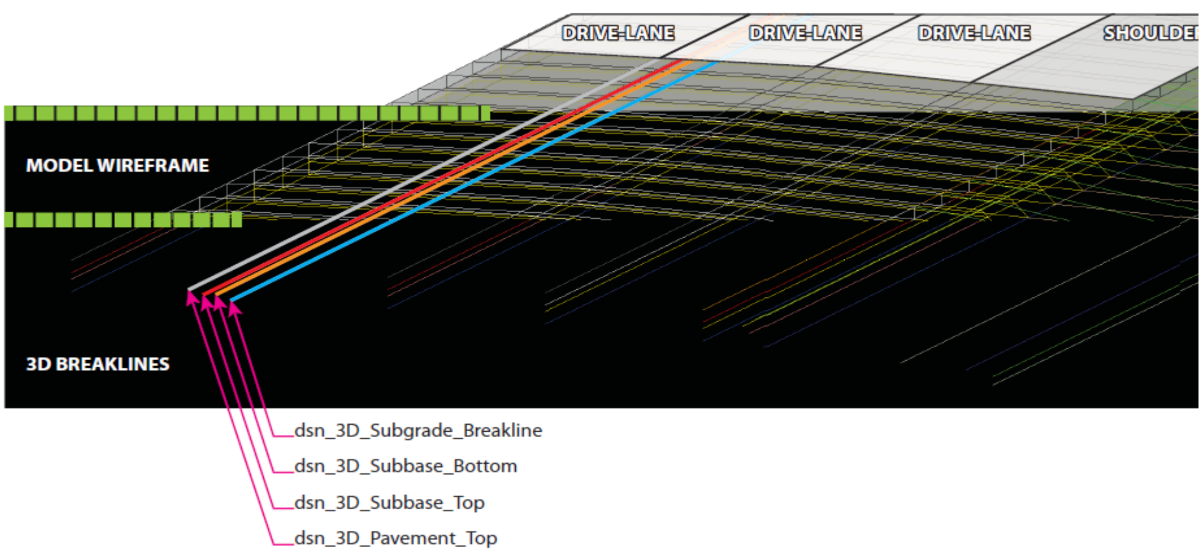
Stringless paving uses different inputs compared to AMG grading and milling. Design data for stringless paving must be derived from the 3D engineered model, including the pavement plan, profile, and geometrics. The data that will control the paving machine is referred to as 3D break lines. 3D break lines are lines in a file that reflect a distinct change in the surface type or slope. 3D break lines contain X, Y, and Z coordinate information that can be referenced by AMG equipment. Figure 5H-1.01 shows how a stringless paving machine uses 3D break lines for horizontal and vertical control.

Figure 5H-1.01: Pavement Edge Lines and Break Lines



It is recommended that the engineer perform data conversion to transform the CAD coordinate data contained within the 3D engineered model into 3D line strings and curve equations representing the pavement edges and interior break lines. A typical CAD file contains a significant amount of information that is not actually necessary for paver guidance. Therefore, part of the transformation process is to extract the 3D break lines that represent the pavement edge lines, significantly reducing the amount of information the onboard stringless computer must interpret. Figure 5H-1.02 shows a cross-section of 3D break lines in a CAD file for horizontal and vertical control.

Figure 5H-1.02: 3D Break Lines Contained within the 3D Engineered Model



The files that are available for AMG also need to be designed at the correct interval. The interval refers to the lateral distance between X, Y, and Z coordinates that make up a 3D surface. The interval can also be used interchangeably with the term “template drop”. For final design, a maximum interval of 5 feet should be used to minimize the opportunity for irregularities between template drops. The shorter interval improves the accuracy of the model and reduces the potential for errors within the project limits. The preliminary design stage may use 25 foot intervals since the project would not be constructed from the model and accuracy requirements are not as stringent.

C. What to Include/Not Include in 3D Engineered Models

Through several years of successful 3D implementation, the Iowa DOT determined that it is not necessary for engineers to spend a great deal of time merging side-road models and other features into a single “master” model. Contractors will take whatever information they can get and have the ability to merge information on their own to match specific staging operations. Additionally, designers should not expend effort trimming 3D models into more manageable sizes. Most software programs that contractors utilize have the capability to trim files into their desired area.

The 3D engineered model should contain the appropriate beginning and ending of transitions for key geometric features. Beginnings and endings of vertical and horizontal curves should be included in the model. Intersection radii and intersection grading should also be modeled to clearly communicate the drainage patterns and design intent of the project. All unique grading areas such as berms, detention ponds, and ditches should be included in the model for AMG construction.

The 3D engineered model that is provided to the contractor should not contain gaps or void spaces within the model boundaries. Traditional design methods have gapped difficult areas such as bridge berms and intersection radii. This required contractors to spend time and money to fill in the gapped areas and created difficulties for construction personnel in interpreting design intent. Misinterpretation by construction personnel can lead to errors and costly rework. Agencies need to strike a balance between the level of model completeness and how much effort is required by the designer. For example, it is often too labor-intensive to model ADA compliant pedestrian ramps when contractors will likely not be using the 3D model to construct them. In this type of situation, the engineer needs to decide whether or not to model intricate details.

D. Component Naming

Although CAD standards are helpful for consistency purposes, agencies should not let the lack of CAD standards prevent the use of 3D design and construction. Designers must clearly communicate what each layer and line type represents within the model to prevent confusion during AMG and stringless paving. Clear and intuitive naming of each line and layer within the model is recommended.

E. Bid Letting

All 3D files that will be used by the contractor for construction purposes should be provided prior to the letting. This approach levels the playing field for all potential bidders and avoids an unfair advantage for contractors who knew the files would be available after the bid letting. All deliverables that are provided to contractors should be well documented for each project.

The paper plan set and specifications should be considered the “signed and sealed” data. The electronic 3D files are provided for information only and are not signed by a professional engineer. The contractor is responsible for ensuring the project is constructed according to the “signed and sealed” plan set. A disclaimer statement should also be included in the paper plan set that indicates the paper copy on file with the agency is the official copy and the contractors are responsible for constructing the project to those plans.

The use of AMG should be considered incidental to construction and be at the option of the contractor. If approved by the Engineer, the use of stringless paving should be considered incidental to construction. No separate payment should be made for the use of AMG and stringless paving as the reduction in survey needs and improved operational efficiency offset the added costs.

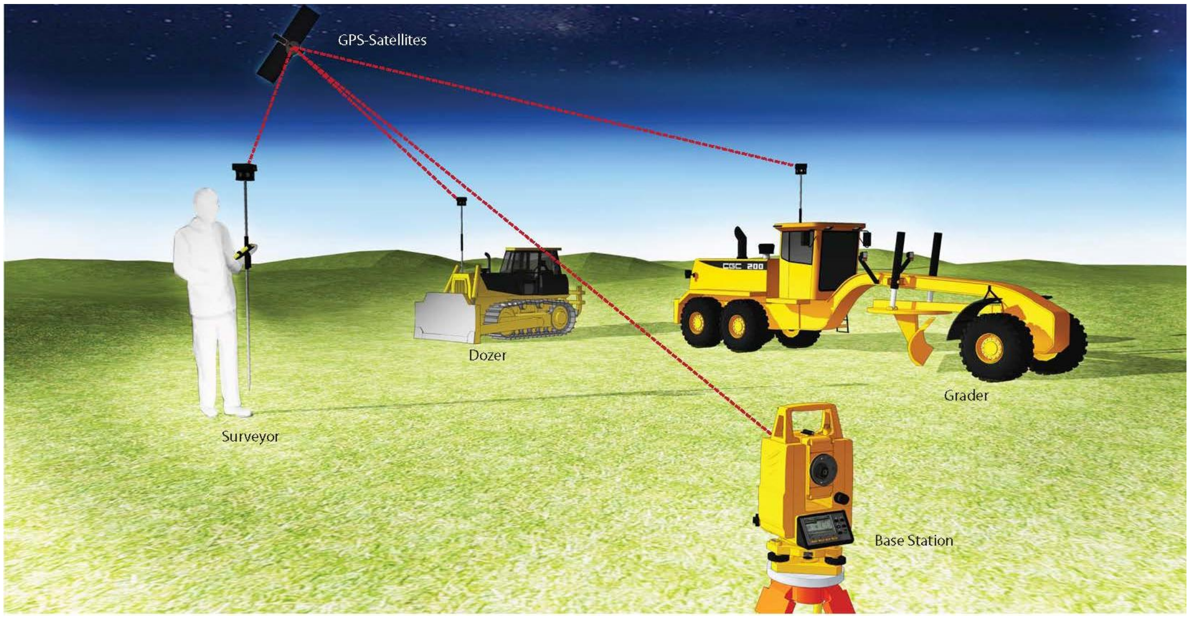
F. Construction Staking Requirements

Traditional construction staking requirements can be reduced for machine guidance in an effort to increase cost savings. Reducing the requirements for construction staking also improves safety for surveyors traversing the construction site while in close proximity to large equipment. Construction staking, although limited, is still required at reduced intervals to ensure the 3D engineered model and construction equipment is giving the correct layout and elevations. This provides another layer of quality control for a more accurate finished product.

G. Survey Control for AMG Grading

A survey base station or control network needs to be set up near the site prior to any machine control use. Machine control grading activities including dozers, excavators, and motor graders typically use GPS for AMG. The AMG system needs to be able to reference a known X, Y, Z coordinate location through a GPS base station, such as a portable GPS unit on site. The GPS base station transmits corrections to the GPS receiver on the associated AMG equipment.

Figure 5H-1.03: AMG Utilizes Satellite Positioning and Onboard Computers to Guide Equipment



For proper use of AMG technology, accurate survey control is a necessity. The survey control should contain at least one "monument" survey point that is set by a licensed surveyor and remains undisturbed throughout construction. Some states that have successfully implemented AMG technology rely on a monumented survey point that has specific X, Y, Z coordinate data that are used by the surveyor, contractor, and inspection personnel. The benefit of all parties using the same control point is an added layer of quality assurance that construction is meeting the designed elevations.

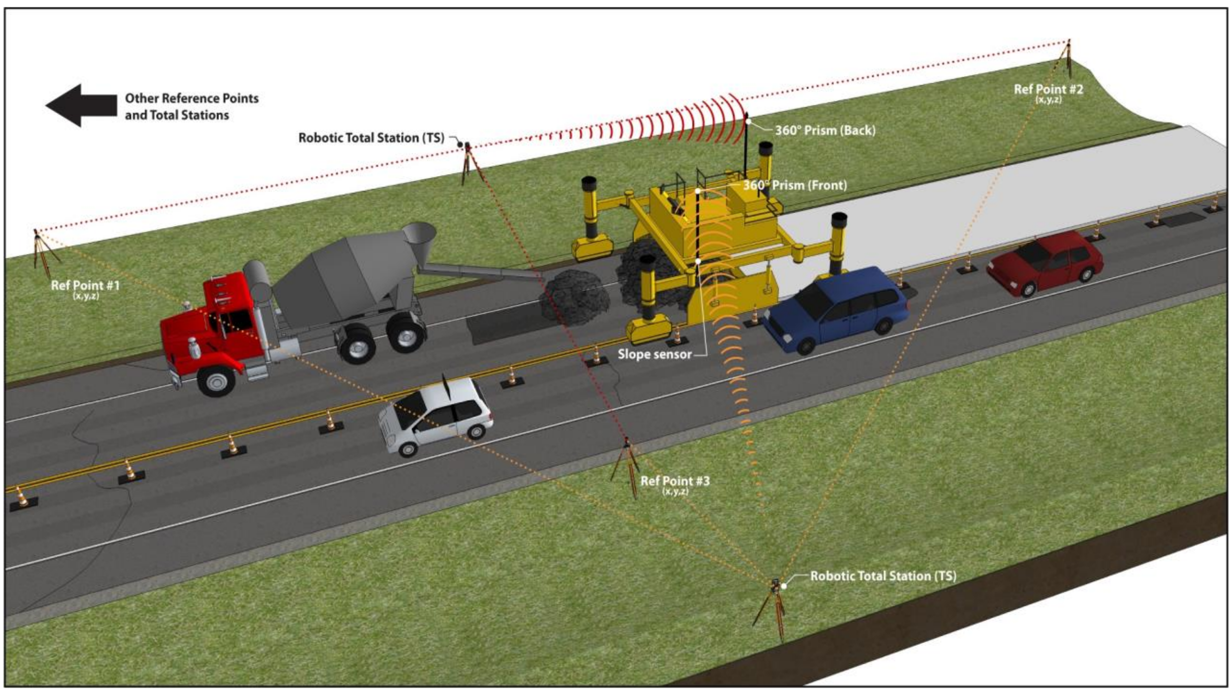
H. Survey Control for Stringless Operations

Survey and machine control for stringless operations is different than the GPS base stations used for grading operations. Stringless paving and milling machines typically use total stations or laser augmented GPS for machine control purposes because paving and milling operations require tighter tolerances than what is necessary for grading purposes. As with machine control grading, stringless guidance systems need to know their location in space (X, Y, Z coordinate). For total stations, survey control points are set by a surveyor. Typically, control points are set along the project corridor at approximately 250 foot intervals. Control points for stringless paving should be established from accurate field surveying and tied to known benchmarks. These control points should be positioned so they are out of the way of any operations and will not be disturbed by the public, but will allow instruments for machine control to see at least three control points at all times. Figure 5H-1.04 shows how stringless paving machines use robotic total stations for horizontal and vertical control.

When stringless paving is utilized, location and elevation of the finished slab should be verified against grade check hubs for the first 100 feet of each days run and at critical locations, such as intakes and through intersections where grades may be flat. The Engineer may waive these requirements if experience has shown compliance with the design elevations.

After each modification to the paving machine, verify the paving equipment is calibrated per the manufacturer's recommendations.

Figure 5H-1.04: Typical Layout of Control Points on Stringless Paving Applications



I. Quality Assurance

Conventional 2D methods of construction required inspectors to rely upon grade stakes, pavement hubs, and 2D paper plan sheets to ensure that grading and paving operations were constructed according to the intended design. However, with the proposed grading surface within the 3D engineered model, inspectors should traverse the site and take random spot checks with GPS rovers to make sure the site is being graded properly. Similarly, the inspector should spot-check elevations behind the paving machine to ensure the paving equipment is set up and working properly. Inspectors should be working from the same up-to-date files the contractor is using to eliminate the possibility of irregularities or discrepancies between different 3D files.

It is recommended that agencies require the contractor to provide GPS equipment for use by inspection personnel during grading construction. One benefit of this is the cost of the equipment does not need to be budgeted by the contracting agency. Another benefit is that any potential discrepancy caused by different equipment manufacturers is eliminated. If the contractor provides the rover, all parties are working from the same files and equipment.

J. References

Reeder, G. and G. Nelson. 2015. *Implementation Manual - 3D Engineered Models for Highway Construction: The Iowa Experience*. National Concrete Pavement Technology Center, Ames, IA.