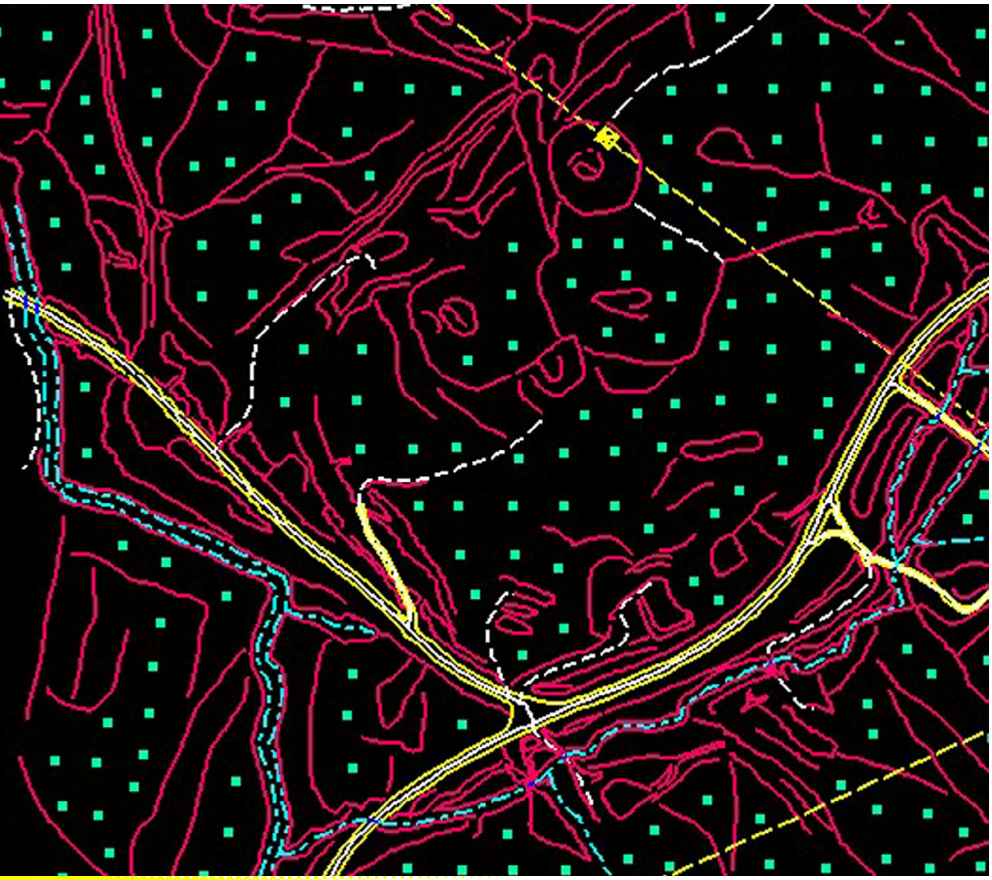
Should Contours Be Generated from Lidar Data, and Are Breaklines Required?



This image illustrates traditional photogrammetric terrain modeling with breaklines and mass points. The generation of breaklines is time consuming and can yield more appealing contours at road edges or other sharp breaks in the terrain, but breaklines will not add to the accuracy or the quality of the contours when using a dense lidar dataset.
Courtesy of Woolpert

BY DR. QASSIM A. **ABDULLAH**

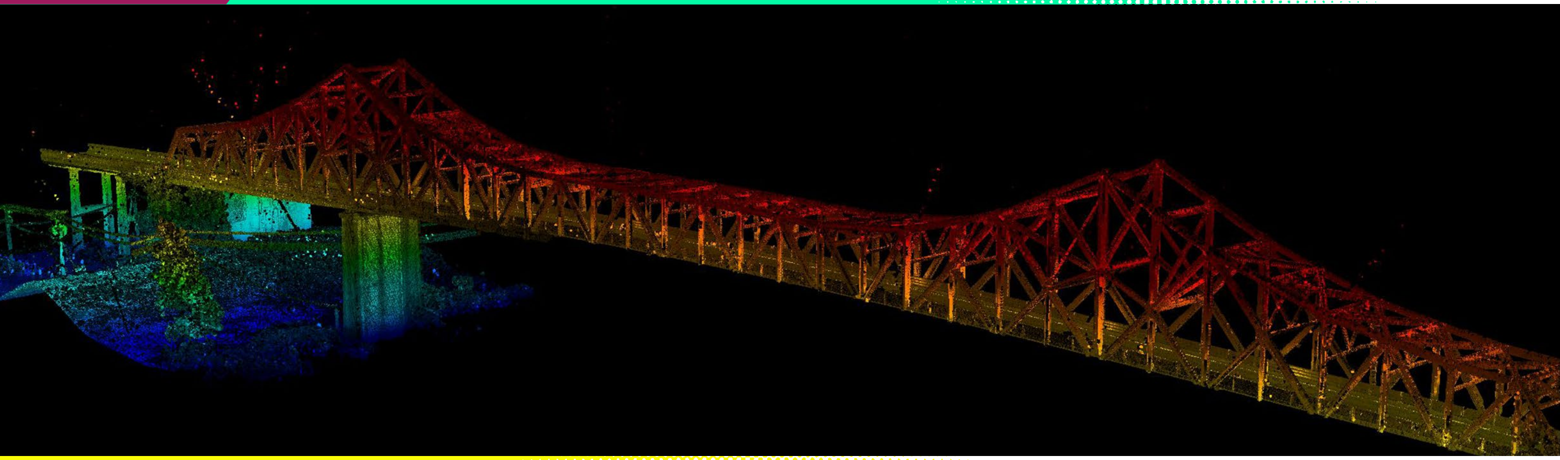
Lidar data provides the most accurate and reliable representation of the topography of the earth. As lidar technology advances and point clouds continue to become richer and denser, elements of lidar collections that once were necessary to the process naturally phase out.

However, government agencies and other users contracting for lidar data often additionally request specific outdated mapping components, not realizing that these additions cost them unnecessary time and money. These mapping components include contours generated from lidar data, and the use of breaklines to support lidar data.

Understanding why these mapping components were developed, what roles they once played and what roles they can play in modern lidar applications will help agencies decide whether to request their inclusion.

History and Application of Contours and Breaklines

For centuries contour lines, which connect places of equal elevation, were the most common way to numerically represent land elevation and topography on paper or hard-surface maps. When they were developed, it was not practical for land surveyors to manually record relief, so a limited number of spot elevations were surveyed.



The Clarendon Bridge spans the White River at U.S. Highway 79 in Monroe County, Ark. This image shows static lidar modeling.
Courtesy of the Arkansas Department of Transportation

The U.S. Geological Survey (USGS) produced the first topographical survey maps that included contour representation of terrain relief, and this paved the way to soft copy, digital modeling and representation of land topography, and diminished the need for contour lines.

The use of breaklines evolved as the digital mapping industry matured. Breaklines, developed using photogrammetric stereo-compilation, are three-dimensional lines in a digital mapping environment. They were introduced to more accurately capture changes in terrain in the presence of sparse 3D points, sometimes called "mass points," or what we refer to today as point clouds.

Since it's not economically feasible to trace the ground and generate height information for every square foot of land through the 3D digitization process, the industry devised the breakline approach to ease the labor-intensive and expensive map-making process.

As digital map-making moved forward, terrain topographies were modeled by pulling contours. An operator would fix a floating mark at a contour elevation and manually digitize the terrain where the elevation was equal to the set contour elevation.

This process was replaced by what is sometimes is referred to as a digital terrain model (DTM). DTMs usually contain course mass points that represent terrain elevation in flat and rolling terrain, and breaklines to represent abrupt changes in the terrain. The mass points and vertices of the breaklines are converted to a triangular irregular network (TIN), from which contours and other terrain models are derived in a digital environment.

These initial mass points were far less frequent and dense than today's lidar point clouds. This density depends on map scale and the relief in the terrain. Collecting mass points with post spacing of 50 feet to 150 feet was and still is common when modeling the terrain using stereo photogrammetry.

With coarse post spacing of mass points and with the absence of breaklines, terrain modeling is less accurate because it fails to represent the true shape of the terrain.

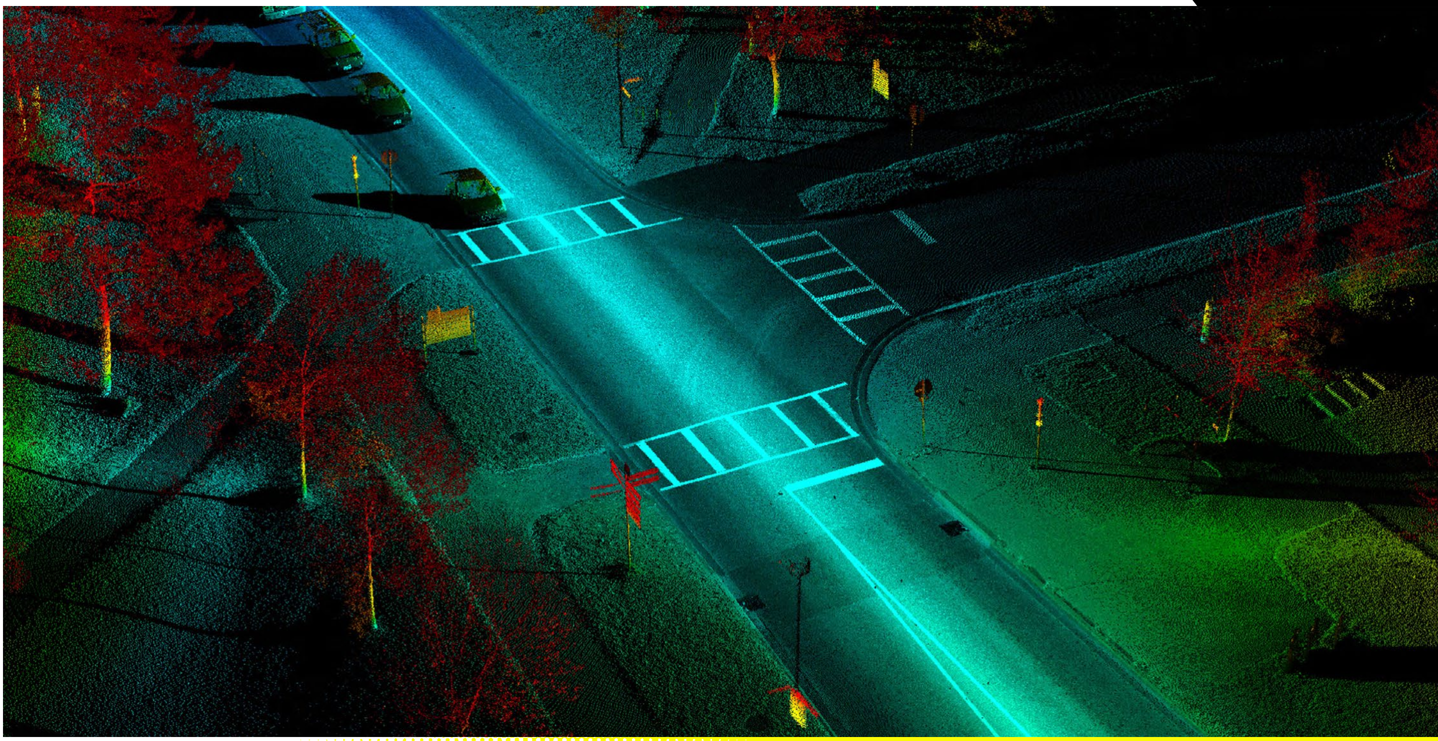
Enter Lidar Technology

When lidar technology started taking off in the mid-1990s, pulse repetition rate—which contributed to the point cloud density—was very low. Collecting a lidar-based point cloud with a post spacing of 5 meters was a normal practice at the time, improving to a post spacing of 2 meters a few years later and steadily increasing in density over time.

Today, the industry is collecting USGS Quality Level 2 (QL2) lidar data with a density of 2 points per square meter and a post spacing of around 0.71 meter (or 2.3 feet). Soon, Quality Level 1 (QL1) lidar data with a density of 8 points per square meter and a post spacing of around 0.35 meters (or 1.15 feet) will be the norm within the industry.

Lidar point clouds, which provide an elevation post down to each foot of the terrain, provide the most comprehensive method of modeling terrain.

Contours are generated by the subsampling, or thinning, of dense lidar data. This process takes valuable labor hours to produce, and creates a product



Providing breaklines with mobile mapping system (MMS) data, as modeled in this image, allows for the reduction of delivered data and enables the modeling software to handle it more efficiently. However, lidar points from MMS alone are sufficient for any type of 3D modeling if the modeling software matures to handle the amount of data necessary.

that effectively hides valuable information about the terrain elevation in the point cloud.

Contours generated from the DTM, like breaklines and mass points, are smooth, as the contours are interpolated from mass points (and breaklines, if they exist) with post spacing of 50 feet or more. Such wide spacing of mass points smooths the interpolated contours, as it is less sensitive to the micro changes in elevation across the terrain.

On the contrary, lidar point clouds, because of their high density, are very sensitive to changes in elevation, so contours generated from lidar do not look appealing. However, such contours are more accurate in representing the terrain than the photogrammetric contours.

For most applications, when using a USGS QL2 lidar dataset, breaklines do not need to be added due to the high density of the point cloud. Breaklines are only needed in the absence of a dense point cloud, as was the case with the photogrammetric modeling of terrain.

Although breaklines can yield more appealing contours at road edges and other sharp breaks in the terrain, they will not add to the accuracy or the quality of the contours when using a dense lidar dataset.

Many software applications expect lidar points not to fluctuate, even within the noise limit or accuracy of the lidar data and when used with down-slope flow modeling. That is the only reason the massive modeling of breaklines is added—to represent linear water features and to assure a smooth and enforced downhill flow.

Modeling software companies can help the industry and reduce project cost if they would implement a tolerance of elevation fluctuation to within the repeatability of the lidar point cloud, which is specified in the USGS lidar base specifications to be around 6 centimeters.

Some agencies specify breakline compilation solely for hydro flattening of water bodies, but most of the time this is done for aesthetic reasons. Users of lidar data should accept that lidar data is dense, and there always will be an unevenness in the surface due to the random errors in the data represented by the repeatability of lidar data, which in most cases amounts to within 6 centimeters.

By accepting that lake surfaces do not need to look completely flat in a lidar dataset, it could save hundreds if not thousands of hours flattening such surfaces.

Even for volumetric computations, such unevenness of lidar data will not compromise the volume computations' accuracy. Such fluctuation is random and occurs around the mean terrain elevation, assuming all biases are removed from the lidar dataset.

Where Breaklines and Automated Contours Have Value

Although breaklines don't play the key role they once did, until processes and modeling software change, collecting breaklines from a dense lidar dataset still has useful applications in specific cases.

Breaklines are beneficial in defining obscured drainage lines in vegetated areas, a practice which can be inaccurate if generated by lidar points alone, and in the identification of free-standing walls, like sound barriers or retaining walls around bridge approaches.

But most often, the use of breaklines is applicable in road design and engineering, as departments of transportation (DOTs) require precise delineation of edge of pavement, road crown, curbs and gutter lines, top and base of curves, and other elements of the road.

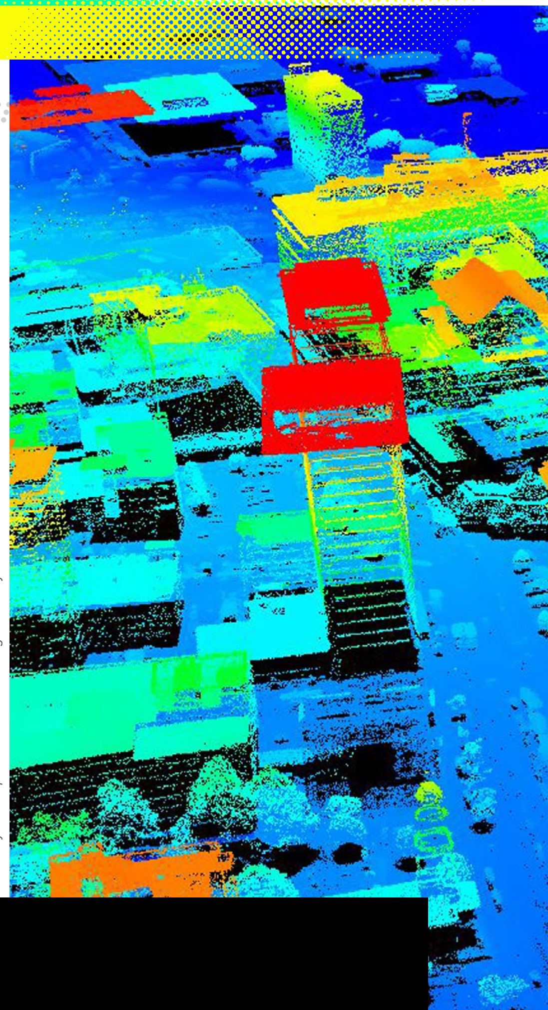
Current capabilities of aerial lidar collection do not allow engineers to accurately determine these lines from lidar, therefore manually collected breaklines are needed to complete DOT road engineering activities.

Also, providing breaklines with mobile mapping system (MMS) data allows for the reduction in size of delivered data so modeling software can handle it more efficiently. In many cases, the full density of the MMS data is used to extract breaklines after which the data is decimated to a 3-foot grid and delivered with the breaklines to be used within the modeling/CAD software.

As computing power and the ability to store and readily access these massive amounts of data advance, however, the reliance on breaklines in road design and engineering also will diminish.

If the end user requires breaklines to augment lidar data and if the accuracy requirement allows, there is a less expensive approach to extract breaklines, and that is automated breaklines.

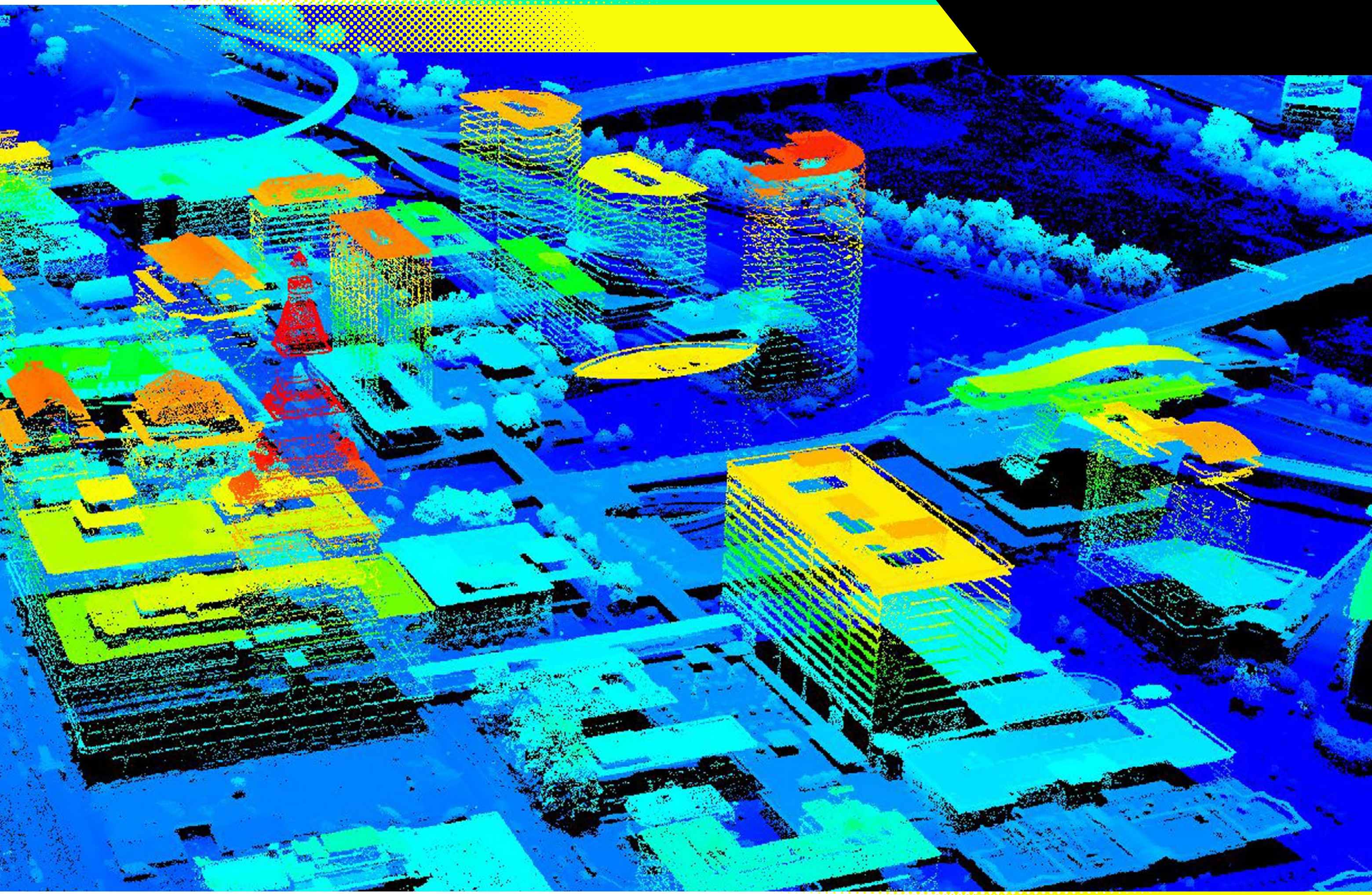
For automated breaklines, lidar point clouds and lidar intensity and/or existing imagery can be used through image segmentation techniques to extract edges that can be used as breaklines. This is a work in progress, but is one that bears pursuing.



Courtesy of Woolpert and the U.S. Geological Survey

Courtesy of Woolpert and the U.S. Geological Survey

This dense aerial lidar modeling of Hartford, Conn., was generated through the use of single-photon lidar.



This alternative view of Hartford, Conn., also illustrates a dense, aerial collection using single photon lidar.

If contours are desired, users should know that contours generated from lidar are more accurate and make a better representation of the terrain than the contours generated from DTM.

When contours are generated from elevation posts spaced every 35 or 71 centimeters, the maximum length of the triangular sides of the generated TIN always will be less than 100 centimeters. This is not the case with the photogrammetric-derived contours modeled from DTM with triangular sides exceeding tens of feet in length.

Contours generated from a lidar dataset appear jagged because lidar is more sensitive to the changes in terrain. Lidar-based contours can be described as "hypersensitive" due to the wealth of elevation details they carry.

Contours will have the accuracy of the lidar data and will reflect nearly the actual elevation of the lidar point cloud at the location where these contours are plotted.

However, contours in general do not represent the lidar data quality, as the lidar point cloud provides better details about the relief than the contours alone, unless the contours are created with a 5- to 10-centimeter contour interval.

Evaluating Need Will Save Time, Money

The mapping industry is evolving quickly and can seem like a moving target for those outside the industry. That is why, whenever possible, these changes in the technological process and application should be shared—even if this creates a short-term financial loss for the lidar data provider.

By being aware of these advances and their ramifications, government agencies can request and receive the best and most appropriate lidar data for their statewide or countywide mapping projects, and save time and money in the process.

Dr. Qassim A. Abdullah, Ph.D, PLS, CP, is Chief Scientist, Geospatial Services and Associate at Woolpert.