Rapid Development of Road Elevation Data to Support Hurricanes Katrina and Rita Operations

Abstract

One of the obstacles in the aftermath of Hurricanes Katrina and Rita was determining the status of established emergency evacuation routes for use in post-event evacuation and emergency response. The Louisiana Department of Transportation and Development (LADOTD) was able to aid emergency responders by rapidly providing LiDAR-based road elevation GIS data that was used for routing vehicles and watercraft through flooded streets.

This paper presents the processes used in creating the road elevation datasets and compares the results of using alternative elevation models. The limitations of using the datasets are also presented, in addition to providing recommendations for supplementary uses of the data products

I. Introduction

The purpose of this project was to provide a dataset of road elevations for Federal, State, and Local roads in the State of Louisiana, consisting of a 17-parish area affected by Hurricane Katrina and an additional 10-parish area affected by Hurricane Rita. Due to flooding caused by Katrina and the failure of levees, LADOTD requested that road elevation data be provided to emergency responders, to aid in determining roads that could be navigated by vehicles and vessels. With this information, the predicted availability of rescue routes could also be determined using dewatering rates and rescue vehicle submersion toleration levels. The information was also useful in determining viable evacuation routes for individuals that eventually decided to seek refuge elsewhere.

3001, Inc. provided Jefferson Parish road elevation data (based on 5-meter LiDAR DEM's) to LADOTD as part of a previous project, and this information was determined to be very useful to responders in the early phases of the rescue and recovery effort. Based on these results, LADOTD requested similar information for a 17-Parish area affected by Hurricane Katrina and subsequent flooding. Fortunately, LiDAR datasets were available for all of the affected areas, as 3001 had been contracted to produce LiDAR products for the entire State of Louisiana.

The urgency of the request required an effort to produce the results in the most expedient fashion, with a four-Parish area of high priority taking precedence. The following Parishes were processed, with the highest priority assigned to Orleans, Plaquemines, St. Bernard, and Jefferson Parishes:

Table 1. Katrina Processed Parishes

Parish	LADOTD District
Assumption	61
Ascension	61
Iberia	03
Iberville	61
Jefferson	02
Lafourche	02
Orleans	02
Plaquemines	02
St. Bernard	02
St. Charles	02
St.James	61
St. John the Babtist	62
St. Martin	03
St. Mary	03
St. Tammany	62
Terrabone	02
Washington	62

Hurricane Rita struck the remaining coastal parishes almost one month after Katrina, and 3001 was requested to perform the same routines for the following 10 parishes affected by Rita:

Table 2. Rita Processed Parishes

Parish	LADOTD District
Cameron	07
Calcasieu	07
Vermilion	03
Jefferson Davis	07
Acadia	03
Lafayette	03
Beauregard	07
Allen	07
Evangeline	03
St Landry	03

This paper describes the methods used in processing the datasets to provide road elevation maps to emergency responders, discusses the limitations of the techniques used, and provides recommendations to aid in disaster preparation.

II. Methods

As part of an ongoing LADOTD contract with Roadware, Inc. to provide video logging along state-maintained highways, GPS locations were available at 50-foot intervals, in the right-hand travel lane. LADOTD determined that these GPS points provided the best available current dataset of points located on the road surfaces, so this dataset was processed to obtain the first set of road elevation data. Because the Roadware GPS points were only obtained for State and Federal roads, none existed for local streets. A second set of road elevations were calculated from local road datasets to supplement the Roadware points. Local road data was primarily provided by Tele Atlas North America, Inc. (TANA), with additional datasets provided from individual parishes and municipalities. The methods for producing road elevations for each dataset are described in the following sections.

Each set of data requires procedures for extracting and configuring the points, and procedures for developing the surface used in defining the elevations. After completing these procedures, the surface dataset can be used in conjunction with the point dataset to assign elevations to the points.

Various techniques and software products can be used to create the surface and assign elevation values, so a short amount of time was initially devoted to testing the most expedient combination of procedures and products that would minimize the time needed to deliver the final product. The following methods list the steps that were used:

A. *Processing methods for Calculating Elevations on GPS point dataset*

1. Extract Parish boundaries

   Individual Parish boundaries were extracted from a State of Louisiana dataset and exported to shapefiles.

2. Clip GPS point dataset to Parish boundary

   The GPS point dataset was clipped to the individual Parish boundaries, and exported as a shapefile.

   Some GPS point datasets were delivered to 3001 with multiple subsets, so each was processed individually, at the request of LADOTD.

3. Select GPS points only on desired portion of roadway

   The GPS point datasets contained points that were collected as collection vehicles approached the road segment and exited the road segment, so these points were eliminated.

4. Eliminate extraneous GPS points

   The GPS point dataset also contained points that were used for video image use, but not relevant for use with this project. These intermediate points were eliminated by using a modulus function to reduce the dataset to the desired points.

5. Mosaic Digital Elevation Models

   For expediency, 30-meter DEM's were used to create the elevation surface for each Parish in the initial stages. Although 5-meter LiDAR DEM's would provide more accurate results, it was determined that the amount of time needed to process these files would be substantial and delay the delivery considerably. Mosaic time for 30-meter DEMs was approximately 32 minutes per parish, but increased to over two hours for 5-meter DEMs. For Hurricane Rita processing, the more accurate 5-meter DEMs were used.

DEM's covering each Parish were mosaiced to cover each individual parish and verified for consistency of spatial attributes (coordinate system, elevation units).

6. Assign Z values to point datasets

   The resulting surface grids (DEMs) were used to process the GPS point datasets and extract elevation data (in feet) for each point, storing the result in the "Z" attribute.

7. Quality control and delivery

   The datasets were briefly reviewed to determine if the Z values seemed reasonable. Due to the urgency of the request, the elevation values were not sampled or fully reviewed for accuracy. The shapefiles were then compressed into a Zip format and placed on the 3001 FTP site for LADOTD retrieval.

B. Processing Methods for Local Road Elevations

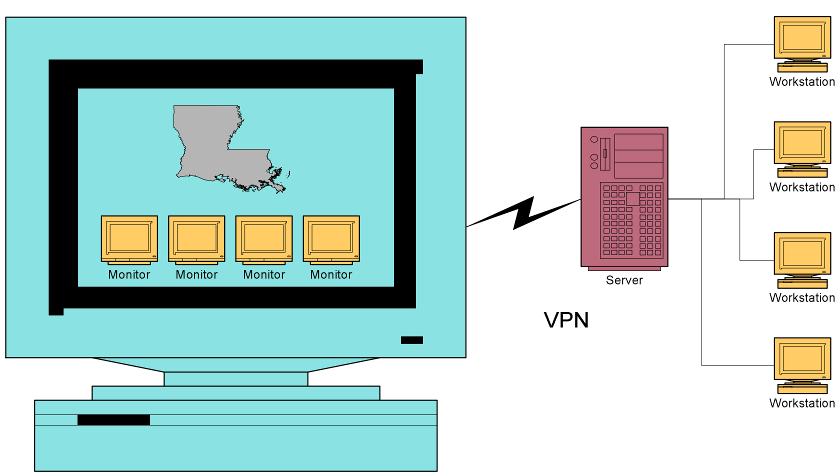
Point values for local road datasets (polylines) were extracted by exporting the polyline vertices (beginning and ending points) of each segment to a point shapefile. The resulting dataset was used to calculate elevations using the methods described in the previous section.

C. Processing Techniques for Expediency

1. Remote connections through multiple virtual desktops

   To process the maximum amount of data in the shortest time period, a single (main) workstation was configured to have four virtual desktops (Deskwin, MS Virtual Desktop Manager), with each having a remote connection through a virtual private network (VPN) to a unique workstation at 3001. The main workstation also used the VPN connection to access the license server to run locally installed GIS software on the main workstation. The entire configuration allowed a single operator to have five GIS workstations processing the data in parallel from a single "console".

Figure 1. Workstation configuration



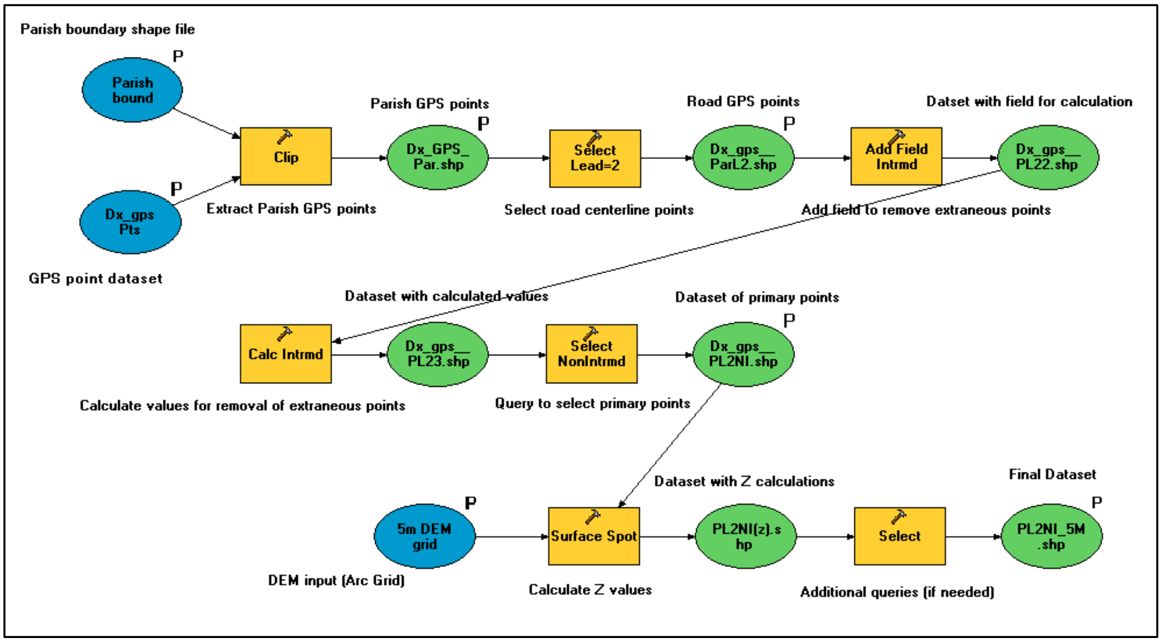
2. Automation through ModelBuilder and Python scripts

During the short time lag between Katrina and Rita, the processing routines were converted to ModelBuilder (ESRI), and Python scripts were written to reduce processing time.

ModelBuilder allows the user to diagram the workflows of a process and is linked directly to the GIS system so the model can be executed to produce the desired outputs.

Figure 2 (below) presents one of the ModelBuilder diagrams for processing the GPS points and using the DEM to assign elevations to the appropriate GPS positions. The oval shapes represent inputs and outputs (e.g. datasets, files), while the rectangular shapes represent tools or processes.

Figure 2. ModelBuilder diagram

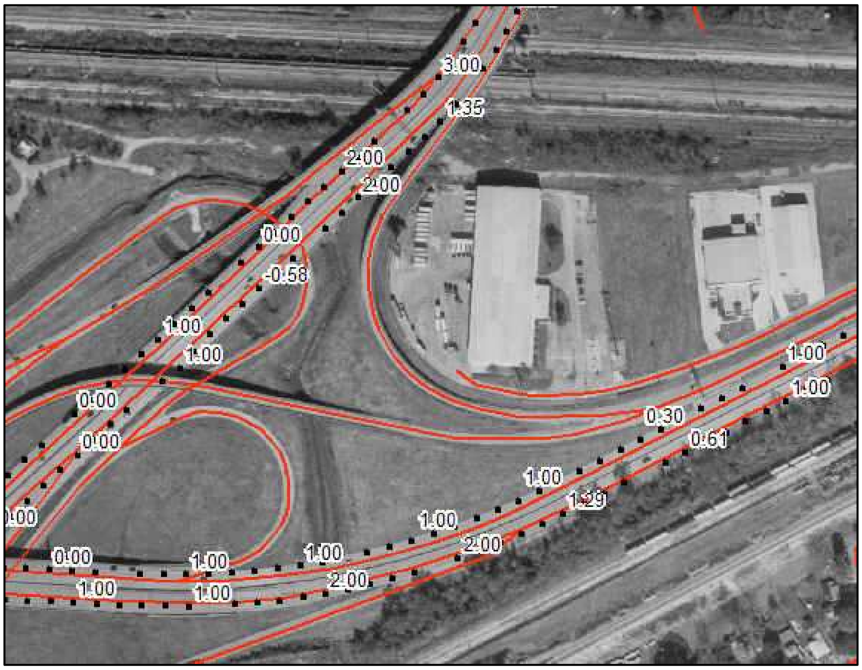


III. Results

For the two hurricane events, 3001 processed and delivered the equivalent of 60 parishes (due to 30-meter and 5-meter requests, state and local roads, multiple district datasets), with each dataset going through a 15-step procedure. The ModelBuilder diagram in Figure 2 only shows the primary steps, but the utilization of ModelBuilder reduced processing time by approximately 2 hours per parish.

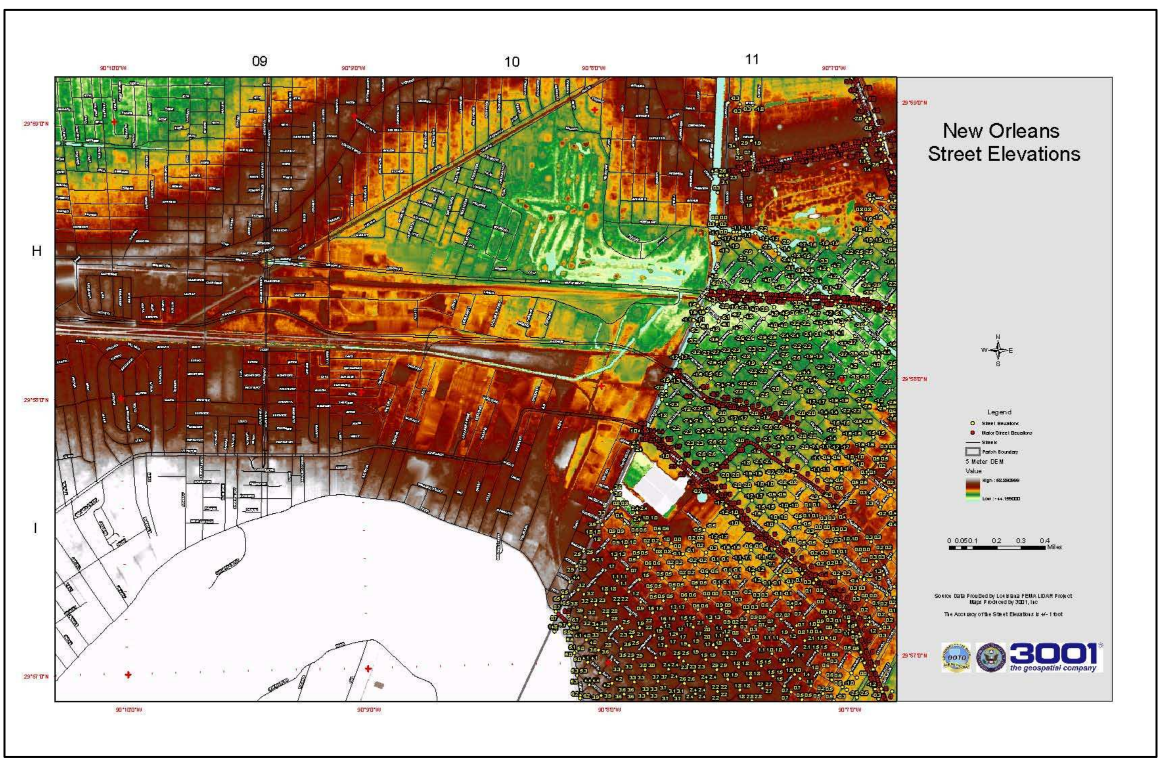
Samples of map products that could aid responders were developed, similar to the example in Figure 3, with the final product choice resulting in an 11” by 17” color map.

Figure 3. Sample map of GPS points with elevations labeled every 250 feet.



As each elevation dataset was produced, the results were transferred to LADOTD through an FTP site. The retrieved dataset was displayed with the appropriate overlays, and 11" by 17" maps produced, similar to the map shown in Figure 4.

Figure 4. Plotted map example



A more detailed representation of the map is presented in Figure 5, with local road vertices and elevations (yellow) and GPS points/elevations displayed in red.

Figure 5. Detailed view of plotted map

The hardcopy maps were then distributed to emergency responders to use in rescue and relief efforts. The high-water vehicles used by responders were able to tolerate water depths up to four feet. Feedback provided from responders indicated that the maps were quite accurate and invaluable in saving lives.

To aid in determining the validity of using the 30-meter DEMs, a comparison was made between the elevation values resulting from processing data with 30-meter and 5-meter DEMs. Using TANA road vertices (63,423 points) for the Orleans Parish, the distribution of variation is presented in Table 3 below.

Table 3. Elevation differences (30-meter and 5-meter)

Elevation difference (feet)	Number of Points (63,423 total)	Percent of Total
< 1 foot	52,171	82.2
1 foot to 2 feet	9,991	15.7
2 feet to 3 feet	983	1.5
3 feet to 4 feet	208	.32
4 feet to 5 feet	48	.07
5 feet to 6 feet	19	.03
6 feet	3	<.001

IV. Discussion

Staff members in all of the organizations worked continuously to produce the desired products, and as each was completed, it was placed on the FTP site for immediate use by LADOTD staff. Telephone communications were sporadic, but fortunately e-mail and Internet access remained available throughout the entire duration. LADOTD staff was notified via e-mail after each dataset was processed, with details about the dataset or processing included in the e-mail.

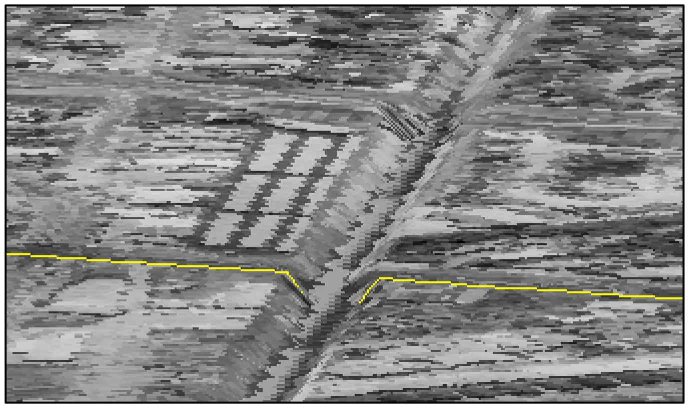
The 30-meter DEM's were produced a number of years ago and may not reflect current conditions. These DEM's should not be used to rely on accurate elevation information due to their accuracy level and method of compilation. They did provide a dataset of generalized elevation information that could be retrieved and utilized in the time frame allotted.

The high correlation of elevation differences measured between the 30-meter and 5-meter DEMs is probably due to the lack of terrain relief in the target area, but areas of greater terrain relief will most likely see more variation in the measured values. The variation will also become larger over time in some areas, as the terrain is subsiding at rates of up to one foot per decade.

It should also be noted that using the road polyline datasets that are not as accurate as the GPS points may provide a false indication of actual road elevations, because the road polylines may not be located accurately. If the road endpoint is incorrect by 10 feet in the horizontal, then the assigned elevation for that point will be the height of the point that is at that displaced location. The displaced point may be in an adjacent grid cell containing an elevation value not consistent with the actual road elevation.

Caution should also be urged in the use of the final map products that can be produced from LiDAR-based calculated elevation values. The end product of LiDAR processing results in a "bare earth" surface, where buildings and bridges have been removed. Although elevation data will be assigned to points that are coincident with bridges and other elevated road structures, the elevation value will not be the correct elevation of that point on the structure, but will be the elevation of the ground surface below the structure. The image below, created from draping a road centerline and DOQQ over a LiDAR-based DEM, highlights the results of removing the bridge.

Figure 6. Road centerline draped over DEM.



The benefit of assigning road elevations has proven useful in the rescue and recovery efforts following the aftermath of Hurricane Katrina. The information will also be invaluable for planning evacuation routes in the event of future flooding events, so it is recommended that road elevations be determined before the need arises. The results can be compiled into digital map books, so that hardcopy and digital maps can be rapidly produced and delivered to emergency response agencies, rescue teams, and other responders. Combined with flood modeling software and orthophotos of flooded areas, the information can also be used to calibrate flood models more accurately and aid in saving lives.

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