Geospatial Management of Commercial Seafloor Data

Devorah Joseph, Ph.D.
Donald M. Hussong, Ph.D.
Fugro Seafloor Surveys, Inc.
Seattle, WA

A typical transoceanic submarine cable route survey includes a vast amount of information spanning thousands of kilometers, with additional data types and increased resolution near continental margins. Formerly, cable installers have requested paper charts. This information is static, and changes to routing can result in increased costs and lost data. In addition, retrieving the charts for later maintenance purposes is awkward. We submit that submarine cable survey data would be more useful if organized into a geographically-referenced database. This GIS database would include route-planning information and all survey data. We present an example of a GIS database created for a recent survey.

Introduction

Pre-installation surveys for undersea telecommunications cables have evolved from simple single beam surveys to projects employing a variety of sophisticated instruments that collect large quantities of diverse data types covering vast areas of seafloor worldwide (Fig. 1). State-of-the-art bathymetric and backscatter collection systems (Fig. 2a, 2b), are routinely deployed to map the morphology and composition of the seafloor, and sophisticated refraction and resistivity instruments are utilized to collect information about the geotechnical properties of the subsurface. In addition, large databases must be maintained to hold hazards, cables, oil and gas, shipping, and fishing information, and any other data that may impact the placement and safety of the cable.

Information about the cable's immediate environment is required not only to determine precisely where the cable will be laid, but also to establish the type of cable that will be used and the location of amplification units (repeaters). Cable types run from lightweight to double armor and a bad decision here can cost millions of dollars in repair costs and lost revenue later on.

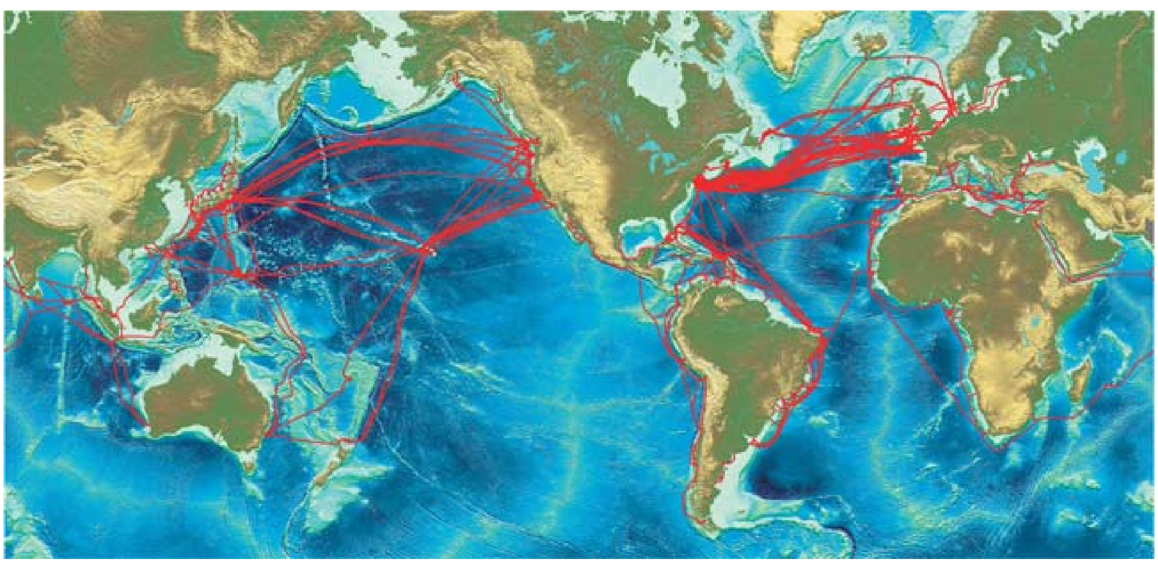

Figure 1. Fugro has produced over 900,000 km of desktop studies and cable route surveys worldwide. Background bathymetry from dataset published by Smith and Sandwell (1997).

Near continental margins and generally in water less than 2000 meters deep, cables are now trenched and buried to protect them from fishing and shipping. Multimillion-dollar ploughs are employed for this purpose requiring soundings of exceptionally high accuracy and reliable data for bottom and shallow subsurface composition.

Cable route surveys and cable route determination require expertise from both engineering and earth science disciplines. Distance measurements must be on the order of decimeter accuracy, even when measuring across ocean basins. Position information must have the greatest precision and accuracy available. The bottom line is a vast amount of high-resolution information to be presented for pre-lay route analysis, cable installation, and maintenance.

Figure 2a. The Sys09 instrument, owned and operated by Fugro Seafloor Surveys. Sys09 operates at 9/10 kHz is towed at ~100 meters below the sea surface. This instrument is used for surveying in 2,000 to 9,000+ meter water depth.

Figure 2b. The high resolution Sys100 instrument is employed for shallow water operations, in the 30 to 2,000 meter depth range. The instrument is towed near the seafloor, operating at a frequency of 100 kHz.

Current Cable Survey Products

CAD software is most commonly utilized for cable route survey products because CAD has traditionally been the platform of choice for engineering projects. Fugro maintains a MicroStation platform, although digital charts can be translated to AutoCAD format. However, the large amount of information that underlies each piece of printed information on a CAD-derived chart is lost. We find that pertinent attribute information such as source, resolution, edition, etc. are more readily available to the user in a GIS format.

Three stages of deliverables are typically produced: shipboard charts, draft final, and final charts. Specifications usually require 1:100,000 scale charts across the deep ocean (water depths over 2,000 meters – Fig. 3), 1:10,000 scale charts in areas where water depths are less than 2,000 meters (burial areas), with 1:1,000 and/or 1:5,000 scale charts at cable landings.

Shipboard charts are produced within 24 hours of data collection during the route survey. These include bathymetry contour charts, seabed composition and structure charts based on imagery data, and imagery charts. These plots are used for initial refinement of the route planned during the feasibility-planning ("desktop study") phase of the project. All other pertinent

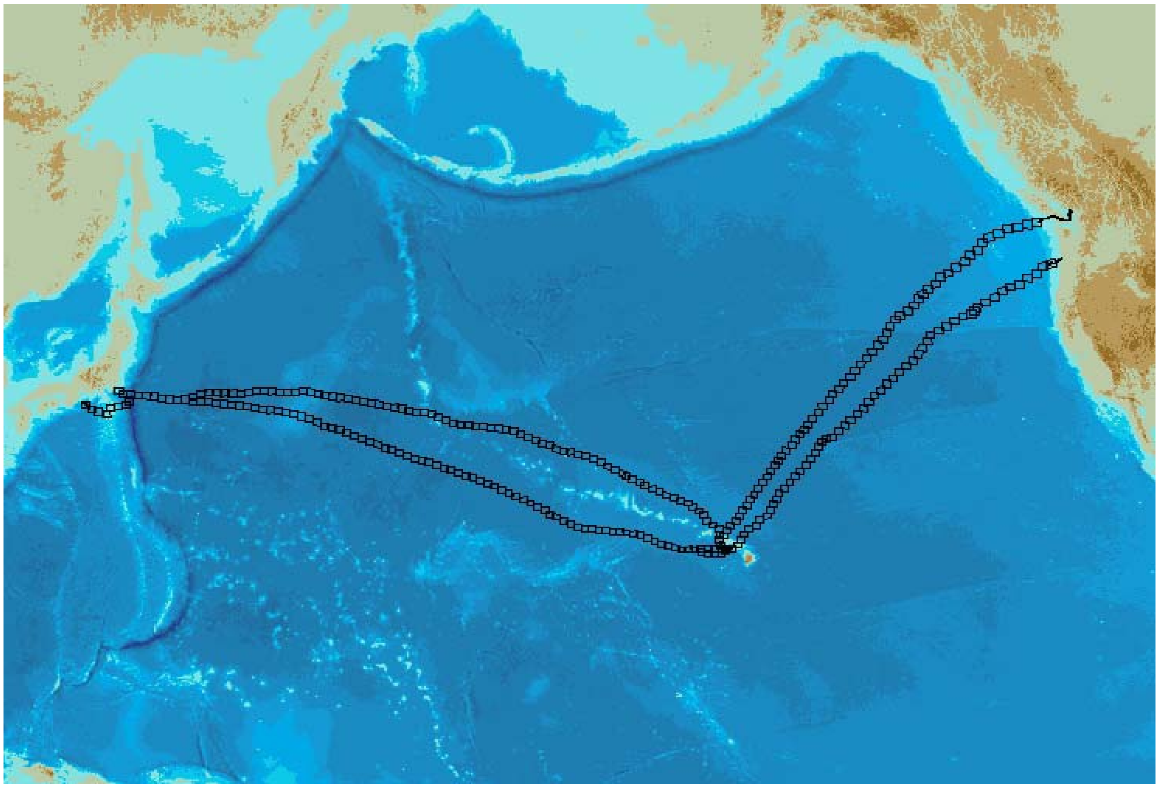

Figure 3. A typical transoceanic cable route survey showing 1:100,000 scale chart boxes. In water depths less than 2,000 meters, charts at a scale of 1:10,000 are produced, with 1:1,000 or 1:5,000 scale charts at cable landings.

information is added to these charts – bottom samples, proximal cables (planned, active, and retired), hazards and obstructions, marine sanctuaries, fishing grounds, shipping routes, maritime boundaries, etc.

Bathymetry, geologic interpretation, hazards, etc. are repeated through the draft-final and final stages (Fig. 4a), however bathymetric profiles and geotechnical data such as subsurface layering, composition, and ploughability (for burial areas) are added. The route is refined and the draft-final stage of charting assists in burial assessment. Thus, the draft-final issue includes alignment sheets for the burial areas, charts in which the data are broken at each change in bearing of the route and rotated to an east-west orientation (Fig. 4b). In this regard, alignment sheets differ from the strip charts produced for pipeline surveys. In an alignment sheet, data presented in plan view (bathymetric contours, seabed composition and structure) will directly correlate with data presented in altitude orientation (bathymetric profiles, sub-bottom composition and properties). The final charts show the final route and are used for cable installation and burial purposes.

A typical transoceanic survey can encompass hundreds of charts (Fig. 3). FSSI has developed automated processes for attaching data types per charting types (bathymetry only, bathymetry and geologic interpretation, etc.) and for automatically producing large numbers of chart .dgn files and plot files by running macros and MicroStation .mdl programs. Before moving in total to a GIS platform, we must be able to reproduce these capabilities in the GIS platform.

Currently, FSSI is working in both ArcGIS and MicroStation platforms because the ESRI products cannot yet meet all requirements. For example, we must convert the route file from CAD to GIS. In MicroStation, we have developed special programs to map the route across a global (curved) surface, and can select how the route is to be drawn. The route can be calculated as a line of constant bearing (rhumbline), a great circle (geodesic), or merely a line drawn from point to point (grid), according to customer preference. Furthermore, the position of cable crossings is

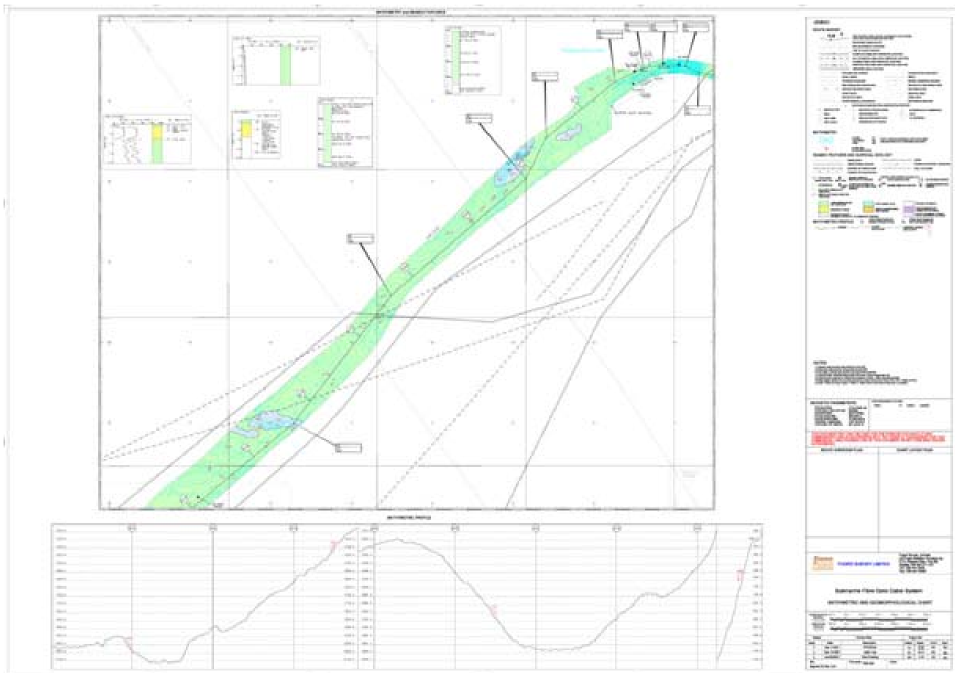

Figure 4a. A 1:100,000 scale North-up chart produced for final delivery of charting products. The chart presents both bathymetric contours and seafloor composition and morphology. Bottom sample positions and sample panels are added as well as call-out flags showing the position of each change in bearing of the route. Below the plan view, a bathymetric profile shows relief through the route with slope indicators showing any slope over 6°.

reliant upon how the routes are drawn. We are currently developing these capabilities for ArcGIS. In addition, we must create bathymetric profiles to specified vertical exaggeration (we do not find the tool in 3D Analyst sufficient), and map other x-z data types such as subsurface layering.

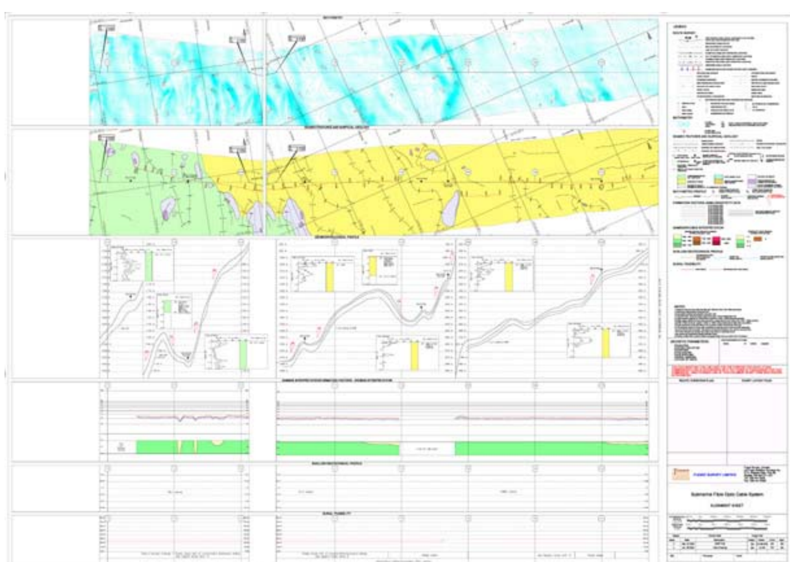

Figure 4b. An alignment sheet produced for a burial assessment. The top two panels show bathymetric contours and geologic interpretation in plan view. Note that the boxes are cut at each change in bearing of the route and rotated in an east-west direction so that the altitude views below (bathymetric profile, resistivity measurements, subsurface composition based on these measurements, and plough tow force estimates) will directly correlate to positions on the plan view boxes.

Preliminary GIS Products

FSSI is currently producing digital products for “desktop” studies and cable route surveys in an ArcGIS platform, however charts is still produced in MicroStation.

All available data are compiled and displayed in ArcGIS for the desktop study to determine the best route for the cable before actual survey operations commence (Fig. 5). A Mercator geodesy is often chosen for the desktop study GIS data frame because routes can cross several UTM zones. UTM is, however, the preferred projection for displaying survey data.

The .mxd file created for the desktop study is updated with survey data when survey operations begin. Hence, the ArcGIS project becomes a compendium of all data relating to the project from the desktop study phase through survey ops. Daily reports from the survey phase may be added as hyper-linked documents. Bottom sample and core penetrometer test results are added as hyperlinks, as are videos and photos collected by divers at the cable landings.

Gridded bathymetric data collected by the towed systems are converted into ESRI grid file format (Fig. 6a). The grid files are used to create contours at the interval specified by the client. Slope files and hillshade files are also created from the bathymetry grids. The imagery geotiff files (Fig. 6b) are converted into MrSid format for faster viewing, although the original geotiffs are maintained in the project for calculation purposes.

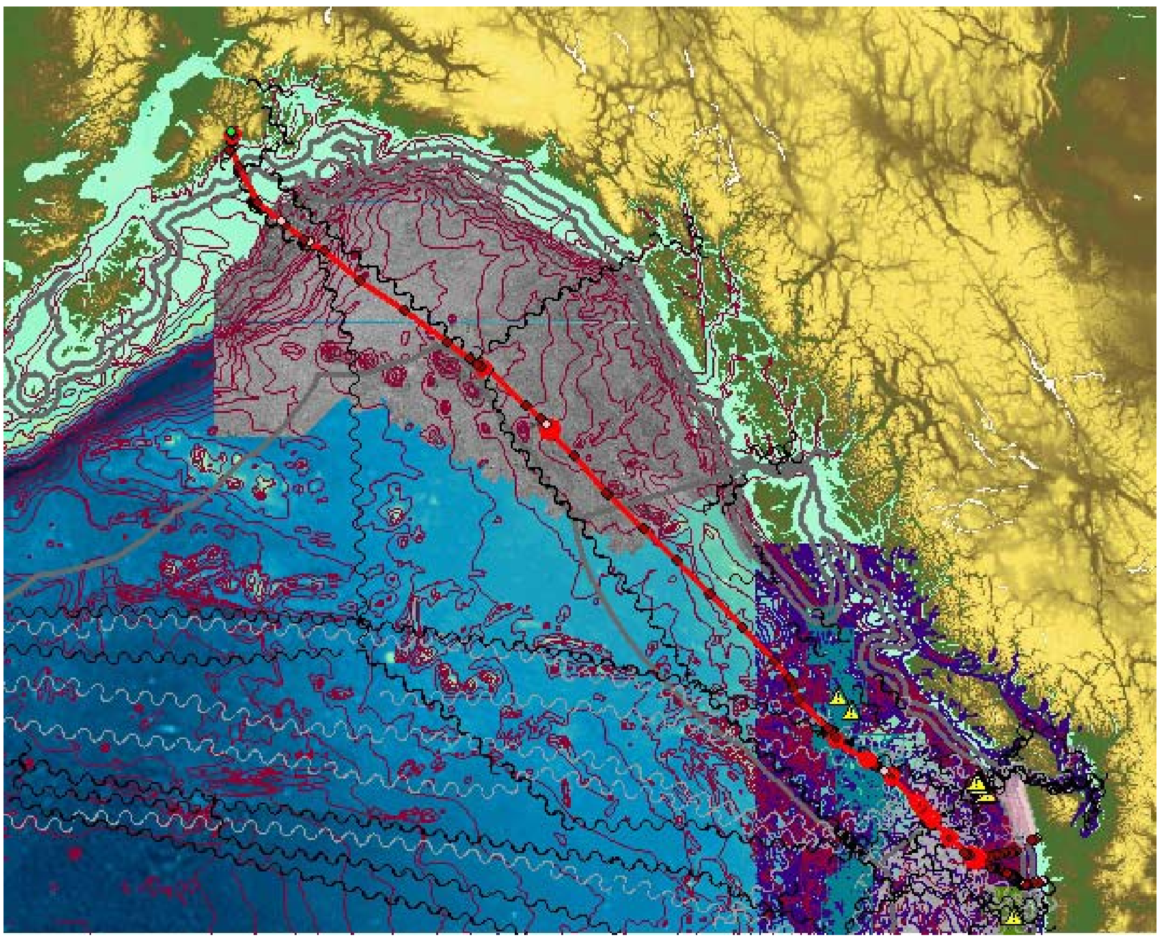

Figure 5. A digital desktop study compiled for a projected cable route survey from Oregon to Alaska. The route was planned using the available data shown here. Survey data were added to this GIS project once shipboard operations commenced. Background bathymetry from Smith and Sandwell (1997), Gloria data collected by USGS (Groome et. Al., 1997; USGS, 1991), bathymetric contours off Washington and Canada collected by NOAA and various academic institutions.

The geologic interpretation which includes seafloor composition (a polygon file using colors or patterns to designate bottom types – sand, silt, rock, etc.) and seafloor structure (canyons, faults, pock marks, etc.) is digitized from the imagery charts into MicroStation files that are converted into GIS (Fig. 6c). However, this task will be easily originated in ArcGIS when we can move in total to a GIS platform. All additional information such as cables, hazards, boundaries, etc. are added from GIS-native databases.

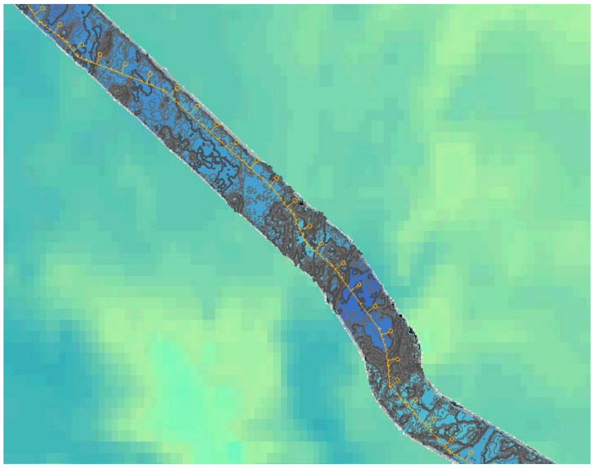

Figure 6a. Fugro proprietary format gridded bathymetric data are converted to ESRI grid files and contoured using tools in Spatial Analyst. Slope and hillshade files are also produced.

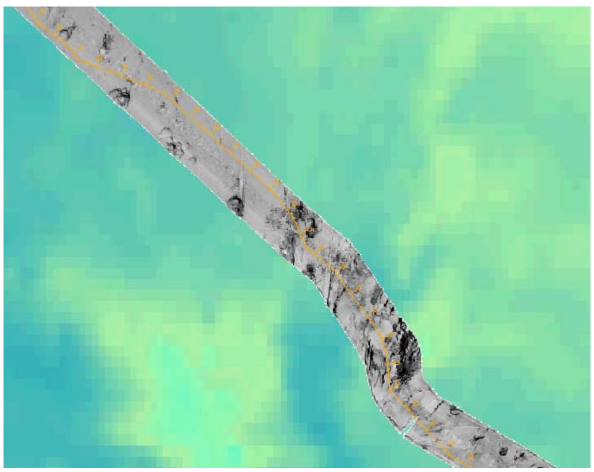

Figure 6b. Imagery geotiff files are converted to MrSid files for viewing, however the original tiff files are kept for calculation purposes.

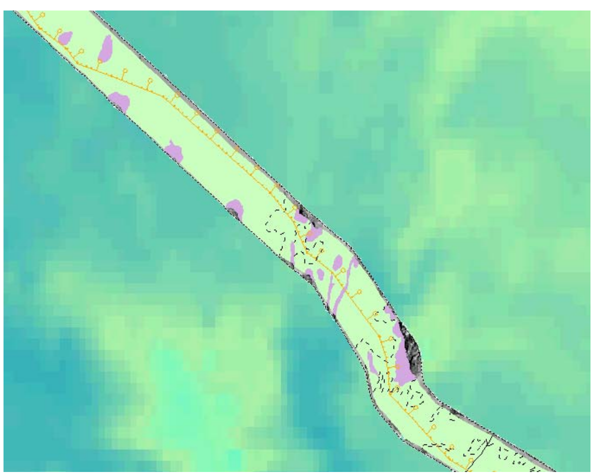

Figure 6c. The imagery data is used to determine geologic structure and composition of the seafloor. These data are digitized to create MicroStation files which are then converted to GIS.

Using the gridded slope files created from the bathymetry grids and the imagery geotiff files (Fig. 7a, 7b), FSSI produces a feasibility surface for cable installation (Fig. 7c). Cables are not draped over slopes greater than 15° and a soft, sedimented bottom is preferred for cable lay.

Using Raster Calculator in Spatial Analyst, a calculation is rendered to show areas where slopes are equal to or exceed 15° and where imagery pixel values indicate rock or thinly sedimented rock. In this manner, the cable engineer has a quick view of where and where not to position the cable. Of course, the cable engineer must refine the route based on parameters such as turning radius, however the feasibility surface is an excellent first approximation.

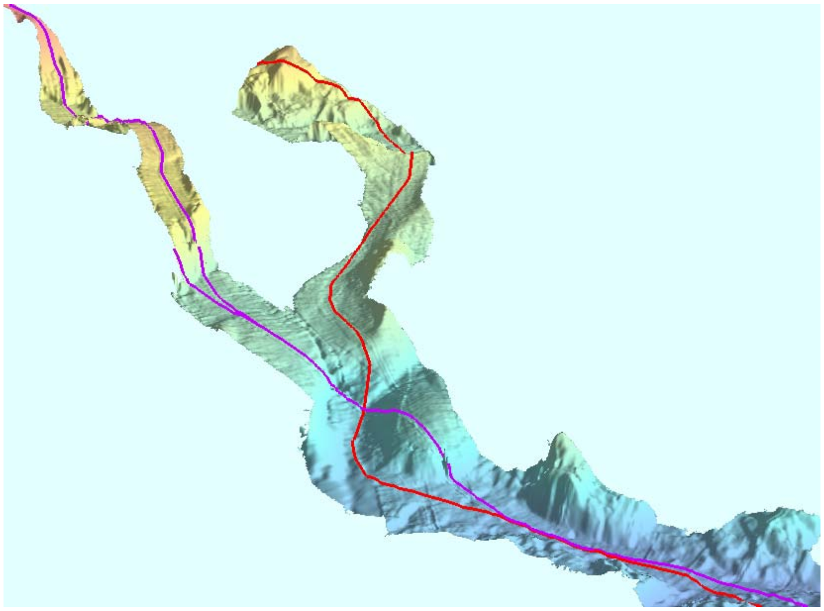

Figure 7a. Bathymetry data collected by FSSI's Sys09 instrument. The desktop study route (in purple) was found to be unsuitable and other route options were surveyed. The final route is shown in red. The Fugro-format gridded depth data are converted into ESRI grid format for display and use in creating slope files, hillshade files, and feasibility surfaces.

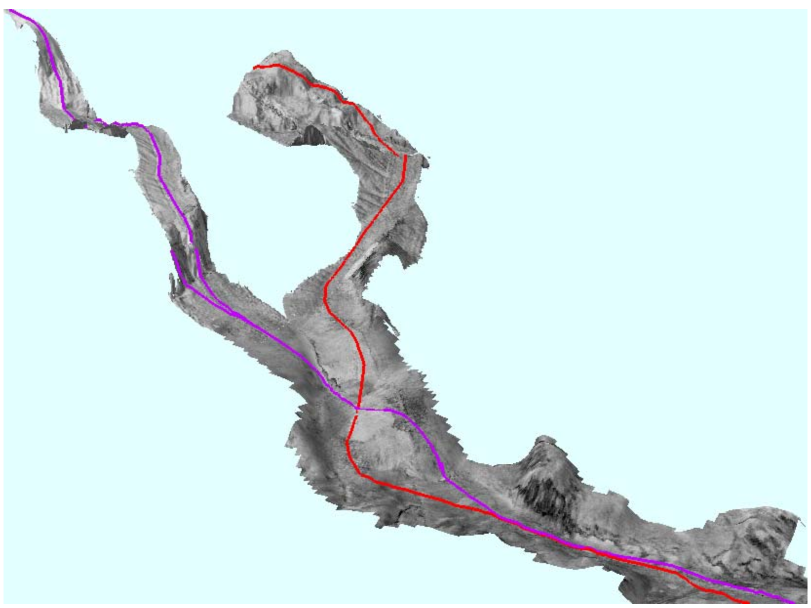

Figure 7b. Imagery data collected by FSSI's Sys09 instrument. High reflectivity (dark return) indicates either a hard seafloor or steep surface angled toward the towfish. Low reflectivity (light return) indicates sedimented seafloor. These data are the basis of the geologic interpretation.

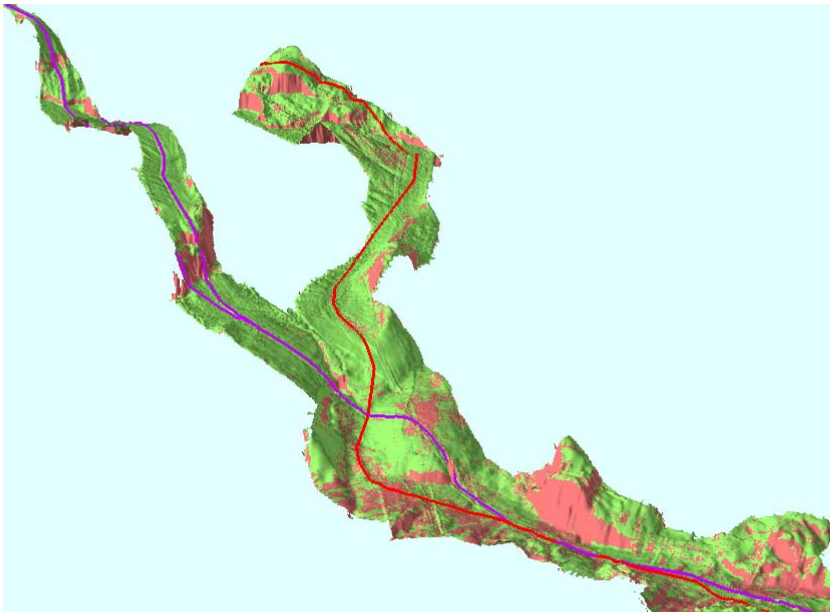

Figure 7c. FSSI's route planning feasibility surface created using Raster Calculator in Spatial Analyst. The calculation looks for slopes equal to or greater than 15° and pixel values in the imagery data that indicate a hard surface (rock or lightly sedimented rock). The pink shows areas that meet these criteria. The green shows areas that are more conducive to cable placement.

Additional GIS Products

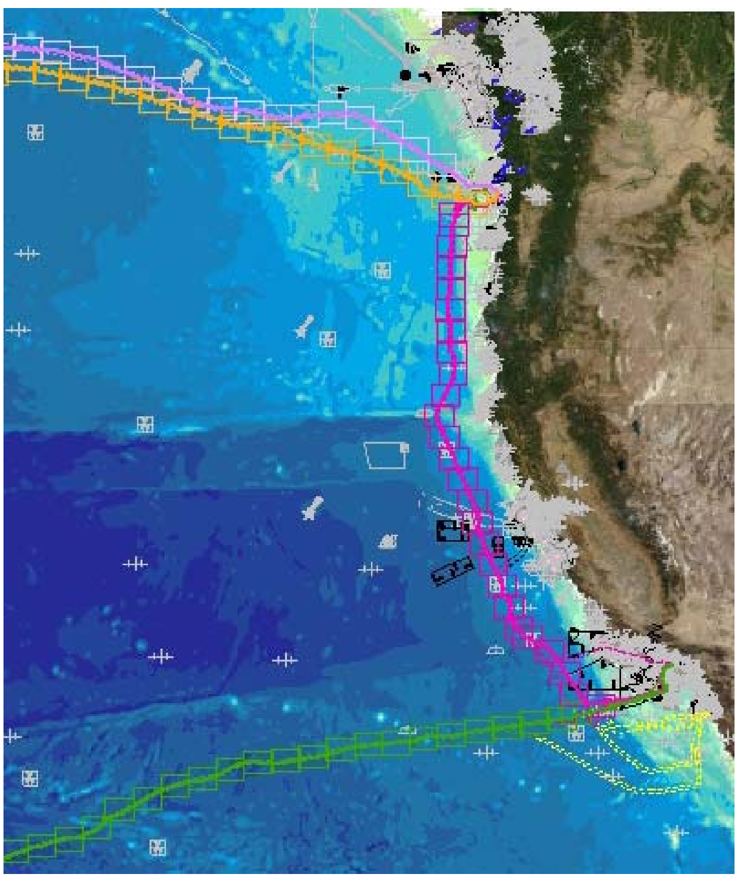

Figure 8. GIS conversion of CAD-formatted data collected for a multi-segment project. At full scale, chart boxes, data extents, and hazards are shown. The data (bathymetry, imagery, geologic interpretation) appear when zoomed in to appropriate scales.

FSSI has converted past projects from MicroStation format into GIS and add as much attribute information as possible. We find that the majority of the labor and time involved comes from correcting the MicroStation files for conversion. In MicroStation we use a fairly rigid level structure and this allows us to easily symbolize features. However, we must first check the MicroStation files to confirm that features are set on correct levels so that the conversion will run smoothly and features will not be mislabeled.

The GIS compilation is an excellent repository of all survey data and ancillary information collected during the route survey. Cable lay information such as installation reports and burial statistics can be added thus making the GIS compilation an easily retrievable, interactive storehouse of information for cable maintenance.

We have also compiled all data collected for particular areas, such as congested cable landings and areas that have experienced multiple cable failures. The recent earthquakes in Algeria caused a submarine slump or turbidity current that resulted in five cable failures. The cost to find and repair these cables is on the order of millions of dollars not including lost revenue. We are currently using all available geologic and geophysical data to investigate this mishap in an ArcGIS platform utilizing the various analytical tools available.

Current and Future GIS Usage and Development Efforts

Presently FSSI is using personal geodatabases to compile data. The geodatabases may be organized by data type or by UTM zone, depending upon customer preference. We will move to multiuser geodatabases when our customer base is functional within the GIS platform. We also plan to grant web access to our customers through an ArcIMS interface. We estimate that this development is at least a year or two away.

Our current development efforts include a route-plotting tool accurate across global surfaces with cumulative distance calculations and position markers (both kilometer posts and call out flags with geographical position for important points along the route). We are developing algorithms to plot the route as a line of constant bearing, a great circle, or merely a line joining

g
c
p
a
fi
b

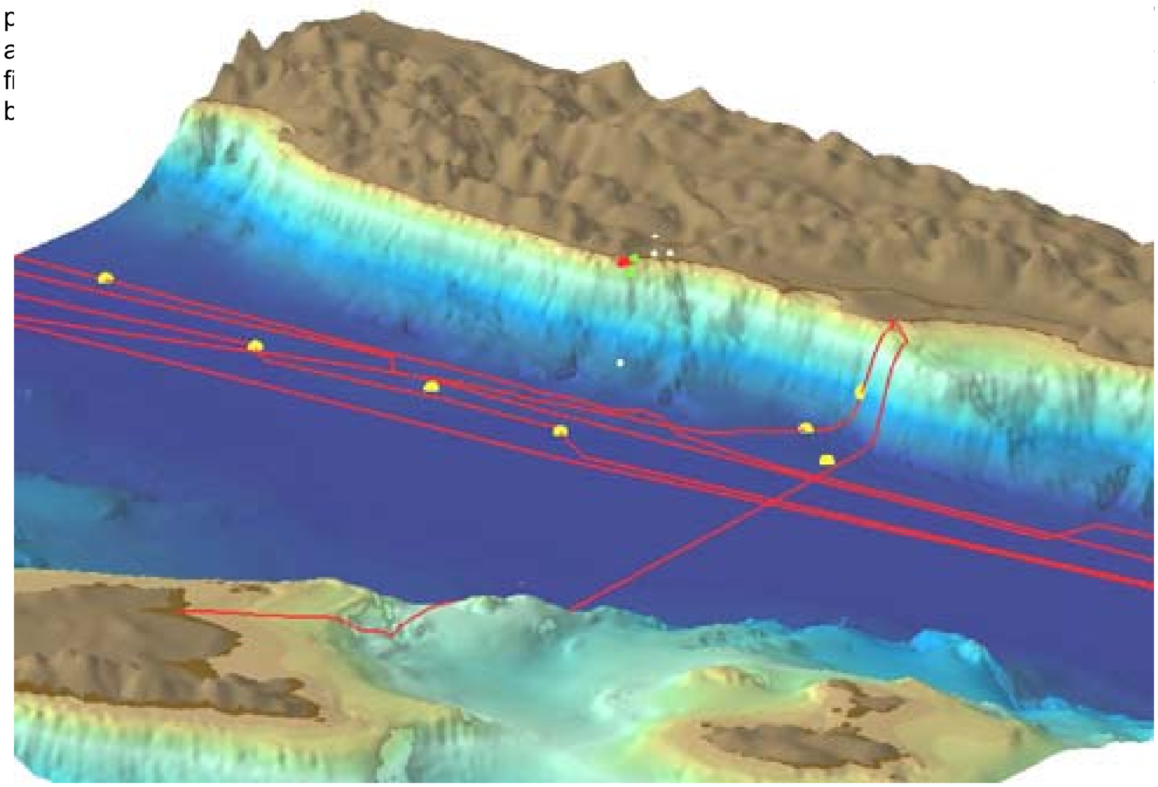

Figure 9. A 3-D Analyst rendering of the seafloor off the coast of Algeria. The earthquakes that began on May 21, 2003 with a massive 6.8 temblor caused submarine avalanches or turbidity flows that broke five submarine cables. The pink dots show the locations of magnitude 4.0 to 4.9 aftershocks, the green dots show the magnitude 5.0 and 5.8 aftershocks, and the large red dot shows the location of the main 6.8 magnitude quake. Submarine cables are shown as red lines; the position of the cable breaks or faults are shown as yellow boxes. The islands of Majorca, Ibiza, and Formetara on the Balearic platform are shown in the foreground. Note the texture on the steep slopes proximal to the seismic events that suggest that slumping has occurred here in the past. A major part of FSSI's job is to foresee hazards such as this seismically active area that could impact cable safety. Background bathymetry data from the Naval Oceanographic Office Data Warehouse (1 minute resolution).

We intend to add subbottom information (composition, depth and thickness of layers). These algorithms will be useful for burial assessment data as well to show predicted plough tension. This capability must span both 2D and 3D representations – in 2D as a hyperlinked image designated by the span of route that the subsurface information covers, and in 3D in the appropriate geographical position.

In order to move fully to a GIS platform we must be able to produce charts at given scales with predetermined overlap along the route survey. Due to the number and various types of charts that we produce, this must be an automated process. A chart box generation tool will be the first tool created, followed by the capability to "cookie-cutter" the requested data types for that chart's geographical area and the addition of an appropriate legend. Creation of alignment sheets must also be an automated process because currently a change in the route causes a total repetition of the process from the changed position onward, thus increasing costs to the client.

Conclusion

FSSI is currently in the process of moving from a CAD (MicroStation) platform to a GIS platform using the ESRI software products. We find that a GIS project is a natural repository for submarine cable route survey data and all related data items. A GIS project started for a desktop study may be appended to include the route survey data, the geophysical surveys that map the properties of the subsurface, and all ancillary information such as hazards, marine reserve areas, proximal cables and pipelines, etc. Survey documents, such as daily reports, films and photographs of cable landings, and bottom sample information can be hyperlinked for easy retrieval. This geospatial data repository may be extended to include all installation information and burial statistic and thus would be of immense benefit for cable maintenance purposes. Before we can work fully within a GIS environment, however, we must overcome some deficiencies in the software that our particular usage requires. These are:

1. Automated generation of charts, both north-up and alignment sense;
2. Correct plotting of routes and cables that take the curvature of the earth into account. This includes the capability to plot the route as a rhumbline or a great circle;
3. The capability to add geographically located x-z data to 2-D and 3-D representations.

Acknowledgements

The authors wish to thank Bruce Rein and General Communication, Inc. for permission to use data collected during the Alaska United Fiber System – West Survey, and Don Hunt of Tyco Telecommunications for permission to include a graphic from the TGN Pacific GIS.

References

Groome, M. G., C. Gutmacher and A. Steveson, 1997, Atlas of the GLORIA Sidescan-sonar Imagery of the Exclusive Economic Zone of the United States: EEZ View, US Geological Survey Open File Report 97-540 (CD-ROM).

Smith, W. H. F., and D. T. Sandwell, Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings, Science, v. 277, p. 1956-1962, 1997.

U.S. Office of Energy and Marine Geology, 1991, GLORIA Imagery and Bathymetry U.S. EEZ off Washington, Oregon and California, U.S. Geological Survey Open File Report 91-396 (CD-ROM).

Devorah Joseph, Ph.D., Data Manager
Donald M. Hussong, Ph.D., Managing Director
Fugro Seafloor Surveys, Inc.
2727 Alaskan Way, Pier 69
Seattle, WA 98121
(206) 441-9305 (Phone)
(206) 441-9308 (Fax)
d.joseph@seafloor.com
http://www.seafloor.com