GIS Applications in the Saudi Aramco Offshore Hydrographic Surveying Environment

Fahad Al-Amri & Dr. Kevin Gibson

Hydrographic Survey Unit, Saudi Aramco

Tel: 038807822

Mobile: 0504617872

fahad.amri@aramco.com

Abstract

This paper introduces the current capabilities of Geographic Information Systems (GIS) with reference to the modeling of the offshore environment as used by Saudi Aramco's Hydrographic Survey Unit. A historical perspective is given of the techniques that are presently used in processing high density sonar data and reducing this data to the significant features to be stored in the GIS database. There after the migration of the data to other formats such as Electronic Navigation Chart (ENC) and corporate Geospatial Framework Data (GFD) center will be explained with discussion of end-user applications. An example is given of a GIS application in a hypothetical catastrophic situation at an offshore installation in an adverse weather condition.

Keywords: Hydrography , ECDIS, ENC, Multibeam, ,

Introduction

To define Hydrography, it can be split into two words. Hydro means water, and grapher means a person who draws. A hydrographer measures the depths of lakes, rivers, and oceans. Therefore the science of hydrography is the measurement and description of the waters on the surface of the earth in the form of a chart and related publications. [i]

Historically the art of hydrography was cultivated by early navigators who sailed around the world and discovered new lands and continents. In the region of the Arabian Peninsular records tell that in 1498 the legendary Arab Navigator Ahmed Bin Majid, known the "Lion of the Sea", helped the famous Portuguese explorer Vasco Da Gama sail around the Cape of Good Hope by providing charts of routes and wind directions for the Indian Ocean. He guided the Portuguese ships toward India via Cape Horn. He made a historic contribution to charting and oceanography.

The importance of hydrography became recognized by the British during the American civil war when more ships floundered due to grounding than by gunfire from American warships. Soon after, a specialized branch of Hydrography was established within the British Navy.

The demand for accurate charts was as important then as it is today. The tradition carries on now in Saudi Aramco within the Hydrographic Survey Unit (HSU).

Hydrography Role in Saudi Aramco

Saudi Aramco has a vast exploration concession offshore and also numerous port activities on both the East and West Coasts of Saudi Arabia. Our east coast offshore oil production and supply consists of a network of 514 platforms and 3600 kilometers of pipelines in a concessional area of 30,000 square Kilometers.

Hydrography plays the role in all aspects of offshore production. Planning and design require knowledge of the both the sea bed topology and the sub sea strata. After construction oil field assets must be surveyed to ensure contract compliance and charts updated to provide engineers and mariners with the latest information. Barges and drill rigs require high precision surveys before moving into location for maintenance and drilling to ensure the area is clear of hazardous obstruction. Therefore, pipelines must be inspected regularly to define required maintenance work. The accurate positions of the pipelines are critical for divers to do maintenance and shipping not to damage the pipeline.

Initially ports require hydrography for environmental study and constructions. Thereafter, Ports maintenance requires hydrography to monitor the siltation; requiring first defining dredging survey and later assuring compliance dredging survey and position of buoys and beacons. Hydrographic survey must ensure that there is sufficient water depth on the predefined navigational routes and approaches for the vessels coming into pier facilities.

HSU provides the above services and more in support of the offshore community within Saudi Aramco.

HSU Past and Present

In 1981, HSU first survey vessel was acquired and it was called Karan-7. This vessel had traditional Singlebeam (SB) Echosounder and Racal Hyper- Fix Radio positioning system. Compared with today's hydrographic surveying, these early two pieces of equipment were much simpler systems; one provided discrete water depths of the survey vessel track, while the other provided positioning of those water depths.

Figure 1 The Survey Vessel Karan-8

To better meet the requirements for offshore hydrographic survey, Saudi Aramco's commissioned the building of a dedicated survey vessel, Karan-8 which went into service in August 1994.

The ship's sensors are constantly upgraded to state of the art technology. The present positioning system is a GPS with differentially corrections via satellite. Other equipment includes high resolution multibeam echo sounders, side scan sonar, remote operated vehicle and an integrated Navigation and data collection System

DEPTH MEASUREMENT TECHNIQUES

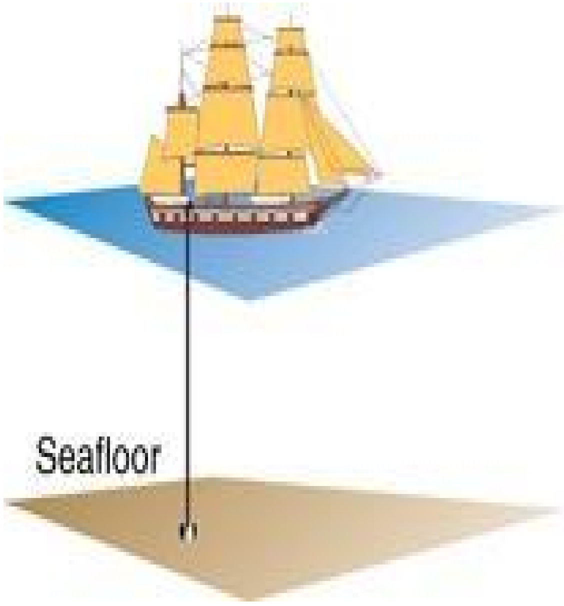

Figure 2 Lead Line Sounding

Early hydrographic surveying used a lead weight attached to the end of a hand-held rope that had graduated depth markings. This rope was called a lead line and lowered into the seabed from the bow of the ship until it touched bottom. The depth then was recorded manually. This measure of depth is known as sounding (See Figure 2).[ii] Using known mapped references on shore, a three-point fixes determine the position of each sounding. This method was labor-intensive, time-consuming and left a lot of area between selected sounding un-surveyed. Therefore, mariners would be unaware of the actual relief of the seabed and possible dangers to navigation.

Following the sinking of the *Titanic* in 1912, there were determined efforts to develop acoustic methods of discovering hazards in the water. SB Echo sounders were developed to accurately measure the depth of the water underneath the vessel track. They take advantage of the principle of SONAR (Sound Navigation and Ranging). Knowing the speed of sound in the water, they calculate water depth by measuring the time it takes for the sound to reach the bottom and the echo to return to the ship

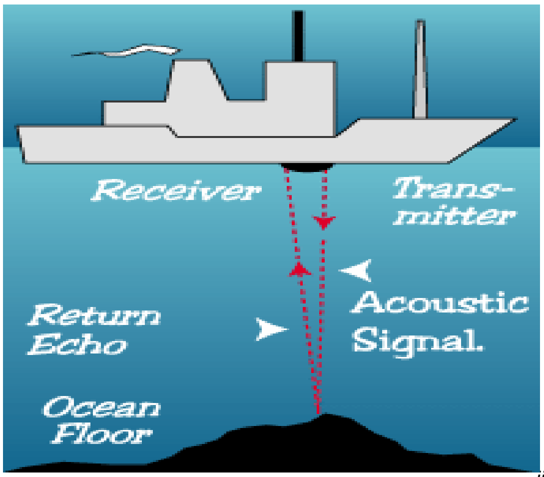

Fig. 3 Single Beam Echo Sounder [iii]

.

Since SB has also shown limitation as it provides no knowledge between adjacent survey lines, in 1990s a new method was developed as major breakthrough in measuring depth known as Multibeam (MB) Echosounder or Multibeam (MB) Sonar.

This instrumentation is usually either mounted in the hull of the survey vessel or mounted to the ship side. It transmits multiple beams of sound waves in a fan-shaped pattern to produce a swath of sounding data in a single pass over an area of the seafloor.

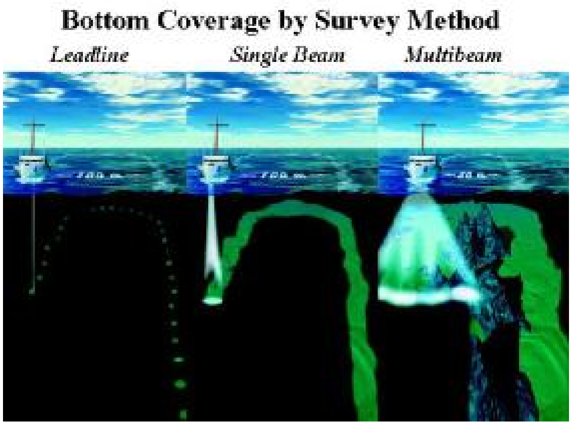

Figure 4 Evolution of Depth Measurement Techniques

Figure 4 [iv] shows the development of the depth measurement techniques and corresponding depth coverage from lead line going through SB into the latest technology of MB. In this Figure, SB will definitely miss the in-between mountain in the above picture. MB provides complete ensonification or mapping of the seafloor and leaves no area of speculation.

MB systems produce high-resolution bathymetry data throughout the survey area. Since they acquire dense sounding data both along the ship's track and between the track lines, they can provide 100% coverage of the seafloor. MB bathymetry sonar is used to locate underwater pipeline, cables, debris, or any obstruction such as shipwrecks. It can also locate topographical features on the seafloor such as sediment ridges and rock outcrops. Survey ships also use this technology to avoid areas that would endanger their vessels or gear and to precisely map the seafloor. Objects as small as a decimeter long can be located with this technology.

POSITIONING TECHNIQUES:

Early surveys used to utilize already determined land features to obtain the position of the ship using a three-fix. This positioning technique was associated with sextant fixes and leadline depth measurement. The system necessitates the need to visually see either known object on land or use of celestial navigation observing heavenly bodies.

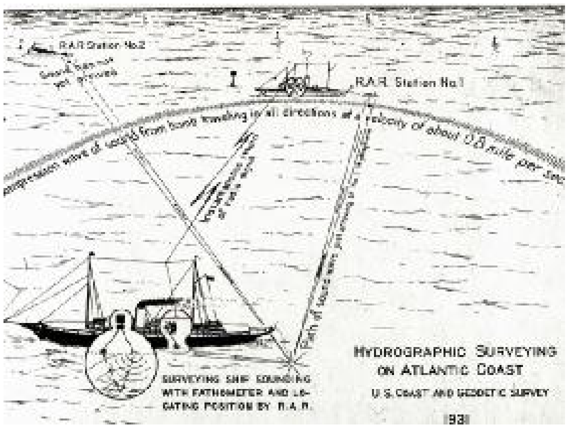

Figure 5 RAR Principle

To overcome the limitations in the above positioning system, a radio acoustic ranging (RAR) was developed within the United States Coast Guard and Geodetic Survey. The method relied on the ability of determining the ranges of a sound source from two or more fixed listening devices and fixing the position of that sound source. [v]

.

The method was to drop a TNT bomb off the stern of the surveying vessel and listen for its explosion at the ship and at two or more fixed hydrophone locations. When the fixed hydrophones received the signal from the explosion, this activated a radio transmitter that would immediately transmit the reception of the signal back to the surveying vessel. Thus by knowing the time of the explosion at the ship and comparing it to time of radio signal reception from a fixed hydrophone, the travel time of the sound wave from explosion to the fixed hydrophone could be determined. With knowledge of the velocity of sound in the surrounding seawater, wave travel time multiplied by velocity of sound in seawater would give the distance.

The intersection of two or more distances (ranges) would fix the position of the surveying vessel at the time of the explosion

Electronic Navigation

After World War II, the need for RAR was no longer needed and an electronic system was developed such that fixed land stations emitted signals that ships received on board. The signals would then be displayed on board the ship as either time differences or ranges that correlated with lines of position relative to the fixed land station.

Later on the electronic position indicator was developed which is a system that gave accuracies from 50 to 100 meters over a range of 400 to 600 KM.

Many navigation systems emulated this over the next forty years until the widespread availability of the global positioning system (GPS) in the 1990s

Differential Global Positioning System (DGPS)

With the improvement in depth coverage and accuracy of MB sonar, advancement was moving side by side in horizontal positioning. In the early 1990s, differential global positioning systems (DGPS) was developed to provide instantaneous of horizontal positioning of moving vessels within 2-5m accuracy within an area of 400KM radius. The principle for this system is simply assuming the common factors contributing to the error budget for GPS in the 400KM area is the same. Using radio link transmit differential corrections to a receiver at the moving vessel after comparing the raw GPS of the occupied point to an already accurate position of that same point (See Figure 7). This innovation meant that field units were usually no longer required to establish shore navigation control, a time consuming and sometimes dangerous practice. This meant survey operations could commence immediately knowing that they had accurate survey positions available with no time lost to setting up of horizontal station.

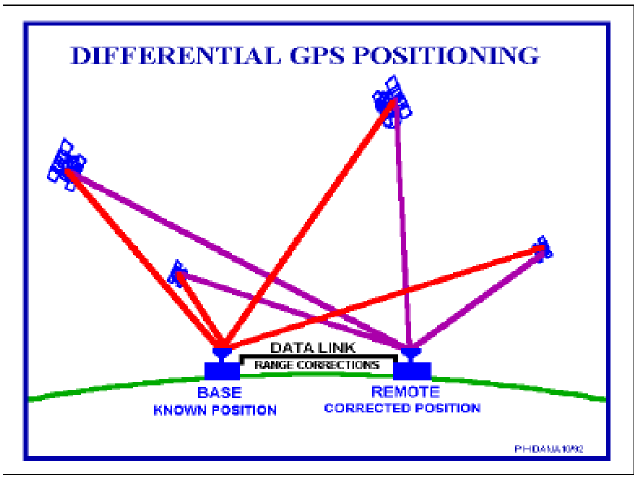

Figure 6 DGPS Principle

Electronic Chart Display and Information Systems (ECDIS)

In the mid 1990s two events precipitated HSU's entry into GIS technology. Saudi Aramco initiated the Vessel Traffic Management System (VTMS) project to control vessel movement around oil loading facilities, at the core of this project was an ECDIS system. At the same time the navigation system of Karan-8 was upgraded to include ECDIS capability. Both systems required Electronic Navigation Charts (ENC) conforming to the S57 standard of the International Hydrographic Organization (IHO). To be effective these charts would have to included 'Restricted' data concerning offshore oil facilities and so would have to be produced internally by HSU.

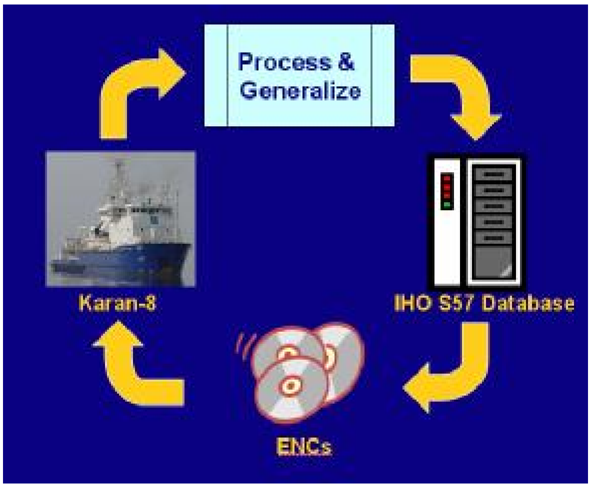

Fig 7 Ship to Shore Data loop

ECDIS are basically GIS systems dedicated to offshore navigation. The system on Karan-8 allows for accurate navigation, display of attribution of chart objects and planning of survey lines.

The ENC data required is generated from an onshore 'Nautical Database' which is updated from the vessels survey data, basically forming a data loop as illustrated.

DATA PROCESSING

The introduction of multibeam (MB) technology has provided the capability of obtaining complete seabed coverage, but introduced the challenge of processing large volumes of data. MB data can be considered in 3 classes, mathematically normal data, spurious data which is obviously invalid and anomalous data which may be a feature, such as reef or pipeline. The initial cleaning approach was based on line by line approach which is time consuming and does not provide any correlation to the neighboring soundings from adjacent lines. Lately, bathymetric data are reviewed and cleaned on an area basis.

The CUBE (Combined Uncertainty and Bathymetric Estimator) developed by Dr.Brian Calder at the Center for Coastal and Ocean Mapping, University of NewHampshire creates a best-fit surface with correlation coefficient to indicate goodness of fit. This allowed software to guide the hydrographic surveyor to those areas where the CUBE indicated dubious results and hence needs further validation. Whilst a major step forward it was still somewhat time consuming.

The latest techniques use a localized area spline surface generated from soundings. Deviations from the spline are used to flag spurious data, while the spline fit maintains feature definition. This method is extremely powerful for cleaning random noise, vegetation, etc. It leaves a high level of detail (e.g. pipe lines, structures, wrecks, etc.). and these features may now be digitized

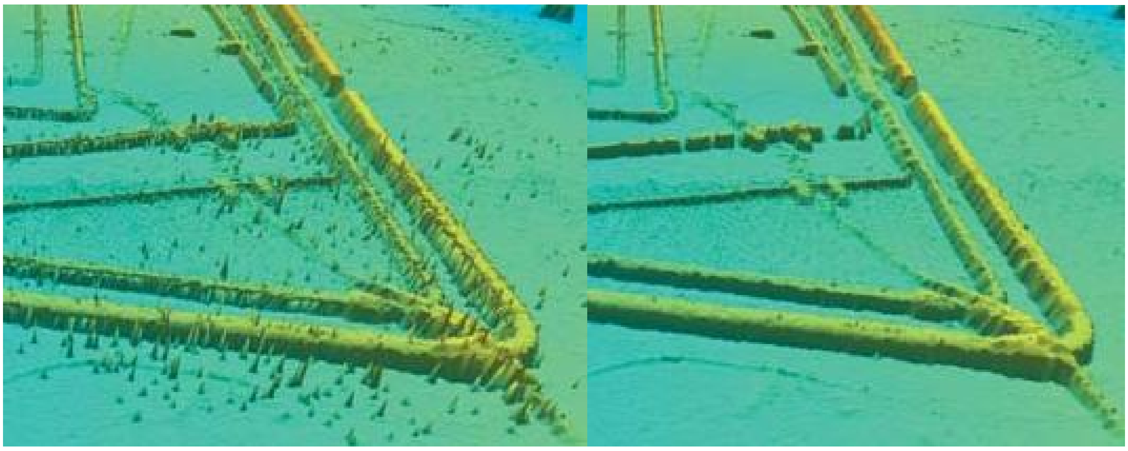

Figure 8 : Before and after Spline cleaning.

Generalization of Sounding Data

The next stage of bathymetry processing is to generalize the dense data to sub sets of data that can be displayed in the GIS system at different viewing scales. Since the primary purpose of Hydrography is navigation all generalization of data must be performed with a “shoal bias”. That is the surface inferred by the mariner form the soundings and depth curves on a chart should always be shallower than the surveyed surface. To do otherwise might lead a mariner to run aground.

IHO charting standards define the minimum and maximum spacing between soundings for a given scale and the soundings are then selected to meet these criteria while minimizing the deviation between the original surface and the newly selected surface, but with a shoal bias. The illustration (fig.9) shows how a selected surface would relate to the original surface.

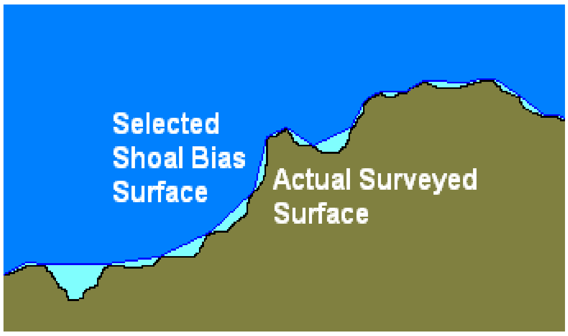

Fig.9 Shoal Bias Selection

The initial selection is executed for a scale of 1:1,000 and those soundings selected are loaded to the GIS database with a scale attribute set to 1000. Sequences of selections are then executed at increasingly lower scales. The input for each selection is the soundings from the previous selection. Selected soundings have their scale attribute reset to the appropriate scale. The end result is that each sounding has an individual scale attribute such that given the viewing scale the sql statement..”*select soundings where sounding.scale>viewer.scale*” will result in the appropriate soundings been displayed in an uncluttered manner.

The Nautical database.

The implementation of GIS systems in the Hydrographic Community can not be considered without reference to the work done over the years by Subcommittee Number 57 of the International Hydrographic Organization, which gives its name to the S57 model and interchange format used for the production of the ENCs that are required for the operation of ECDIS systems. The S57 model defines topology, a data dictionary of all objects and attributes required to produce either an ENC or hard copy chart and the record definitions for data transfer between systems. The implementation of the model at the physical, software levels however is left totally to the end user.

The S57 topology model requires a 'chain-node-explicit' level of topology. Linear features must start and end at defined 'connected nodes' and may be displayed or non displayed. Areas are defined in terms of a sequence of linear edges with direction. One specific dataset know as ‘Skins of the Earth’ must have a fully topologically structured surface so that any 'isolated nodes' exist in an area. The Object records with their attribution then reference the spatial vectors of the topology.

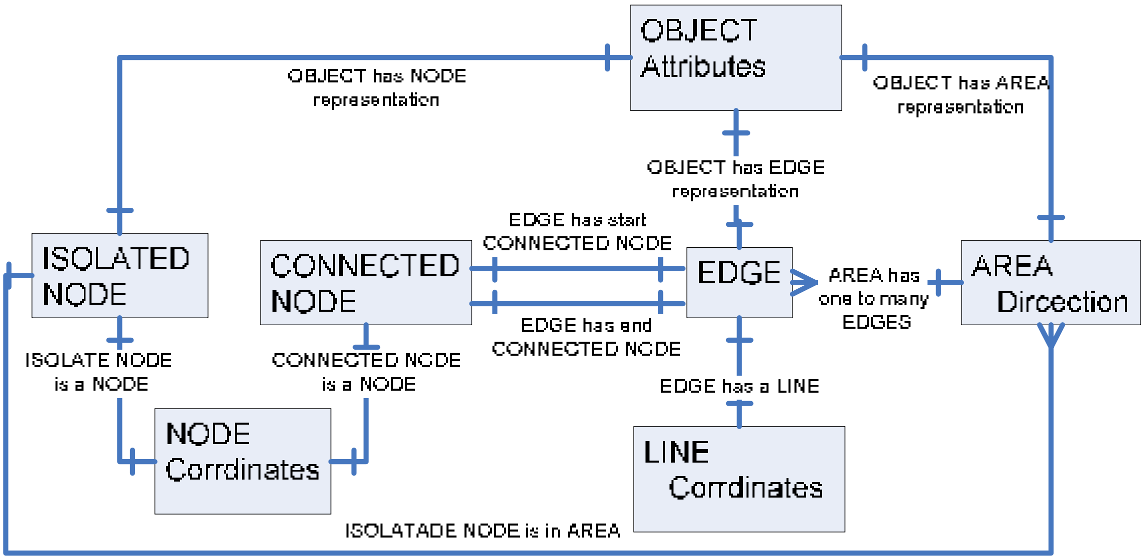

Figure 10. S57 Topology Model

In 1994 commercial software for ENC production was very weak, and spatial capability for databases was still in its infancy. Most databases used a vector of point, line or polygon where attribution and geometry were stored in the same feature record, such systems could not easily support this topology, and none could support areas where part of the boundary was displayed and part was not.

Additionally the learning curve for any new technology could have delayed the VTMS project considerably.

HSU, at that time, had a CADD system and all navigation data for the concessional area of the Arabian Gulf existed in digital form, albeit in UTM projection based on the

Ain Al Abd datum. The CADD system also allowed for attachment of database record pointers to the graphic elements. It was therefore decided that, due to time restrictions and familiarity, the S57 model would be implemented in the CADD system with Database attachment.

The data was merged, from the numerous map sheets where it existed, into a single file and the transformed into WGS84 geographic coordinates, being the coordinate system required for S57. Any area graphics were dropped to their basic edge definitions, and then circles, ellipses, arcs etc., which are not supported in S57 , were stroked into line-strings. At the time of migration, under version 2 of the S57 data was gathered into groups known as 'cells', each cell being a square, where the size depended upon the compilation purpose of the data. HSU data was for coastal navigation, compiled at 1:10,000 and so by S57 specification the data was formed into cells of size 15 minutes.

The original navigation data was well structured in terms of CADD data and by using the graphic elements level, color and line style it was possible to identify the type of S57 Object and create and attach an attribute record in an appropriate table in the supporting database. Numerous small automated and semi-automated programs were written to extract attributes from the textural labels of the navigation charts to update the base records. Much of the attribution was in hard copy in the form of volumes of “The Offshore Data Book” and the final attribution for the database was performed by clerical key-in.

The final program to be developed was the ENC extractor, which read the data from the CADD system and database, and then produced the ENC files meeting the required interchange format. Saudi Aramco's first Electronic Navigation Charts went into use in March 1995 when the Ras Tanura Vessel Traffic Management system was commissioned.

The Offshore Data Center

Even during the implementation of the S57 model it was realized that a more extensive attribute capability would be required to support the demands of the company not only for navigation purposes but also for oil production.

During the migration, if part of a hard copy record was required for S57, then the all attribution of the record was collected. For example the attribution required by an oil company for offshore platforms and pipelines far exceeds those needed for navigation. Additional feature objects were added, and continue to be added to create what is now referred to as the Nautical Database. This Nautical database is intended to be the 'single point of truth' for all offshore data under the custodianship of HSU, effectively a database model of the offshore environment.

The rationalization and consolidation of HSU data into the S57 model and its developing extensions, allowed HSU to move to the next stage of data leverage using the unit's first web site to render data specification, drawings and photographs of offshore platforms to users desktops. Such capability was extended until in 2001 all data previously available in “The Offshore Data Book” was available from the unit's web site, now renamed “The Offshore Data Center”

Figure 11 Offshore Data Center: Platform List for Berri Field Platforms

Platform Column is Hyperlinked to Platform Detail Page

Figure 12 Offshore Data Center: Platform Detail Page (1of 5)

Coordinates are obscured for security.

The Offshore Data Book had been a key document for offshore operations and planning since the 1920's. The printing, correlation, distribution and maintenance of this document were a major manpower effort which had now been eliminated. The re-organization of this data allowed the redesign of the Offshore Data Book into an A4 document that could be easily printed from the database. However since the data is now available on-line only a few copies of the new books are requested by those who operate offshore with no web availability.

On-line Charts.

The Nautical Database was meeting the requirement for ENCs , and the Offshore Data Center had increased internal productivity and improved customer service, however we had now created a demand for on-line charts to display the spatial aspects of our data. The CADD based format of the data did not lend itself to being displayed on the Web.; but fortunately Saudi Aramco had a new division E-Map that was specifically formed to develop web based GIS solutions.

E-Map and HSU worked in collaboration to produce an on-line chart but there were some challenges to be over come. E-Map used spatially enabled databases and specific commercial packages to enable on-line maps. This meant that the hydrographic data had to be migrated to a second database. The map viewers used were not capable of rendering the data to the IHO standards that were required by HSU and finally the structuring of the extensive attribute data and the display of that data was going to make for a lengthy project.

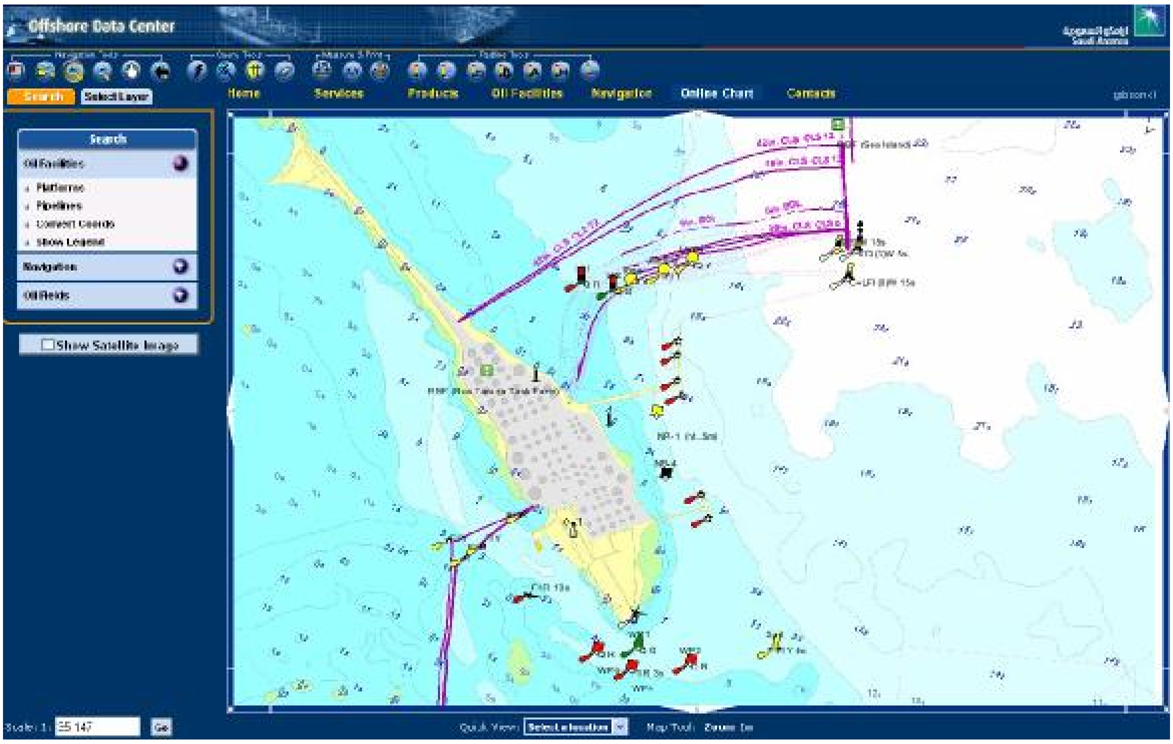

Figure 13 Offshore Data Center: On line Chart

Since the sole purpose of the database to be hosted by E-Map was to render spatial data visually there was no requirement for it to meet the S57 topology specification, and so it was decided to migrate the vector data only from the Nautical Database to this new 'spatial database'. This data was structured in simple point, line and polygon types and the attribution attached to the vectors was feature coding information, used to control the rendering on the screen and web page pointers to the page that best displayed the attributes of that vector.Controls were added to the web map viewer which allowed the user to click on a graphic element, such as an offshore platform, and the web page would be activated showing the user the familiar platform page with attribution and photos.

On such pages as these an additional control was added and entitled 'Show On Map'. This control would when clicked would display the on-line chart with the object centered in the view.The system went on line at the end of 2002 and was very well received.

Other Applications.

Once the base data for the offshore area was available other applications started to take advantage of its presence, such as helicopter routing, barge movement, operational planning etc. The spatial backdrop provided by the Offshore Data Center also allowed data from multiple systems to be integrated in a more meaningful manner.

Figure 14 Offshore Emergency

One good example of systems complimenting each other would be the development of a system for coordinating offshore response activities in case of an emergency

The picture to the left illustrates the kind of emergency situations that can be faced offshore. The picture is NOT a Saudi Aramco platform!

.

About two years ago Saudi Aramco implemented Automated Identification System(AIS) technology on all its fleet vessels and along the coast of the Arabian Gulf. Larger vessels traveling in international waters must carry AIS systems by the laws of the seas. These vessels have systems that transmit their name and position at frequent intervals. The signals are received by one of six stations along the coast and transmitted to two systems, in different locations to allow for redundancy.

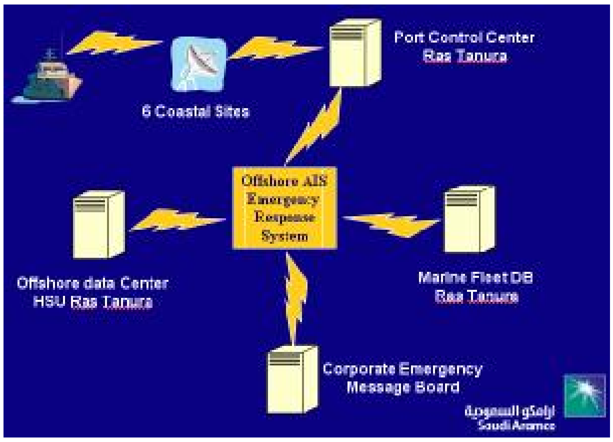

Fig 15 Offshore Emergency System

The Offshore AIS based emergency Response System (O.A.R.S.) brings together data from the AIS, marine fleet database and the Offshore Data Center and also integrates with the corporate emergency messaging system.

Should an offshore incident such as a blow out and fire be reported to a control center, the incident location is registered and the system shows the offshore platform center screen and indicated a default 1000m exclusion zone for shipping.

The marine fleet data base is accessed to find the best vessels for response. The coordinator can, for example, filter to see all fire fighting vessels. This data correlated with the AIS position for the ships, and knowing the ships maximum speed, allows the vessels to be listed by the soonest to be able to arrive.

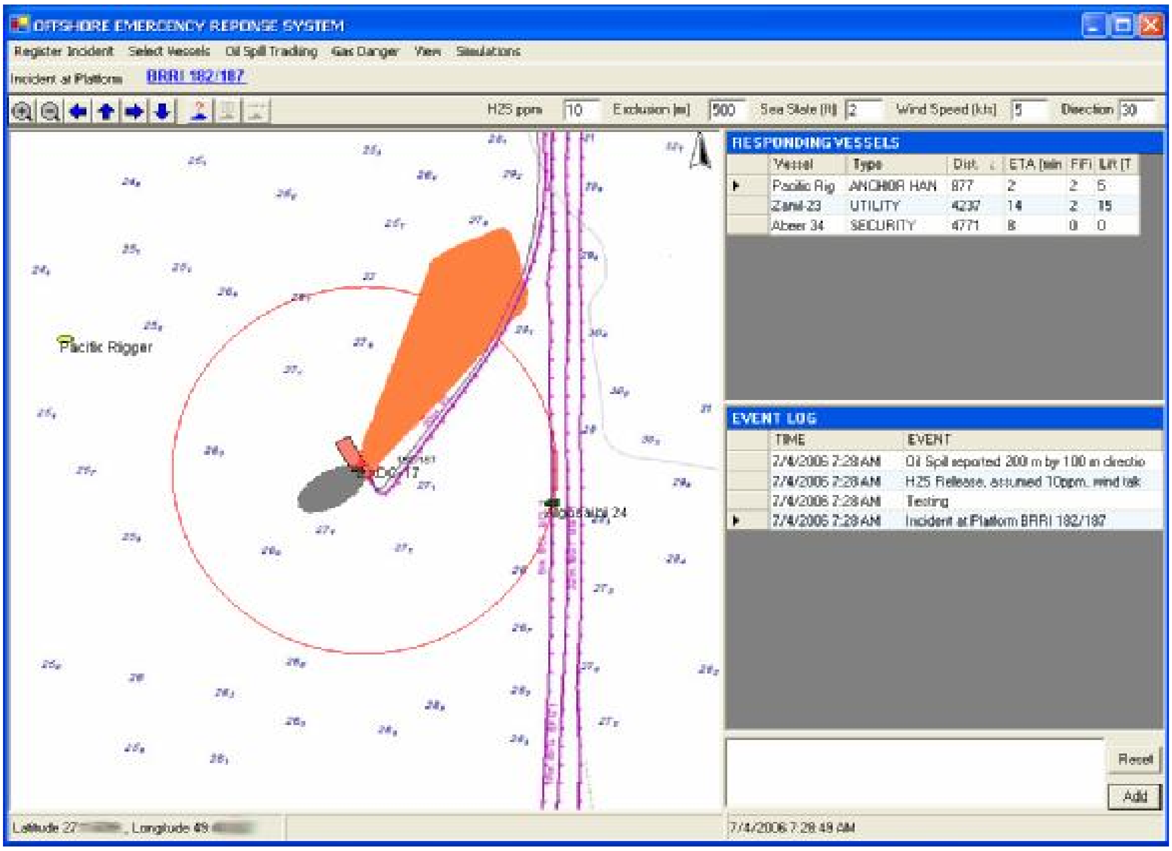

Figure 16 O.A.R.S interface Showing H2S plume and Oil Spill

The controller clicks the vessel he desires to respond and the system formulates the required message to the vessel including the course the vessel must set and the coordinate of the station to be taken up. The controller radios the vessel and relays the message. When the responding vessel replies, the controller clicks ADD on the message and it is logged and transmitted over the corporate emergency system.

The procedure is repeated until all vessels needed are responding. At the control center the system screen can be zoomed and panned as needed, and approaching vessels can me monitored and coordinated. The vessel position, direction an speed are displayed over the electronic chart. The system also monitors other, non-responding, vessels in the area and should a projected course enter the exclusion zone an alarm is sounded and the offending vessel highlighted. Should the vessel refuse to respond to radio, the system can calculate for a vessel, usually a security vessel, the optimum intercept course.

Meanwhile on the responding vessel, the bridge may have either an ECDIS system or chart plotter. These systems display HSU electronic navigation charts keeping the vessel centered on the chart at all times. Systems can also overlay AIS data so that Captains can see other vessels in the area, and especially if moving at night or in foggy conditions, the radar signal may also be overlayed indicating any unidentified radar target. The end result is the right vessels arrive in the fastest possible time and in the safest manner.

Conclusion

The use of GIS technology in HSU has been one of evolution. This has been deliberate and governed by a strategy of going for early deliverables to meet the highest priority need, rather than attempting to implement a single all encompassing solution.

The S57 model of the IHO gave a solid data structure for the initial ENC implementation, which in turn allowed both development staff and end users to become familiar with GIS concepts and better plan and implement extensions to both data and function. The evolution continues, and HSU is presently planning the next phase, which considers three basic aspects.

Firstly, central to the GIS effort is the Nautical Database. This will soon be upgraded to commercial software that is S57 compliant and uses an open architecture spatial database. The database system will continue to be extended and in the next phase will encompass platform details down to control valves and also encapsulate geo-technical information.

Secondly, methods for loading and generalizing survey data will continue and be predominantly driven by advancements in hydrographic survey equipment.

Thirdly, methods and application which exploit the value of the acquired data will be pursued. In this area we have come to distinguish a difference between a ‘cartographic database’ and a ‘published database’; a philosophy which will guide the near future development.

The Nautical Database is a form of ‘cartographic database’. It is highly dynamic, having numerous edits performed on it on a daily basis. It’s structure specifically support the generation of IHO compliant charts both hard copy and electronic.

This source data will in future be migrated and updated in ‘published databases’ which will be accessible by the company as a whole and form a base for GIS application development, both within and external to HSU.The source data may be manipulated during the migration to multiple database structure. For example, the same source data will migrate to a two dimensional corporate database integrating both onshore and offshore data. Additionally this data will be migrated to a 3 dimension pipeline database for flow analysis.

These ‘Published Databases’ are corporate assets which will open the door to spatially enabling many datasets and applications. The possibilities for use of the data will then become boundless, beyond the scope of this paper.

[i] Canadian hydrographic Service

Web Site: *www.charts.gc.ca/pub/*

[ii] Woods Hole Oceanographic Institution

Web Site: *www.punaridge.org*

[iii] University of Rhodes Island: Office of Marine Programs

Web Site *www.dosits.org*

[iv] National Oceanic and Atmospheric Administration

Web Site: *oceanservice.noaa.gov*

[v] NOAA Photo Library

Web Site: *photolib.noaa.gov*