Geographic Information System (GIS) in Offshore Pipeline Route Selection: Past, Present, and Future

Abdul-Lateef Balogun (Corresponding Author)
Department of Civil Engineering,
Universiti Teknologi PETRONAS (UTP), Perak, Malaysia
Tel: +60133619767 E-mail: geospatial63@gmail.com

Abdul-Nasir Matori
Department of Civil Engineering,
Universiti Teknologi PETRONAS (UTP), Perak, Malaysia

Khamaruzaman Yussof
Department of Civil Engineering,
Universiti Teknologi PETRONAS (UTP), Perak, Malaysia

Dano Umar Lawal
Department of Civil Engineering,
Universiti Teknologi PETRONAS (UTP), Perak, Malaysia

Imtiaz Ahmed Chandio
Department of Civil Engineering,
Universiti Teknologi PETRONAS (UTP), Perak, Malaysia

Abstract

The merits of Geographic Information System (GIS) as an effective and versatile analytical tool have enhanced its acceptability as a route selection tool for oil and gas pipelines. Proper pipeline route selection using GIS has numerous benefits including minimizing pipe failures and negative environmental impacts which could be caused by accidental oil leakages. Hence more operators are utilizing the technique, especially for onshore pipeline routing projects. With attention and activities rapidly expanding from onshore to ultra-deep water offshore oil exploration and transportation, it is pertinent to extend the GIS spatial decision making procedure to the offshore domain. The study of offshore pipeline corridor and route selection using GIS and/or Spatial Decision Support System (SDSS) is a relatively new research field. This contrasts sharply with the use of GIS in onshore routing projects which have several case study reports in the literature. The dearth of open access reference materials on offshore pipeline route selection using GIS makes it challenging for students and academic researchers to conduct further research on this vital field. Therefore a comprehensive study will likely provide valuable information on the current efforts of academics in this field and offer possible leads for further research. Consequently, this paper examines and discusses various offshore routing projects in the past and present, with special attention on GIS application. Limitations of GIS in multi-criteria and multi-participant decision making tasks such as offshore pipeline route selection are also discussed. Suggestions on the enhancement on accuracy and reliability of the decision system are proffered. It is hoped that this paper will serve as a valuable catalog of the subject matter and stimulate further research in this relatively nascent field thereby facilitating environmentally safe offshore pipeline routing operations.

Keywords: Environment, GIS, Offshore, Pipeline, Route Selection, SDSS, Uncertainty

1. INTRODUCTION

Presently and since inception, oil exploration and transportation has predominantly been onshore (Smith 2006; 2010; 2011; 2012). However, recent discoveries about the benefits of offshore exploration are beginning to stir more interest in offshore product transportation. Offshore or subsea configuration has numerous merits over an onshore alternative. Offshore solutions generally do not have any major effects on the environment; they offer a significant reduction in community disturbances; and are an environmentally sound alternative to onshore structures (Hegde 2006; Nord Stream 2008; 2012). Furthermore, the continuous depletion of onshore oil and gas reserves is compelling companies to seek alternatives in offshore solutions. These and other considerations are driving interests in offshore product transportation via pipelines. Consequently, submarine pipeline corridor and route selection is becoming extremely important and will attract more attention in the future (Oynes 2004; Robertson et al., 2004; Chai et al. 2006).

Pipeline route selection is a strategic component of a company's pipe laying activities. Selection of an appropriate pipeline route is perhaps the single most important element in the development of transmission lines (Khene 1997; Degermenci 2001). The pipeline route selection process focuses on achieving the optimal location for a pipeline. Optimization of route selection brings about risks and costs reduction, as well as a better decision making process. The selected route can significantly affect the success or failure of a project. It is thus essential to find a route which causes minimum damage to the environment, is technically feasible, is constructible at reasonable costs, and creates minimum resistance from the public (Feizlmayr et al. 1999). Basically, critical issues affecting route selection are societal risk, environmental impact, and engineering and operational efficiency. Other route selection considerations include physical, political, economic, and regulatory concerns (Carpenter et al. 1984; Ryder 1987; Feldman et al. 1995; Montemurro et al. 1998).

A system that can optimize relationships among these routing factors and identify trade-offs is capable of generating several feasible alternatives. A GIS-based system can do this because of its ability to model both qualitative and quantitative analyses (Montemurro et al. 1998). Multiple topographic, environmental, and pipeline data layers can be integrated in various ways to produce required maps and alignment sheets thereby facilitating detailed route survey, with minimal field work required (Feizlmayr et al. 1999). Due to the merits of GIS, efforts have been made and are still being made to utilize it for pipeline route selection projects. If properly used, GIS will enhance the speed and consistency of pipeline corridor and route selection process (Montemurro et al. 1998; Matori 2009). However, a vast majority of the reported works on the application of GIS to route selection have been limited to onshore routing projects-there is sparse mention of the use of GIS in offshore pipeline route selection. This dearth of open access reference materials on offshore pipeline route selection using GIS makes it challenging for students and academic researchers to conduct further research on this vital field.

To tackle this problem, this paper examines some of the major offshore route selection projects reported in literature in the past and present and an attempt is made to review the use of GIS in these projects. It is believed that this work will give a quick insight to possible applications of GIS in offshore routing projects in future and serve as a reference material to research students and research fellows interested in exploring offshore pipeline route selection.

2. GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic Information Systems (GIS) is a collection of geographic data, computer hardware, software, people, and organizations, for the purpose of collecting, storing, analyzing and disseminating all types of geographically referenced information (Dueker and Kjcrne 1989). GIS are designed to handle information relating to spatial locations. According to Peuquet (1990) and Clarke (1999), five core elements must be present in a GIS namely: data acquisition, data pre-processing, data storage and retrieval, manipulation and analysis, and data reporting. These five components literally represent the flow of work in a GIS system. Since early ’90s, GIS has become a state-of-the-art technology suitable for maintaining and analyzing spatial and thematic information on spatial objects. An effective decision making tool, GIS is progressively being depended upon by an array of professionals from diverse fields with regards to accessing, viewing, relating and analyzing maps and data. When used together with other applications, GIS has got the unparalleled capacity to handle, aggregate, quality-control, preserve, and secure spatial data (Balogun, 2009). With these unique capabilities, GIS is widely reputed as an effective tool for planning and development.

3. OFFSHORE PIPELINE ROUTE SELECTION

Offshore pipeline route selection has not benefitted as immensely as onshore pipeline routing with respect to the use of GIS and other analytical tools (King et al. 2011). During a routing project within the Persian Gulf recently, it was observed that there were no examples of GIS-based marine pipeline projects from which to derive route selection risk factors (Byron 2010). This contrast sharply with onshore pipeline projects which have several examples of GIS based routings that are well documented in various journal papers. GIS previously has been the domain of onshore pipelines (Oil & Gas 2007). Instead of GIS-based routing, a popular approach in offshore route selection is conducting series of preinstallation and pre construction surveys on selected routes (usually the most direct and straight route) in-order to identify possible pipeline routes (Beckmann et al. 1991; Oil & Gas 1993). This is similar to the traditional onshore route selection approach which typically begins with a start to end (source to destination) plan. A large area within the start and end points is identified and detailed data within this whole area is acquired. Typical data sources include maps, field surveys, aerial photographs, or other sources that provide information on routing obstacles which must be overcome. If the proposed route presents insurmountable physical obstacles, environmental constraints, or other barriers, a new route must be explored and the data collection process begins again (Oil and Gas 1993; Humber 2004; Berry et al. 2004). This traditional method is characterized by small scale paper maps, hand delineation, and manual topographic map overlay (Jankowski 1995; Price 2009). There is limited use of technology in this process and feasible results obtained from the data acquisition process serve as a preliminary pipeline corridor on which decisions are based. The core strength of the traditional route selection method lies in its reliance on experts' experiences, interpretations, and judgments in selecting the final pipeline route (Jankowski 1995; Matori et al. 2009). However, the process has been criticized for its inaccuracies and resources wastage (Feldman et al. 1995; Humber 2004). It is claimed that this manual procedure is usually tedious, time consuming, and lacking details (Price 2011). It is further argued that it lacks a defendable, documented procedure that clearly demonstrates the constitution of a best route (Matori et al. 2009).

This approach is quite expensive and lacks the robustness provided by a GIS route analysis. For instance, using non-GIS analyses, a straight-line route crossing gentle sloping terrain might appear economically cheaper when considering constructability alone, but such analyses often underestimate the cost of social and environmental impacts. Consequently, some spatial analyses provide evidence in support of longer, more-expensive alternatives over shorter routes that cross sensitive habitats or a vulnerable population (Humber 2004; Price 2011; Salah et al. 2011). This is one of the core strengths of GIS-giving decision makers the opportunity to view issues from several different perspectives.

3.1 OVERVIEW OF OFFSHORE ROUTING PROJECTS

This section presents a collection of some major offshore/submarine/subsea routing projects in the literature.

Papua New Guinea's pipeline project transporting crude oil from the southern Islands to a marine terminal located in the Gulf of Papua started in 1988.The pipeline included both land and marine components. For the offshore part, a 40 km marine pipeline route, the longest known pipeline route down a river, was selected (Price et al. 1993). This route was eventually chosen after an initial plan to select a straight line route from the onshore terminus was jettisoned. Long term integrity, constructability, and cost effectiveness were some of the factors considered in the route selection process (Mcgovern et al. 1992). Basically, the pipeline route is along the deepest part of the river. The chosen route caused less disruption to the surrounding ecological system. In addition to the merits of the chosen route which was selected primarily based on information obtained from bathymetric and geotechnic data, a GIS based approach could provide more route options, more detailed information on possible routes, and generally enhance the route selection process thereby saving cost and time.

In the early 90's, a 440 mile, 28 inch subsea gas pipeline in the South China Sea was built. This massive project represented Asia's first major (and the world's 2nd longest) subsea pipeline, after Zeepipe in the North Sea (Wilburn et al. 1995). Based on available datasets, two optional routing strategies were considered but there was no mention of the use of GIS or any Spatial Decision Support System (SDSS) in selecting the preferred and most appropriate route.

Canada's first subsea gas pipeline system became operational in 1991 (Yamauchi et al. 1991). Knowledge of seabed topography, soil and current conditions were obtained via detailed offshore survey. Some of the challenges encountered during the route selection process include irregular seabed topography, distance from a functional market catering for offshore construction services etc. (Yamauchi 1990a; Yamauchi 1990b). Subsequently, suitable pipeline routes were selected taking into consideration these factors, as well as possible pipe spanning and other environmental parameters. Similarly, there was no mention of the use of SDSS or even GIS in this project.

For the efficient export of Caspian oil and gas to Europe, the EU commissioned feasibility studies on the construction of new transport systems in 1999. These systems would comprise onshore and offshore oil and gas pipelines, marine loading and unloading terminals etc. Technical, economic, and environmental feasibility of the proposed pipeline routes were the primary concerns tackled in the studies (Degermenci 2001). After careful consideration of necessary parameters, probable pipeline routes for the oil and gas products were identified. Some of the identified routes were code named as follows:

Route Name	Minimum Transport cost (Euro/Tonne)
Option AO	20.2
Option BO	23.6
Option GO	24.1
Option IO	24.8

Option AO is the cheapest of the routes under consideration. However it is not the most preferred because of safety and ecological risks associated with the use of that route. If minimizing environmental pollution is the major concern, option GO will be the preferred route. However based on future projections, it is estimated that increased activities along this route will definitely increase the environmental pollution risk and endanger the black sea. Thus to protect the black sea, option IO (the most expensive route), is the most preferred route since it does not involve the Black Sea (Degermenci 2001).This project shows that selecting an optimal route is usually a subjective process influenced by the interests and mindsets of respective stakeholders involved in the decision making process. The shortest, most direct, or/and cheapest route might not necessarily be the optimal route. Similarly, future projections under conditions of uncertainties also influence the final route selection.

In year 2000, Singapore completed the construction of one of the world's largest bottom-pull installations. The pipeline bundle comprises eight pipelines and two fiber optic cables with a total length of over 36 km. This project was undertaken as part of an expansion project of Shell's oil refinery complex, worth about $100-million. Selecting the optimal pipeline route in the highly active shipping/marine area posed unique challenges (Byfield 2000). Minimum environmental impact and minimum risk to surrounding facilities, shipping lanes, and reefs during construction and throughout the pipeline bundle's life were some of the concerns considered in the route selection process. Seabed profile, the sub-bottom profile, and seabed soil conditions were also evaluated. Furthermore, serious consideration was given to the preservation and protection of the vast network of submarine pipelines and cables around the congested area (Byfield 2000). In the end, the 15 months project was completed on schedule and on budget. The export gas pipeline from the Espirito Santo basin's deepwater Golfinho field off Brazil leveraged geophysical and geological data in selecting suitable routes for the pipes. These data obtained in 2004 facilitated the identification of areas of the seafloor to be avoided during the route design. Erosion prone areas and areas of high slopes were tagged as non-favourable routes (Marcelo Jose et al. 2006). Like other projects mentioned above, this work did not provide details on the use of GIS or SDSS for this project.

Between 2006 and 2009, a multidisciplinary team was assembled to determine feasible pipeline routes for a major pipeline project proposed for western Canada. The major task was how to preserve water-course crossings along the proposed route. Preservation of various fish species and environmental features, geomorphologic features, Hydrologic features, and constructability factors were some of the parameters considered. In several instances, the most suitable location with respect to minimum risk to fish and fish habitat was not the best location from a construction view point (Jasper et al. 2011). During the three year assessment period, the route corridor changed several times and many route revisions were implemented. The methodology adopted for this particular project works best for small to medium-sized watercourses and is not suitable for large study areas.

Selecting an appropriate offshore route for the transportation of natural gas from Algeria to Spain required the consideration of several factors. These include: minimization of environmental impact; protection of marine flora and fauna; avoidance of natural obstacles; low geological, geotechnical risks; minimal number of cable crossings; minimization of free-span lengths (Chaudhuri 2005; Smith 2008). The 198.3 km offshore route includes 19 curvature points and five places where the line crosses telecommunications cables. It also passes through a fault and some areas of steep slopes. Though a GIS was developed for this project, it was designed and deployed primarily for integrity management rather than optimal route selection.

The Nord stream natural gas pipeline project across the Baltic Sea is one of the key projects embarked upon by the EU for the construction of new import routes for gas offshore. It is the biggest infrastructure project in the Baltic Sea region. Without Nord stream, it would be impossible for the EU to meet future energy demands (Nord Stream 2008). Over 100 million Euros were utilized in surveying and planning the optimal route. In planning the pipeline route, the consortium conducted the most comprehensive research of the Baltic Sea ever. Well over 2,500 square kilometres along the route were precisely surveyed. Extensive dialogue and consultations were held with governments, authorities, experts and stakeholders in all Baltic Sea states to ensure that the design, routing, construction and operation of the pipeline will be safe and environmentally sound (Nord Stream 2012). Many potential routes and landfall locations were identified during the route selection phase and the preferred route was chosen after an integrated evaluation of environmental, technological and economic factors. The selected route was the shortest possible route of all the alternatives. Like many other works in this field, detailed information on the GIS/SDSS methodology adopted (if any) in selecting the optimal route isn't offered. Similarly, the European Union (EU) REACCESS project basically utilized GIS for the geographic representation and visualization of identified energy routes and infrastructures (Pregger et al. 2011). The more advanced capabilities of SDSS for simulation of several alternative routes and optimal route selection were not reported. The information provided by the REACCESS GIS system include route starting points, destinations, geographic setup, corridor length and corridor sections (REACCESS 2010).

A summary of the various projects discussed shows that the use of GIS is rarely mentioned in most of these projects. This is in spite of the fact that a route selection process based on a GIS-least cost path analysis has the potential to further reduce project costs by 15 % to 30% (Delavar 2003; Humber 2004; Exprodat 2012). The few cases that adopt GIS do not provide sufficiently detailed explanation of particular analysis techniques or validation procedures used.

4. GIS APPLICATIONS IN OFFSHORE ROUTING PROJECTS

While many onshore route selection efforts have detailed their methodology as it relates to the use of GIS in achieving the overall scientific goals of a project, only very few published research works focus on the offshore route selection process using GIS (Khene 1997; Oil & Gas 2007; King et al. 2011). Most of the publicly available reports are found in magazines rather than in peer-reviewed scholarly works. Specifically, the offshore pipeline routing literature often briefly describes data collection and analysis methods, but fails to provide sufficiently detailed explanation of particular analysis techniques or validation procedures so that others can employ them. There is a lack of reference material and readily available tools to give modelers a reliable pipeline corridor from which the most suitable route can be chosen. Below is a summary of the identified projects that utilized GIS as a route selection tool.

In 1996, a pipeline routing project around the US gulf of Mexico was initiated. The approximate route included 80-90 miles of pipeline offshore and 120 to 130 miles of pipeline onshore. Offshore and onshore supporting GIS data bases were developed for this project. To save cost and enhance the accuracy of the generated route, an automated method involving GIS, satellite-image processing, and GPS satellite positioning, was adopted. The GIS-based route proved to be less-expensive and more reliable than routes generated from previous similar projects using a manual approach (Scott et al. 1998). During this project, three core application areas of GIS were utilized:

Buffer Analysis: This was utilized to obtain information about the proximity of the pipeline to relevant features. The quantity and identity of features around a specified area of interest can be detected using buffer analysis.

Overlay Analysis: This type of spatial analysis is used to resolve location sensitive issues i.e. provide answers to queries concerning the location of different datasets.

Route Analysis: This helps determine the extent of encroachment of the pipelines across sensitive areas like wetlands, stream crossings e.t.c.

GIS was also utilized as a preliminary pipeline planning tool for the Devil's Tower prospect located in the Gulf of Mexico. Using GIS, it was easy to instantaneously spot a number of features that made the traditionally preferred straight route undesirable (Gaddy 2000). Several scenarios were simulated to avoid the pipeline risk areas and minimize pipeline crossovers. As a cost alternative, alternative routes were designed to pass through the risk areas while paying heed to steep or rocky seafloor. The attributes of these routes can be used to assess each route's cost-effectiveness and preference over another.

The oil and gas field in the North Sea close to Norway has an unusual seabed topography, which makes pipeline routes design of the area a very challenging task. Proposed pipeline routes could not avoid passing over obstacles in some areas. GIS was used for the planning and selection of transponder sites along the pipeline routes (Ingebretsen et al. 2006).

More recently in 2010, GIS was used as part of a risk based approach in making pipeline routing decisions. Simple weighted index (SWI) and pair-based comparison methods were used for weight derivation of routing criteria (Byron 2010). The results were validated by comparing calculated routes against existing pipelines. GIS was also used to optimize different pipeline routes and configurations for an offshore project in the arctic (King et al. 2011). Ice gouge crossing rates, gouge depth, trench depth, pipeline cost, and trenching cost are some of the basic parameters utilized in the GIS Least cost path (LCP) analysis for determining the suitable pipeline route. This GIS application in this project seems peculiar to sea beds with ice gouge.

These projects represent the few documented and published works highlighting the use and efficacy of GIS in offshore pipeline route selection as shown in table 1.

Table 1: Summary of Offshore route selection works utilizing GIS in published Literature

S/N	Author	Year	Source	Main DS Tool	Other DS Tools Used
1.	Scott and Schmidt	1998	Magazine	GIS	None
2.	Gaddy	2000	Magazine	GIS	None
3.	Ingebretsen et al.	2006	Magazine	GIS	None
4.	Matori and Lee	2009	Conference Proceedings /Magazine	GIS	None
5.	Bryon	2010	Magazine	GIS	Simple weighted index (SWI); Pair based comparison index
6.	King et al.	2011	Conference Proceedings	GIS	None

5. OFFSHORE PIPELINE ROUTE SELECTION USING GIS, THE FUTURE

Over the last decade, there seems to be an increase in awareness on the merits of GIS in offshore route selection projects and the number of pertinent case studies appears to be rising. However, there are also concerns regarding the reliability of GIS especially when dealing with multi-participant and multi-criteria problems like offshore pipeline route selection. Many researchers have expressed concerns that GIS is a limited tool in spatial decision-aid domain. This is primarily attributed to its lack of more powerful analytical tools which makes it challenging to reliably deal with spatial problems involving several diverse groups with conflicting objectives/criteria (Janssen and Rietveld 1990; Carver 1991; Fischer and Nijkamp 1993; Laaribi et al. 1996; Malczewski 1999; Chakhar et al. 2003). It is argued that decision makers' preferences, represented by criteria weights are not accurately represented by current GIS (Chakhar et al. 2003). To overcome this challenge, several researches have been undertaken to integrate GIS with other analytical tools to produce robust spatial decision support systems (SDSS) capable of effectively solving multi-criteria and multi-participant problems (Chakhar et al. 2003). Specifically, Multi criteria decision making (MCDM) tools have been successfully used for various applications since the 1960s and many of these tools are working well with GIS too. Though MCDM is divided into two broad groups: Multi Attribute Decision making (MADM) and Multi Objective Decision making (MODM), MADM tools are more commonly integrated with GIS (Malczewski 2006). While GIS is a powerful tool for managing spatially referenced data, MADM tools offer powerful techniques for modeling spatial problems (Chakhar et al. 2003). Collectively, they form very powerful decision making tools capable of solving complex decision problems (Jankowski 1995; Malczewski 2006). It is thus necessary for researchers to focus attention on the integration of GIS with suitable MCDM technologies in-order to produce robust SDSS capable of accurately and reliably determining the optimal offshore pipeline route. A SDSS-based offshore pipeline route has the potential to minimize negative environmental impacts, as well as protect the eco-system by promptly identifying routes that are vulnerable to pipe damages and subsequently forestall oil leakages which could arise due to damages to such pipelines. The recent proliferation of spatial environmental data offers a unique opportunity for companies and other participants in the offshore industry to significantly reduce possible costs of environmental impacts and liability costs during and after routing projects. Costs of environmental damage; environmental remediation; environmental response and investigation could be lessened by adopting a SDSS in the route selection process (Jones and Barron 2005). Lin (2006) listed major types of MADM techniques as shown in table 2 below:

Table 2: Overview of MADM Techniques (Adapted from Lin, 2006)

MADM Technique	**Description**
Dominance	An alternative is dominated if there is another alternative which excels it at least one attribute and equals it in others.
Maximin	The overall performance of an alternative is determined by its weakest or poorest attribute (Pessimistic attitude).
Maximax	The overall performance of an alternative is determined by its best attribute (Optimistic attitude).
Conjunctive	An alternative is accepted if each attribute meets a set of preset minimal acceptable levels or standards. If at least one attribute doesn't meet the set, it is unacceptable. The minimal acceptable levels for each attribute are used to screen out unacceptable alternatives.
Disjunctive	An alternative is accepted if it scores sufficiently high on at least one attribute. If no attribute meets a set of preset minimal acceptable levels or standards, it is unacceptable. Desirable levels for each attribute are used to select alternative which exceed or equal those levels in any one attribute.
Lexicographic	Uses the most important attribute to evaluate and rank the alternatives from best (most preferred) to worst. If there is a tie for some of the alternatives (performance values of alternatives are equal), use the second important attribute for these alternatives, that is, to compare the alternatives by the order of attributes importance.
Elimination	Alternatives are compared one attribute each time and eliminated from consideration if they do not pass a yes-no or minimum acceptable level. Eliminates alternatives that do not satisfy some minimum acceptable level or standard, and it continues until all alternatives except one have been eliminated.
SAW	The overall score of an alternative is computed as the weighted sum of the attribute values.
Weighted product	The overall score of an alternative is

	computed as the weighted product of the attribute values.
TOPSIS	The chosen alternative should have the minimal distance from the positive-ideal solution and the maximal distance from the negative- ideal solution.
ELECTRE	The concept of an outranking relationship is used.
Median ranking	Adds all attributes ranks (ranks from each attribute) and ranks them in ascending order. If there is a tie for some alternatives (performance values of alternatives are equal), the median value of the ranks of them is used.
AHP	To construct the decision problem into a hierarchical structure. Pairwise comparison matrices are used to evaluate the importance among attributes and alternatives.

In addition to developing robust SDSS, it is also necessary to consider uncertainties in the decision environment in future works. Although most analysts deliberately choose to model MCDM problems and spatial decisions as occurring under conditions of certainty (Hwang and Yoon 1981; Malczewski 1999), this contrasts with reality because a lot of real-world decision situations involve uncertainties. A significant number of the real world decision-making occurs in an environment in which the goals, the constraints and the outcomes of possible actions are fuzzy (Ribeiro 1996). This is particularly important in the offshore environment which is inherently fuzzy. Thus offshore routing SDSS in future should be able to manage incomplete and uncertain (fuzzy) knowledge and information, in addition to being able to manage complete and certain knowledge and information in an offshore environment. Such a comprehensive SDSS will aid decision makers and environmental experts in analyzing various feasible offshore pipeline routing options and ultimately facilitate the selection of an optimal route which poses very minimal risks to the environment.

6. SUMMARY AND CONCLUSION

With attention gradually expanding to offshore oil and gas operations, construction of new oil and gas pipeline offshore routes in coming years is inevitable. The applications of GIS in pipeline route selection are well documented in existing literature. However, most of the available resources address onshore routing, not offshore. There is a lack of reference materials detailing the application of GIS to offshore route selection. This paper aims to draw new attention and stir more interest in this domain by detailing some of the major offshore pipeline routing projects recorded in literature. The dearth of the application of GIS in many of these published works was also highlighted. This is in-spite of the potential benefits of using GIS for pipeline route selection. For future applications, it is recommended to integrate GIS with other analytical tools in order to produce robust SDSSs which will enhance the reliability and accuracy of the route selection process. This is premised on concerns that using GIS alone has limitations when dealing with multiple criteria and multiple participant related projects like offshore pipeline route selection. GIS and MADM have complimentary features and GIS-MADM integration has the potential to tremendously enhance group decision making processes like offshore route selection. Furthermore, future SDSSs should be designed to effectively manage uncertainties/fuzziness in the decision environment. Such a robust and versatile system will have a higher degree of accuracy and be accepted by major stockholders in the offshore industry.

6. REFERENCES

Balogun, A. L. (2009). Three dimensional visualization of water pipelines. MSc thesis, Universiti Teknologi Malaysia.

Beckmann, M. M., Hale, J. R., & Lamison, C. W. (1991). Pipeline spanning-1: Route selection key first step in avoiding ocean floor spans. Oil and Gas Journal, 89(49), 55.

Berry, J.K., King, M.D., & Lopez, C. (2004). A web-based application for identifying and evaluating alternative pipeline routes and corridors. GITA Oil and Gas Conference, Houston, Texas.

Byfield, R. (2000). Harbor pipelay is one of the world's longest bottom-pull jobs. Oil & Gas Journal, 98, 76-83.

Byron, S. (2010). Risk-based pipeline routing improves success probability. Oil & Gas Journal, 108, 58-64.

Carpenter, G., & Callen, R. (1984). Improved procedures for natural gas pipeline routing in Michigan, Environ. Prof. 6, 26-31

Carver, S. J. (1991). Integrating multi-criteria evaluation with geographical information systems. International Journal of Geographical Information Systems, 5, 321-339

Chai, B. C., & Mahmud, M. R. (2006). The Key to Success in Submarine Pipeline Routing. Institute for Geospatial Science and Technology, Universiti Teknologi Malaysia (UTM). Johor, Malaysia.

Chakhar, S., & Martel, J.M. (2003). Enhancing Geographical Information Systems Capabilities with Multi-Criteria Evaluation Functions. Journal of Geographic Information and Decision Analysis 2003, 7 (2), 47 - 71

Chaudhuri, J. (2005). Medgaz pipeline promises energy security for Iberian Peninsula. Oil & Gas Journal, 103 (20), 59-62.

Clarke, K.C. (1999). Getting Started with Geographic Information Systems. Prentice Hall. Upper Saddle River, New Jersey.

Degermenci, O. (2001). EU study of Caspian area oil, gas pipelines compares routes, Costs. Oil & Gas Journal, 99, pp.68-78.

Delavar, M.R. (2003). Pipeline Routing using Geospatial Information System Analysis. ScanGIS-The 9th Scandinavian Research Conference on Geographical Information science. Espoo, Finland-Proceedings, 203-213

Dueker, K. J., & Kjcrne, D. (1989). Multipurpose cadastre: Terms and Definitions. Falls Church. VA: ASPRS and ACSM

Exprodat. (2012). Why use GIS in Petroleum? Version 1.0. Retrieved from: www.exprodat.com

Feizlmayr, A. H., & McKinnon, C. (1999). Lower costs, environmental protection drive future pipeline technologies. Oil & Gas Journal, 97, 83-89.

Fischer, M.M., & Nijkamp, P. (1993). Design and use of geographic information systems and spatial models. In: M.M. Fischer, and P. Nijkamp (eds.) Geographic information systems, spatial modelling and policy evaluation, 1-13. Berlin: Springer-Verlag.

Feldman, S., Ramona, P., Edwalser, C., & Douglas, A. (1995). A prototype for pipeline routing using remotely sensed data and GIS analysis. REMOTE SENS ENVIRON, 123-131

Gaddy, D.E. (2000). GIS-controlled workflow. Oil & Gas Journal, 98 (34), 15

Hegde, N. (2001). El Paso proceeding with offshore gas line from Nova Scotia to US. Oil and Gas Journal.

Humber, J. (2004). Enhancing the Pipeline route Selection Process. GITA Oil & Gas Conference Proceedings

Hwang, C.L., & Yoon, K. (1981). Multiple attribute decision making:

Methods and applications. Springer, Berlin.

Ingebretsen, E., & Stamford-Burrows, C. (2006). LBL array for hostile topography; using GIS to find transponder sites along pipeline routes. Hydro International, 10(9), 20-23.

Janssen, R., & Rietveld, P. (1990). Multicriteria analysis and GIS: an application to agricultural land use in The Netherlands. In Geographical Information Systems and Regional Planning, edited by H. J. Scholten and J. C. Stilwell (Dordrecht: Kluwer).

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. International Journal of Geographical Information Systems 9(3), 251-273.

Jasper, S., Doering, R., & Harris, J. (2011). Coordinated watercourse assessment streamlines pipeline development. Oil & Gas Journal, 109 (11), 126-131

Jones, R., & Barron, M. (2005). Site Selection of Petroleum Pipelines: A GIS approach to Minimize Environmental Impacts and Liabilities. Esri International User Conference. USA.

Khene, D.E. (1997). Cross-border gas-line projects face daunting challenges. Oil & Gas Journal, 95 (50), 33-39.

King, T., Philips, R., & Johansen, C. (2011). Pipeline Routing and Burial Depth Analysis Using GIS Software. OTC Arctic Technology Conference, Houston, Texas, USA

Laaribi, A., Chevallier, J.J., & Martel, J.M. (1996). A spatial decision aid: a multicriterion evaluation approach. Computers, Environment and Urban Systems, 20, 351–366.

Lin, H. Y. (2006). Data Warehouse System Evaluation and Selection Decisions.

Malczewski, J. (1999). GIS and Multicriteria Decision Analysis. John Wiley & sons, USA

Malczewski, J. (2006): GIS based multicriteria decision analysis: a survey of the literature, International Journal of Geographical Information Science, 20 (7), 703-726

Marcelo José, B. T., Claudio Roberto, M. B., Mônica de, C. G., Carlos Terêncio, P. B., & al, e. (2006). Golfinho route optimization keys successful lay off Brazil. Oil & Gas Journal, 104, 88-90, 92, 94, 96.

Matori, A.N., & Lee, H.Y. (2009). Suitability Analysis of Subsea Pipeline Route using GIS. Map Malaysia. GIS Development.

McGovern, R., & Miller, G. (1992). Unique Kutubu Export System Complete; Production Flowing. Oil & Gas Journal, 90 (31), 50-55

Montemurro, D., Barnett, S., & Gale, T. (1998). GIS-based process helps TransCanada select best route for expansion line. Oil & Gas Journal, 96 (25), 63

Nord Stream. (2008). The new gas supply route to Europe. Nord Stream, FACTS Issue 0/2008

Nord Stream. (2012). A Long-Term Solution for Europe's Energy Security. Nord Stream, Background Information.

Oil & Gas. (1993). GIS leads to more efficient route planning. Oil & Gas Journal, 91 (17), 81.

Oil & Gas. (2007). Pipeline challenges magnified in arctic, deepwater conditions. Oil and Gas Journal, 105 (7), S8-S11

Oynes, C. (2004). Deepwater Expansion Continues in Gulf of Mexico. Pipeline &

Gas Journal. 231(6), 58-59.

Peuquet, D. J. (1990). A conceptual frame work on comparison of spatial Data Models. Cartographica. 2(4).

Pregger,T., Lavagno, E., Labriet, M., Seljom, P., Biberacher, M., Blesl, M., Trieb, F., O'Sullivan, M., Gerboni, R., Schranz, L., Cabal, H., Lechón, Y., Zocher, D. (2011). Resources, capacities and corridors for energy imports to Europe. International Journal of Energy Sector Management, 5 (1), 125 - 156

Price, J., & Leipert, G. (1993). Papua New Guinea pipeline overcomes adverse climate, terrain. Oil & Gas Journal, 91, 68.

Price, G. (2009). Cross-Country Pipeline route selection. Mitigating "Costs" for Early Concept Development. MGIS CAPSTONE PROPOSAL

Price, G. (2011). Pipeline Route Selection: A GIS Jumpstart for International Growth. Geoplace.com. Bev-Al Communications.

REACCESS. (2010). "'Captive' and 'open sea' energy import framework", Deliverable D2.1 & D3.1 of EU Project "Risk of Energy Availability: Common Corridors for Europe Supply Security" (REACCESS), EC 7th Framework Programme, Forli.

Robertson, S., Westwood, J., & Westwood, D. (2004). Offshore Pipeline: A $54 Billion Market. Pipeline & Gas Journal. 231(4), 50-52.

Ribeiro, R. A. (1996). Fuzzy multiple attribute decision making: A review and new preference elicitation techniques. Fuzzy Sets and Systems 78(2), 155-181.

Ryder, A. (1987). Pipeline routing-experiences from Northern Scotland, pipes pipelines Int. 27 (39), 5-14

Salah, A.M., & Atwood, D. (2011). Pipeline Alignment Optimization: Automated GIS-Based Approach. Journal of Pipeline Systems Engineering and Practice, 2(1), 2–13.

Scott, D. R., & Schmidt, J. A. (1998). Merged GIS, GPS data assist siting for gulf gas line. Oil & Gas Journal, 96, 80-84.

Smith, C. E. (2006). Surging US, steady asia-pacific lead construction plans. Oil & Gas Journal, 104, 57-58, 60, 62-68.

Smith, C.E. (2008). Medgaz pipelay begins; S-lay, J-lay split duties. Oil & Gas Journal, 106, 17, 86-88, 90

Smith, C. E. (2010). Pipeline construction plans slow for 2010. Oil & Gas Journal, 108, 39-42, 44-46, 48-50.

Smith, C. E. (2011). Pipeline construction plans continue slide despite growth in natural gas. Oil & Gas Journal, 109, 110-111,113-114,116-121. Retrieved from http://search.proquest.com/docview/865935308?accountid=41678

Smith, C. E. (2012). Near-term pipeline plans grow, longer-term projects sag. Oil & Gas Journal, 110, 98-100,102,104-111. Retrieved from http://search.proquest.com/docview/923305240?accountid=41678

Wan, J., Qi, G., Zeng, Z., & Sun, S. (2011). The application of AHP in oil and gas pipeline route selection. 19th International Conference on Geoinformatics, IEEE.

Wilburn, J. S., & Roberts, P. M. (1995). Major Asian subsea pipeline to start up this year. Oil & Gas Journal, 93, 57

Yamauchi, H. (1990a). Vancouver Island Pipeline-1: Long awaited system to expand Canadian gas network. Oil & Gas Journal, 86.

Yamauchi, H. (1990b). Vancouver Island Pipeline-Conclusion: Marine-crossing sections require extensive surveying. Oil & Gas Journal, 47.

Yamauchi, H., & Timmermans, W. (1991). Canada's first subsea gas line conquers rocky approaches. Oil & Gas Journal, 89, 76.

Yildirim, V., Aydinoglu, A., & Yomralioglu, T. (2007) GIS based pipeline route selection by arcgis in Turkey. Twenty-Seventh Annual ESRI International User Conference. San Diego, California