# SUBMARINE PIPENRING AND INSPO
# WH GEORPHICAL INSTO SYSTEM TECHNOLOGY

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## ABSTRACT

Major advances have been achieved in recent years in submarine pipeline routing and inspection. Various tools and techniques are used to ensure the maximum safety of the submarine pipelines. The resulting consequence of these tools and techniques is the ever increasing data volumes, with the management and subsequent analysis of the data becoming more and more of an issue. The objective of this study is to implement the capabilities of Geographical Information System (GIS) to assemble various submarine pipeline related datasets into a common, compelling, efficient, user-friendly and interesting visualization system. In this study, GIS is used as the Spatial Decision Support System (SDSS), to provide appropriate information for efficient decision-making in submarine pipeline routing and inspection activities. A review of the literature concerning submarine pipeline routing and inspection technologies as well as GIS applications for both operations has been made for a better understanding to the existing problem faced by the industry. With the proper conceptual, logical and physical model design, an integration system has been developed to assemble, manipulate and analyze various submarine pipeline related datasets into a geodatabase. Sequentially, numerous Least Cost Paths (LCPs) have been determined to identify the most preferred route from SpringField platform to AutumnField platform, while considering the myriad of complex spatial interactions according to the diversified routing criteria. The best routing is then prudently analysed based on these LCPs with several geoprocessing analysis. Meanwhile, this study has integrated Digital Video System (DVS) datasets into ArcGIS-ArcMap environment to simultaneously record multiple channels of inspection video into a geodatabase and replay them synchronously according to its geographic features. Finally, some recommendations for future studies are made to enhance the quality of this study as well as to minimize the risk of offshore industries.

# ABSTRAK

Pembangunan dalam kerja perancangan dan pemeriksaan laluan saluran paip dasar laut semakin pesat kebelakangan ini. Pelbagai teknik dan peralatan digunakan bagi menjamin keselamatan yang maksimum bagi laluan saluran paip dasar laut tersebut. Ini telah meningkatkan jumlah data dan menimbulkan isu ke atas pengurusan analisis yang berturutan. Objektif utama bagi kajian ini ialah bagi mengimplimentasi keupayaan Sistem Maklumat Geografi (GIS) untuk mengumpul pelbagai data berkenaan saluran paip dasar laut ke dalam dataset yang bersesuaian, efisyen, mesra pengguna dan mempunyai sistem visualisasi yang menarik. Dalam kajian ini, GIS bertindak selaku *Spatial Decision Support System (SDSS)* yang berfungsi untuk menyediakan maklumat bagi membantu membuat keputusan yang lebih efisien dalam aktiviti perancangan dan pemeriksaan laluan saluran paip dasar laut. Kajian literatur berkenaan aplikasi GIS dan teknologi dalam perancangan dan pemeriksaan laluan saluran paip dasar laut dilakukan bagi mendapatkan pemahaman yang lebih mendalam berkenaan masalah yang dihadapi dalam industri ini. Satu sistem integrasi yang berdasarkan model konseptual, logikal dan fizikal telah dibangunkan bagi mengumpul, memanipulasi dan menganalisis pelbagai dataset bekenaan saluran paip dasar laut di dalam satu *geodatabase*. Ini diikuti dengan penentuan beberapa *Least Cost Paths (LCPs)* bagi mengenal pasti laluan yang bersesuaian dari pelantar SpringField ke pelantar AutumnField dengan mengambil kira kepelbagaian interaksi spatial yang kompleks berdasarkan beberapa kriteria laluan. Laluan LCP yang terbaik ditentukan melalui beberapa analisis *geoprocessing.* Dalam masa yang sama, pengintegrasian set data *Digital Video System (DVS)* kedalam ArcGIS-ArcMap secara langsung merekodkan video pemeriksaan yang berbilang saluran ke dalam satu *geodatabase* dan memainkannya semula serentak berdasarkan rupa bentuk geografik. Akhir sekali, beberapa cadangan kajian pada masa hadapan dibuat untuk mempertingkatkan kualiti kajian ini serta meminimakan risiko bagi industri lepas pantai.

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| | | |
|---|---|---|
| $\phi$ | - | Grain size |
| $\theta$ | - | Wave characteristics constant value, $(2\pi t)/T$ |
| $\Theta$ | - | Slope of seabed |
| $\eta$ | - | Wave profile |
| $\rho$ | - | Density of fluid, 2 slug/ft$^3$ for sea water |
| $\delta$ | - | Obstruction elevation |
| $\rho_s\, g$ | - | Weight density of steel (490/32.2) |
| $\xi$ | - | Water particle displacement (Horizontal) |
| $\zeta$ | - | Water particle displacement (Vertical) |
| $\mu$ | - | Coefficient of soil friction |
| $\beta$ | - | Dimensionless tension |
| $\sigma_c$ | - | Characteristic stress |
| $\sigma_m$ | - | Maximum dimensionless stress |
| $a_x$ | - | Water particle accelerations (Horizontal) |
| $a_z$ | - | Water particle accelerations (Vertical) |
| $A_T$ | - | Axial tension |
| C | - | Wave Celerity |
| $C_s$ | - | Remolded cohesive shear strength |
| $C_D$ | - | Hydrodynamic drag coefficient |
| $C_q$ | - | Group velocity |
| $C_L$ | - | Hydrodynamic lift coefficient |
| $C_M$ | - | Hydrodynamic inertia or mass coefficient |
| d | - | Water depth |
| du | - | horizontal water particle acceleration over pipe |
| D | - | Pipe outside diameter |

| | | |
|---|---|---|
| $D_i$ | - | Pipe internal diameter |
| $D/W_t$ | - | Pipe-diameter/wall thickness ratio |
| E | - | Elastic modulus |
| EI | - | Pipe stiffness |
| $f_n$ | - | Natural frequency of the pipe span |
| $f_s$ | - | Vortex-shedding frequency |
| $F_D$ | - | Combined drag force |
| $F_i$ | - | Inertia force |
| $F_L$ | - | Combined lift force |
| $F_r$. | - | Friction resistance force between the pipe and the seabed |
| g | - | Constant value of gravity |
| H | - | Significant wave height |
| $H_o$ | - | Deepwater wave height |
| L | - | Wave Length |
| $L_c$ | - | Characteristic length |
| $L_o$ | - | Deepwater wave length |
| $L_s$ | - | Span Length |
| M | | Combined mass of the pipe and added mass around the pipe per unit length of pipe |
| $M_a$ | - | Pipe unit mass |
| $M_D$ | - | Displaced mass |
| N | - | Normal force |
| p | - | Subsurface pressure |
| $R_e$ | - | Reynolds number |
| S | - | Strouhal number |
| SG | - | Specific gravity |
| $SG_1$ | - | Lower range of pipe specific gravity |
| $SG_2$ | - | Upper range of pipe specific gravity |
| $SG_C$ | - | Specific gravity (during construction) |
| $SG_o$ | - | Specified gravity (during operation) |
| $SG_{float}$ | - | Specified gravity (to float the pipeline) |
| $SG_{sink}$ | - | Specified gravity (to sink the pipeline) |
| t | - | Time (0 second is used for severe oceanographic condition) |
| T | - | Average wave period |

| | | |
|---|---|---|
| u | - | Water particle velocity (Horizontal) |
| U | - | Flow velocity in boundary layer |
| $U_e$ | - | Effective horizontal water-particle velocity over pipe height |
| $U_o$ | - | Measured/calculated horizontal particle velocity at height $y_o$, |
| v | - | Kinematics viscosity of the fluid about $1.0 x 10^5$ $ft^2$/sec for sea water |
| V | - | Flow velocity |
| w | - | Water particle velocity (Vertical) |
| W | - | Submerged weight of the pipe and the weight of the contents |
| $W_a$ | - | Pipe unit weight in air |
| WT | - | Pipe wall thickness |
| z | - | computational oceanographic height |

## LIST OF ACRONYMS

| | | |
|---|---|---|
| 2D | - | Two Dimensional |
| 3D | - | Three Dimensional |
| ACM | - | Accumulative Cost Map |
| AIM | - | Asset Integrity Management |
| ANSI | - | American National Standard Code |
| API | - | American Petroleum Institute |
| ASCE | - | American Society of Civil Engineers |
| ASCII | - | Amsterdam Subversive Center for Information Interchange |
| ASE | - | Average Standard Error |
| ASME | - | American Standard for Mechanical Engineering |
| AUV | - | Autonomous Underwater Vehicle |
| BS | - | British Standard |
| CAD | - | Computer-Aided Design |
| CASE | - | Computer-Aided Software Engineering |
| CWD | - | Cost-Weighted Distance |
| CEOM | - | Centro Oceanologico Mediterraneo |
| CFD | - | Computational Fluid Dynamics |
| CIC | - | Cloud-In-Cell |
| COLOS | - | Conceptual of Learning Sciences |
| CP | - | Communication Plan |
| DBF | - | Dbase File |
| DBMS | - | Database Management System |
| DCM | - | Discrete Cost Map |
| DGPS | - | Differential Global Positioning System |
| DHSS | - | Dual Head Scanner Sonar |
| DNV | - | Det Norske Veritas |
| DTM | - | Digital Terrain Model |

| | | |
|---|---|---|
| DVS | - | Digital Video System |
| E-R | - | Entity-Relationship |
| EPI | - | External Pipeline Inspection |
| ESDA | - | Exploratory Spatial Data Analysis |
| ESRI | - | Environmental Science Research Institute |
| GA | - | Geostatistical Analyst |
| GB | - | Gigabyte |
| GEOPIG | - | Geometry Pig |
| GIS | - | Geographic Information System |
| GPS | - | Global Positioning System |
| GUI | - | Graphic User Interface |
| HCA | - | High Consequence Area |
| HRTO | - | Hydrographic Research and Training Office |
| IBP | | Instituto Brasileiro de Petróleo e Gás / Brazilian Petroleum and Gas Institute |
| IEEE | - | Institute of Electrical and Electronics Engineers |
| IHOCE | - | International Hydrographic & Oceanographic Conference & Exhibition |
| ILI | - | In-Line Inspection |
| IMP | - | Integrity Management Plan |
| IPI | - | Internal Pipeline Inspection |
| LCP | - | Least Cost Path |
| LES | - | Large Eddy Simulations |
| LOOP | - | Louisiana Offshore Oil Port |
| LSD | - | Limit States Design |
| MB | - | Megabyte |
| MCP | - | Management of Change Plan |
| MSC | - | Meteorological Service of Canada |
| OC | - | Optimal Corridor |
| OCM | - | Optimal Corridor Map |
| OMAE | - | Offshore Mechanics and Arctic Engineering |
| OR | - | Optimal Route |
| OSIF | - | Offshore Soil Investigation Forum |
| PDF | - | Portable Document Format |

| | | |
|---|---|---|
| PETRONAS | - | Petroliam National Berhad |
| PKT | - | Packet format |
| PP | - | Performance Plan |
| PSI | - | Pounds per Square Inch |
| PTS | - | Petronas Technical Standard |
| PTTC | - | Petroleum Technology Transfer Council |
| PWG | - | Pipeline Working Group |
| QCP | - | Quality Control Plan |
| RAM | - | Random Access Memory |
| RANS | - | Reynolds Averaged Navier-Stokes |
| RMS | - | Root Mean Square |
| ROV | - | Remotely Operated Vehicle |
| SDSS | - | Spatial Decision Support System |
| SIGSA | - | Sistemas De Informacion Geographica, S.A. |
| SMYS | - | Specified Minimum Yield Strength |
| SPIM | - | Submarine Pipeline Integrity Management |
| SSS | - | Side Scan Sonar |
| SWL | - | Still Water Level |
| TIF | - | Tag Image File |
| TV | - | Television |
| TXT | - | Text File Format |
| ULCD | - | Ultrasonic Crack Detection |
| UML | - | Unified Modeling Language |
| USBL | - | Underwater Short Base Line |
| USGS | - | United State Geological Survey |
| VBA | - | Visual Basic for Application |
| VHS | - | Virtual High Storage |
| VTS | - | Video Tracking System |
| XLS | - | Microsoft Excel Workbook (Microsoft Excel 2002) |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

In recent times, man's inexorable demand of petroleum products has intensified the search for oil and gas in regions of the world which hitherto were unexplored. This has led to the development of petroleum resources in offshore areas which are especially harsh due to deep water and/or the severity of prevailing climatic conditions imposed by high winds, stormy seas and low temperatures as described in Figure 1.1a. In many cases, submarine pipeline is the preferable solution for oil and gas industry to transport the crude, either from offshore platforms to onshore terminals as shown in Figure 1.1b.

The investigations that were carried out by Oynes (2004), Robertson, et al (2004), and Kennedy (1984) proved that, oil and gas pipeline systems are remarkable for its efficiency and low transportation cost as shown in Figure 1.2. Networks of interlinking pipelines have also materialised in several offshore regions to enhance the development of marginal fields and mitigate some of the risks arising from the possible failure of singular pipelines (Mare, 1985). Evidence suggests that the pace of recent developments will continue as onshore reserves of oil and gas diminish, with the result that submarine pipelines will become extremely important to the arteries in an increasingly energy-hungry world (Oynes, 2004; Robertson, et al, 2004; and Mare, 1985).

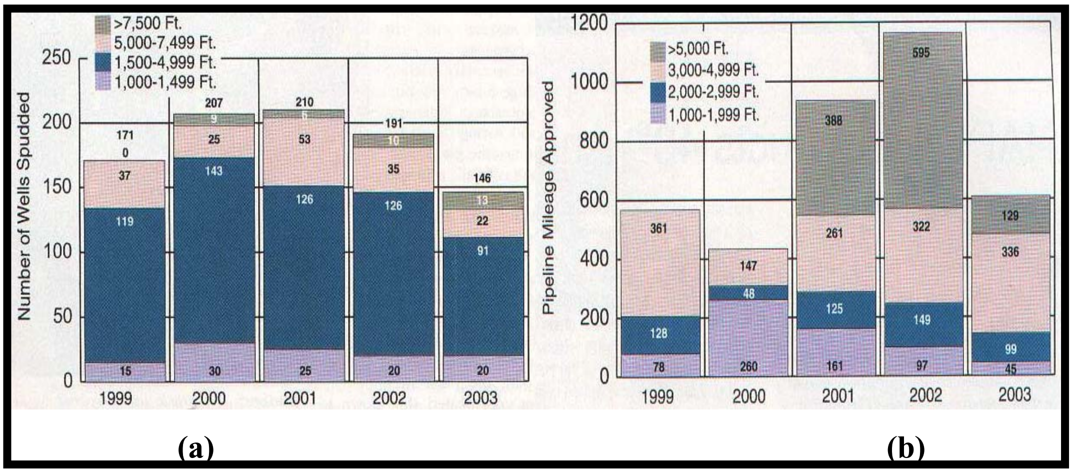


**Figure 1.1:** Submarine pipeline development in Gulf of Mexico (1999-2003): (a) Deepwater exploratory and development wells drilled subdivided by water depth; and (b) Deepwater pipeline mileage approved 1999-2003, subdivided by water depth *(source: Oynes, C., 2004)*

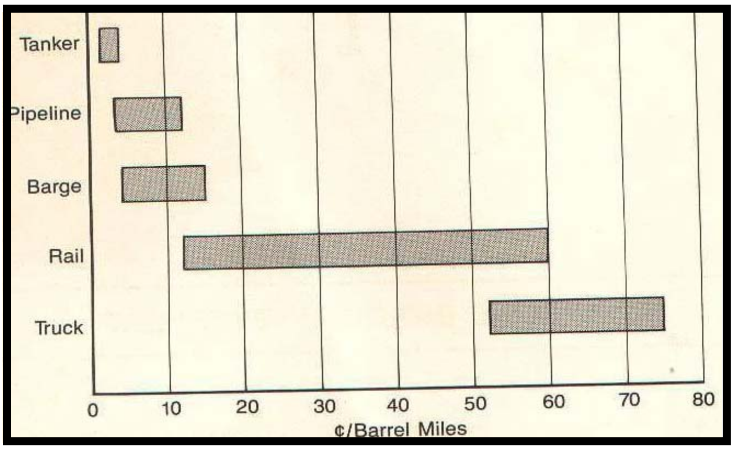


**Figure 1.2:** Petroleum transportation costs

*Source: Kennedy, J. L., 1984*

In general, the growth of deepwater exploration is particularly significant to the pipeline market (Robertson, et al., 2004) due to (a) deepwater means longer lengths of product because not only is the distance from the seabed to the surface greater, but the project site also tends to be farther from shore, so export lines need to be longer; and (b) the technical challenges presented by deepwater conditions means that pipeline design, manufacture, installation and operation become more troublesome and more expensive, making deepwater a high-risk, high value market.

At present, various techniques of submarine pipeline routing design have been established as to ensure the maximum safety to the pipeline. In general, submarine pipeline routing design requires careful examinations on hydrodynamic stability analysis (installation and operating lifetime), soils liquefaction analysis (safe range of pipe specific gravity), soil movements analysis (loads imposed on pipeline), pipe buckling analysis, thermal load / flexibility analysis, pipe lay analysis, route selection, profile extraction and so forth.

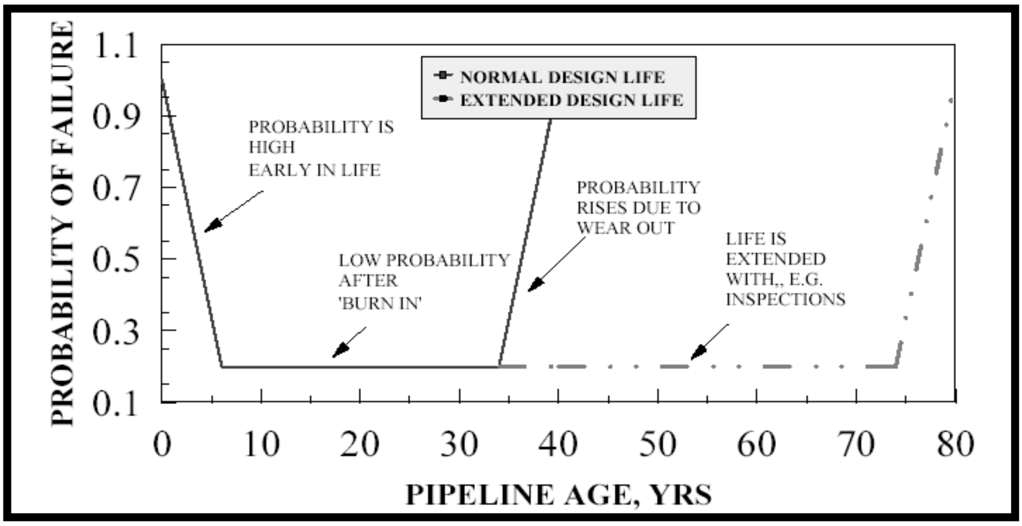


**Figure 1.3:** 'Bath tub" failure curve and extending pipelines' lives

*Source: Penspen Integrity, Inc., 1998*

Meanwhile, an investigation that was carried out by Jones and Hopkins (2002) shows that engineering plant follow a 'bath tub' type failure probability curve shown in Figure 1.3. This curve shows that during a structure's design life the highest failure probability is when the structure is new, or when it is old. This curve applies to automobiles, aircraft, etc., and pipeline engineers will agree with this result; pipelines have high failure rates early in life (e.g., hydrostatic testing) and later in life (due to corrosion) (Jones and Hopkins, 2002; Biagiotti and Guy, 2003). An adequate parameters design and inspection of a pipeline will help to extend the low probability portion of Figure 1.3 to 80 or even 100 years old.

Geographic Information System (GIS), is a computer-based system that is capable of assembling, storing, manipulating, and displaying geographically referenced information. GISs provide analytical capabilities that can greatly help in submarine pipeline design and inspection purposes. The benefits of such analysis will be appreciated by the pipeline engineers, who can now concentrate on analysing his results as opposed to spending time compiling the results. This study deals primarily with assembly of various datasets into a common, compelling, efficient, user-friendly and interesting visualization GIS system for submarine pipeline routing design and inspection purposes.

This chapter outlines the key notes of this study including research problems statement, purpose, objectives, scope as well as the benefits of this study, The following Chapter (*see Chapter 2*) provides an overview of hazardous conditions and basic criteria of submarine pipeline routing design, such as hydrodynamic forces, pipe-soil stability, etc. Chapter 3 illustrates the needs as well as the current technologies of submarine pipeline inspection (e.g., SSS, ROV and so forth). The methodology of this study is presented in Chapter 4. The capabilities of GIS technology in submarine pipeline routing design are evaluated in Chapter 5, section 5.2 and Chapter 5, section 5.3 analyzed the implementation of GIS in submarine pipeline inspection purposes. The conclusion and recommendations for future works are presented in Chapter 6.

## 1.2 Problem Statement

Routing design of a submarine pipeline is a complicated business because of all the parameters that must be prudently considered. Large numbers of effort have been made to ensure the maximum safety and improve the longevity of the pipeline operating lifetime (*the summary of relevant researches are available in section 1.8)*. For a successful submarine pipeline design operation, various techniques and tools are used. As a result, diverse datasets are obtained, such as oceanographic data, bathymetry data, magnetometer, soil sample, sub-bottom profiler and so forth.

Additionally, various datasets are obtained from submarine pipeline inspection surveys (*the detail description is available in Chapter 3*). The Internal Pipeline Inspection (IPI) data consists of attributes such as corrosion areas of the internal pipeline wall, related to the distance from nearest pipe weld (given the geographical locations of the pipe weld / field joints, absolute positions can then be derived for the internal corrosion area). The External Pipeline Inspection (EPI) data consists of attributes, such as debris on the seabed, whose geographical position is known either via interpolation of Side Scan Sonar (SSS) imagery or Remotely Operated Vehicle (ROV) positioning fixing (Riemersma, 2000).

Generally speaking, more data will produce better analysis results. However, most of these datasets are deposited into files and databases where they sit in their separate and unique formats. Hence, the information in these datasets often go un-visualized, un-interpreted and hence do not effectively contribute to the scientific understanding or help pipeline engineers in submarine inspection or routing design operation. Obviously, it is meaningless if the industry managed to survey or collect the required datasets in high precision, but could not efficiently manipulate or manage these datasets for maximum usage.

To overcome this problem, the conventional Database Management Systems (DBMS) are not practical as most of these datasets are not geographically referenced. Traditionally, the pipeline engineers will take time to analyse these datasets for decision making from several separated systems where these datasets are stored in. Evidently, this is inefficient to the industry and even worse is that analysis results may not be accurate as the required information are not integrated.

As the solution for efficient decision-making, oil and gas industries are recently seeking for the information system which is capable in:

- Assembling, storing, manipulating, displaying and analysing the industrial datasets. In this case, the system must be able to manipulate all the required datasets for submarine pipeline routing and inspection activities.

- Able (or at least able to be customised) to integrate with other hardware or systems in order to be upgraded for onboard processing or fulfil the future requirements.

- Comprise various analytical functions that would meet the engineers' needs in their daily operation. In this case, the system must be able to identify the High Consequence Areas (HCAs) to a submarine pipeline, and define the most appropriate path for the pipeline to be installed.

- Security protection to ensure the reliability of the system as well as the confidentiality of the datasets.

## 1.3 Research Purpose

Seas and oceans contain a spaghetti-like labyrinth of submarine pipes and cables that criss-cross the seafloor, providing fuel and communications throughout the world. The condition and welfare of these pipelines remain the responsibility of the pipeline's asset owner. Usually, they will evaluate or design the pipeline route away from all the harmful hazards and minimize the hydrodynamic forces to these pipelines. Besides that, these pipelines are carefully inspected, in order to improve its longevity as well as to minimize its impact to the environment.

For the convenience of the pipeline engineers, this study aims to implement the GIS capabilities into submarine pipeline routing and inspection activities, that is to assemble various datasets into a common, compelling, efficient, user-friendly and interesting visualization system, with the aim of providing appropriate information to pipeline engineers for efficient decision-making.

## 1.4 Research Objectives

The objectives of this study are:

- To integrate the related datasets for submarine pipeline design and inspection purposes into a geodatabase system.
- To integrate the DVS (Digital Video System) dataset into ArcGIS-ArcMap environment for efficient pipeline inspection analysis.
- To customize a proper graphic interface for the conveniences of end user.

## 1.5 Research Scope

This study focuses mainly in the implementation of GIS technology as a Spatial Decision Support System (SDSS) for submarine pipeline routing design and inspection purposes. The basic criteria in submarine pipeline routing design and inspection activities would be taken into account in this project. However, this study is limited as follows:

- **Hardware, software and extension,** the hardware and software that had been used to achieve the objectives of this study are listed in Table 1.1. Thus, this study has been proceeded based on the available functionality of these hardware and software.

**Table 1.1:** Hardware and software

| **Hardware** | | **Operating System** |
|---|---|---|
| ▶ Intel Pentium III | | ▶ Window XP |
| ▶ 128 Mb RAM | | |
| **Software** | | |
| ▶NETmc 3Head Player Tool | ▶ ArcGIS-ArcInfo 8.3 | ▶ RockWorks 2004 |
| ▶ Abode Acrobat Professional 6.0 | ▶ Microsoft Excel 2003 | |
| **Extension** | | |
| ▶ VideoDRS | ▶ 3D Analyst | ▶ Geostatistical Analyst |
| ▶ Spatial Analyst | | |

- **Types of pipeline,** there are four general classifications of submarine pipelines as outlined in Table 2.1 (*see Chapter 2, section 2.2)*. But, this study focuses only in the routing design of gathering lines (interfiled lines). The criteria of routing design for other types of submarine pipeline (e.g., flowlines / intrafield lines and loading lines) are excluded from this study.

- **Study area**, this study attempts to analyse a new proposed pipeline from SpringField platform to AutumnField platform and to inspect the existing pipeline between SummerField platform and WinterField platform (Figure 1.4), based on the available datasets provided by the data suppliers. In other words, the routing design criteria, environmental constraints and available datasets for other offshore platforms would be excluded from this study. However, all the details (e.g., name of the platforms, pipelines) of this selected area has been edited from this report due to the datasets confidentiality (as stated in the agreement that attached in this report).

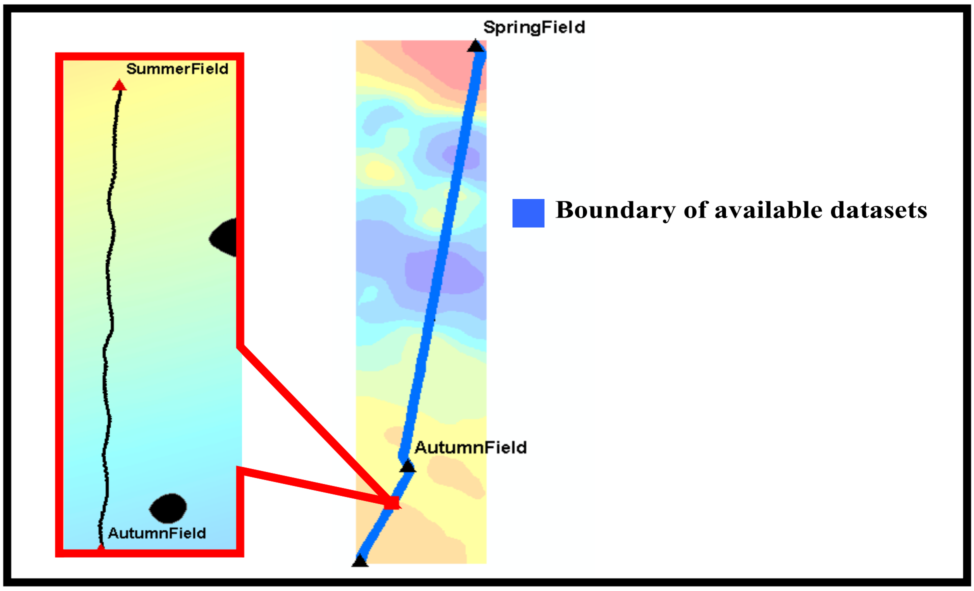


**Figure 1.4:** Study area

- **Data,** this study is limited to some datasets as listed in Table 1.2. Petroliam National Berhad (PETRONAS) agreed to release 3 pipeline survey reports, which consist the datasets of bathymetry survey, Side-Scan Sonar (SSS), sub-bottom profiler and so forth. Besides that, MAPIX Technologies Ltd supplies the DVS files and the relevant software. And, Dr. Sofia Caires from the Meteorological Service of Canada (MSC) provides the requested monthly oceanographic datasets from year 1960 to 2000. This study has been carried out based on these datasets and other datasets are neglected from the study due to the data inaccessibility.

**Table 1.2:** Available datasets

| **Item** | **Data** | **Source** | **Year/ Period** | **Acquisition** | **Accuracy** |
|---|---|---|---|---|---|
| 1 | Bathymetry Dataset | | 1996 | Atlas Deso 20 Dual Frequency Echo Sounder System | overall accumulative accuracy is ± 0.55 metres* |
| 2 | SSS Imageries | | 1996 | EG&G 260 Image Correcting SSS system, complete with an EG&G 272TD dual frequency (100 and 500 kHz) | approx 5m in size and 15m in position* |
| 3 | Sub-Bottom Profiler Dataset | | 1996 | Geopulse Surface-Towed Profiling System | 0.2 m- 0.6m* |
| 4 | Soil & Gravity sampling | | 1996 | Benthos-type Gravity Corer | ± 1cm with maximum distance for two consecutive locations not exceeding 5km* |
| 5 | Oceanographic Dataset | MSC | 1960-2001 | | ± 10 cm § |
| 6 | ROV/DVS Survey Datasets | MAPIX Technologies Ltd | 1999 | | |

Note: * summary from pipeline survey report
§ personal interview with the relevant parties

- **Routing design constraints,** although there are several constraints *(as outlined in Chapter 2, section 2.2)* that must be considered for a successful submarine pipeline routing design, this study focuses mainly in the environmental constraints involved in submarine pipeline routing. Other design constraints like the methods of construction; operation and maintenance are excluded from this study.

- **Assumption,** due to the data inaccessibility, some assumptions have been made in this study:

⇒ the size of purpose pipeline (from SpringField platform to AutumnField platform) is assumed consistent with 1m diameter and 5cm thickness.

⇒ the average direction of wave is assumed normal or parallel to the proposed pipeline axis.

⇒ the velocity and acceleration terms are typically evaluated at 1m above the seabed based on standard wave theories as described in Table 2.4 (Mousselli, 1981). Hence, a boundary layer is then assumed from 1m above the seabed to the seabed where the velocity terms vanish during the hydrodynamic analysis in this study.

⇒ the G-Value, fill percent and soil density must be assigned with numeric values for each soil types in RockWorks2004 to identify each soil types in lithology models. However, these values are unsure in this study. Thus, the recommended setting has been used to assign all the fill percent as 100%, all soil density as 1 and G-Value of '1' for the uppermost class of soil and increment the integer by '1' for each next soil type (RockWare, Inc., 2004).

## 1.6 Overview of Research methodology

Generally, the methodology of this study can be divided into five phases as shown in Figure 1.5. The first part would cover the preliminary works such as assessment of the research problem, research objectives, research scopes identification as stated previously in sections 1.2, 1.3, 1.4 and 1.5. Besides that, the literature review of the relevant studies would be carried out at the earliest stage of this study to ensure the practicalities of this study (*see section 1.8 or Chapter 2 & 3 for detail description*).

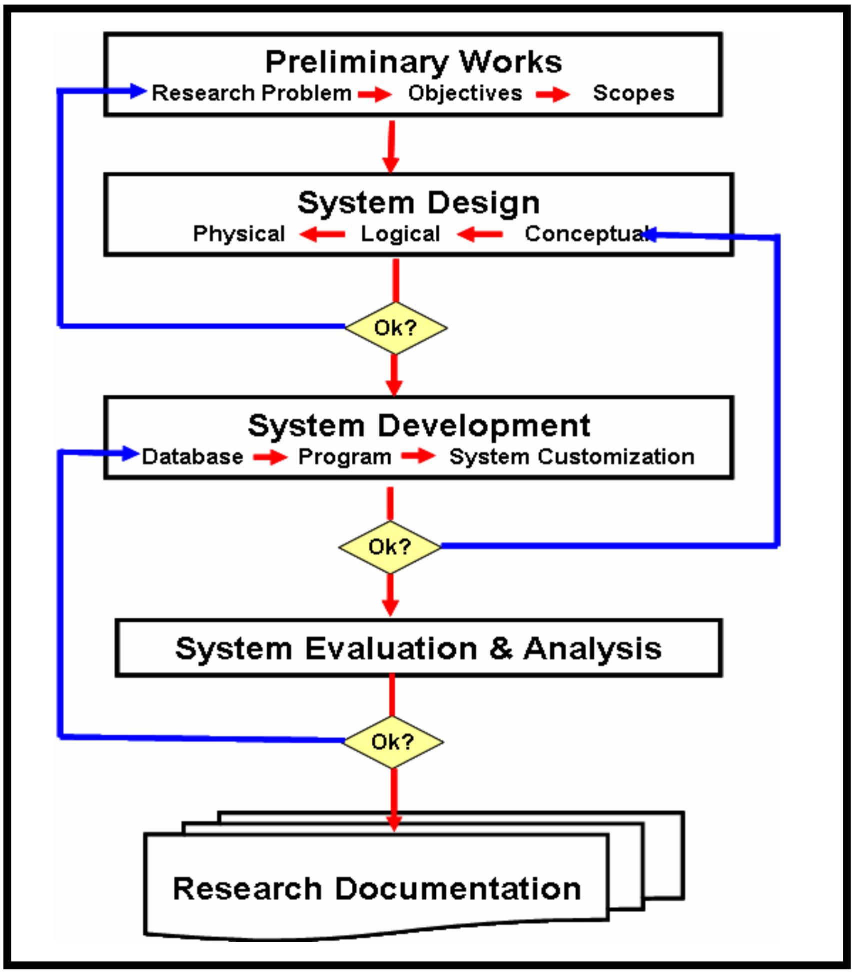


**Figure 1.5:** Overview of research methodology

The second step of this study accounts for system design (*for more detail, see Chapter4, section 4.3*) which consists the conceptual design, logical design and physical design of the system. The system development would be carried out with the selected tools as soon as the design plans are completed in the third phase (*see Chapter 4, section 4.4*). The fourth part of this study focuses mainly on system evaluation and result, that include the application of pipeline routing with spatial analysis (*see Chapter 5, section5.2*); and simultaneously access multiple channels of pipeline inspection video in ArcGIS-ArcMap (*see Chapter 5, section5.3*) according to its geographic features. Eventually, the research documentations are compiled in the fifth phase for future reference.

## 1.7 The Benefit of this Study

GIS is explicitly designed to assemble, manipulate and analyse geographically referenced information, as the support system for decision-making. The following are potential benefits that can be expected upon implementing GIS technology into submarine pipeline routing and inspection purposes:

- Measurable increases in productivity during the creation, maintenance, and seeking/verifying of geographic-related information. A GIS automates routine, repetitive tasks, leaving more time for pipeline engineer to focus on analysis and problem solving.

- Centralized database to provide a single source of pipeline related information. Centralization will enable faster retrieval and selective modification of information and provide more consistent operations, including standardization, since all users will have access to the same current data.

- Improved responsiveness to inquiries through increased information accuracy, improved response time, and ability to quickly analyze larger volumes of data.

- Capability to produce specialty maps at any desired scale to improve emergency preparedness and accelerate work processes (e.g., processing of permits).

- More effective analysis of geographic-related data that greatly enhance and expedite management's decision-making capabilities (e.g., assisted planning of optimal routes)

## 1.8 Related Works

In order to improve the works of submarine pipeline routing design and inspection, various researches had been carried out around the world, which can mainly be categorized as below:

### 1.8.1 Standard Revisions of Submarine Pipeline

Several regulations or standards had been published and widely implemented to ensure the maximum safety to submarine pipeline. For example, American Petroleum Institute (API) Recommended Practice 111, 2$^{nd}$ Edition Nov.93 and British Standard (BS) BS8010: Part 3 1993 Section 4 had been published refers specifically to submarine pipeline routing selection. Det Norske Veritas (DNV) 1996, Page 18, Section 3 and DNV Classification Notes – No. 30.4 refer specifically to soil investigation for pipelines. Meanwhile, API RP5L emphasizes the material aspect than pipeline design guideline against environmental loading (Mousselli, 1981; Mare, 1985; and Karal, 1987).

Over the years, these standards or regulations had been widely used as guidance for design, materials, fabrication, installation and operation of submarine pipeline. However, the pipeline industry has in recent years experienced a growing focus on cost reduction, resulting in innovative design approaches and optimized construction methods in increasingly deeper and rougher waters (Pradnyana, et al, 2000). Hence, these regulations or standards may no longer be applicable and revision must be carried out.

To do so, the Pipelines Working Group (PWG) of the Offshore Soil Investigation Forum (OSIF) has been established. The forum is an informal grouping of oil company geotechnical departments, geotechnical drilling vessel operators, geotechnical contractors and consultants, that has been meeting annually since 1983, to exchange experience and ideas; standardize the procedures, equipment; and continuously improve all aspects of offshore soil investigations.

Besides that, Roberts (2004), reviews some of the major legislative and regulatory changes concerning the integrity of transmission pipelines located in High Consequence Areas (HCAs). Sylvestor (2004), review the elements of an Integrity Management Program in American Standard for Mechanical Engineering (ASME) B31.8S, which includes Integrity Management Plan (IMP), Performance Plan (PP), Communication Plan (CP), Management of Change Plan (MCP), and Quality Control Plan (QCP). Meanwhile, Penspen Integrity (1998), studied the possibility of the Limit States Design (LSD) used to design a pipeline above 80% Specified Minimum Yield Strength (SMYS).

From the existing pipeline design, Pradnyana, et al (2000) tried to do re-calculation using DNV 1981, DNV 1996, DNV 1999, and DNV 1999 (revision). Recalculation has been done by optimizing wall thickness (where internal pressure is kept constant), and optimizing internal pressure (where wall thickness is constant). According to Pradnyana, et al (2000), the results show that the pipeline wall thickness can be reduced by using DNV 1996, DNV 1999 and DNV 1999 (revision), and the most reduction in wall thickness was found when DNV 1999 (revision) is used. And the ultimate internal pressure can be raised by using DNV 1996, DNV 1999 and DNV 1999 (revision).

### 1.8.2 Computational Fluid Dynamics (CFD) Solutions

In the most severe case, the scour hole and resultant forces on the structure may cause failure. In other cases, pipelines, rubble-mound structures, or submerged mines may be enveloped by the scour hole and eventually buried (Summer, et al., 2001). For this reason, the hydraulic and ocean engineers had shown significant interest in predicting the scour of sediment around bridge piers and submarine pipelines.

A number of investigations had been carried out to analyse the scour around the vertical structures, such as steady current investigation by Laursen (1963); Lim & Cheng (1998); and Melville & Chiew (1999); wave investigation (Summer, et al., 1992); wave and current investigation (Summer and Freds∅e, 2001); field investigation include Bayram and Larson (2000). Besides that, investigation of the scour for the horizontal objects has primarily occurred in the last three decades (Kjeldsen, et al., 1973, and Mao 1986).

In the year 1988, the Cloud-In-Cell (CIC) model had been used by Summer et al, (1988) to simulate laboratory observations of the cylinder wake. Followed by that, the efforts to model the pipeline scour process have ranged from potential flow theory (Li and Cheng, 1999) to more complicated turbulence closure models with the Reynolds Averaged Navier-Stokes (RANS) equations (Van Beek and Wind, 1990).

More recently, Li and Cheng (2001) solved the RANS equations with a Large Eddy Simulations (LES) turbulence scheme. Besides that, Br∅rs (1999) utilizes a non-hydrostatic finite element scheme to solve the RANS equations with a k-ε turbulence closure scheme. The morphologic evolution is accomplished with a finite difference bedload transport model. However, the velocity variations downstream of the cylinder were slightly under-predicted. The morphology module was evaluated with Mao's (1986) scour experiments. Overall agreement between the laboratory data and the model for both the shape and depth of the scour hole is good, although the simulated equilibrium depth was less than the final depth reached in the laboratory (Smith, 2004).

### 1.8.3 Enhancement of Structural Stability

As pipeline installations moved into deep water, the problems of pipeline collapse caused by the increased hydrostatic pressure became significant. Pipe collapse depends on many factors, including the pipe-diameter/wall thickness ratio ($D/W_t$), stress-strain properties, initial ovalization (out of roundness), hydrostatic pressure, and bending moment in the pipe (Mousselli, 1981).

To overcome these problems, new methods, tools and equipments are being developed to enhance the structure of submarine pipeline. Dawans, et al, (1986) had carefully evaluated the design and materials considerations for high pressure flexible flowlines.

Meanwhile, various methods are introduced to protect the pipeline from hazardous conditions (*see Chapter 3, section 3.5*), this include concrete coating (Bergan & Mollestad, 1981; and Palmer, 1985); grouting (COLOS, 1983), sandbags, jack-ups, gravel dumping (Melegari & Bressan, 1990) and etc (*see Chapter 3, section 3.5 for detail description of these protection methods*).

Furthermore, several continuous or non-continuous techniques for internal corrosion monitoring has been implemented, such as coupons, iron counts, ultrasonic radiographic calliper, magnetic pigs, electrochemical noise, polarisation resistance and so forth (*see King & Geary, 1985, for a complete summary of internal corrosion monitoring techniques*).

Besides that, numbers of advance equipment and technology are developed and; directly or indirectly contribute to the stability of submarine pipeline. For example, jet barge, fluidizing equipment to trench a pipeline (Mousselli, 1981); and submarine pipeline inspection with Side Scan Sonar (Cheah, 2003; Kamaruddin; 2003; Petillot, et al, 2002 and Rainbow, et al, 1985), ROV/AUV (Thabeth, 2004; Kamaruddin; 2003; Mahmud & Chai 2003a; Petillot, et al, 2002 ), pig (Elmer, 2004; Horton, 2004; Olson, et al, 2004; Agthoven, 2003; and Beuker & Brown, 2003); FluoroTrack sensor (Thabeth, 2004); and some other Ultrasonic Crack Detection (ULCD) tools (Meade and Uzelac, 2004).

### 1.8.4 Spatial Decision Support System (SDSS)

Routing design of submarine pipeline is a complicated business because of all the parameters that must be considered. To analyse the optimal route of submarine pipeline, not only the pipeline scour process (*see section 1.8.2*) has to be simulated, various criteria, regulations or standards must also be achieved *(see section 1.8.1 and Chapter 5, section 5.2)*. Furthermore, new methods, tools and equipments are being developed to enhance the structure of submarine pipeline to oppose the severe conditions in ocean environment (*as described in section 1.8.).* However, in certain cases these are not flexible and cost-effective.

For these reasons, pipeline engineers seek for the solution which is capable to consider all the routing constraints into a systems analysis. Since, most of these constraints are geographically related, GIS has taken place as the Spatial Decision Support System (SDSS) with its distinct spatial analytical capabilities. Various GIS applications had been developed for routing design, such as defining a consensus method for finding preferred routing (McCoy & Johnston, 2001); identifying the most preferred route for power line (Berry, 1996); analyse the shortest and safest voyage (Chai, 2002); finding an alternative access road to the new school site (McCoy and Johnston, 2001); designate the optimal route for submarine cable routing (Joseph & Hussong, 2005; and Osborne & Abbott, 2000); determine the alternative pipe routes (Berry, et al, 2004; Wong, 2004; LoPresti & Miller, 2004, and Yusof & Baban, 2004).

Data integration is a critical process in an Integrity Management Plan (IMP). It will still take several years to have a fully implemented pipeline integrity process. GIS technology has already proven itself as a key-element to successfully manage the data necessary for a pipeline integrity management program (Palmer, 2004; and Mahmud & Chai, 2003b), such as wave modelling (Yaakob, 2003); internal inspection with PIGs (*Porter & Parsons, 2000*; and Czyz, et al, 2000); sonar scanned images (Rasmussen, 1998) and external video tracking system (Rasmussen, 1998).

The focus of this study is on the fourth, that is to implement the true GIS capabilities in submarine pipeline routing design and inspection purposes. To do so, it requires (1) to gather various datasets regarding pipeline routing design & inspection; (2) assembling, storing & manipulating these datasets in a geodatabase system; (3) analyse the optimal pipeline route by taking into account the hazardous conditions (*see Chapter 2, section 2.8*); (4) perform a georeference DVS for submarine pipeline inspection in ArcGIS-ArcMap environment; and (5) customizing a common, compelling, efficient, user-friendly interface for the convenience of end users.

## 1.9 Summary

Submarine pipelines play an important role in offshore hydrocarbon transportation. In order to ensure the smoothness of offshore exploration activities and the stability of marine biology, a large number of efforts have been made to study the issues which are relevant to submarine pipelines, particularly in its routing design and inspection techniques.

The objective of this study is to implement the GIS capabilities into submarine pipeline routing and inspection activities. This study aims to assemble various datasets into a common, compelling, efficient, user-friendly and interesting visualization system to provide the appropriate information for efficient decision-making to pipeline engineers.

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