GIS-Based Prediction of Pipeline Third-Party Interference Using Hybrid Multivariate Statistical Analysis

CONFIDENTIAL

Adewumi Rowland (B.Eng., MSc.)

School of Marine Science and Technology
Newcastle University Newcastle upon Tyne
NE1 7RU, United Kingdom

Petroleum Technology Development Fund
Plot 672, Port Harcourt Crescent,
Off Gimbiya Street, off Ahmadu Bello Way,
Area 11, Garki, Abuja.
Tel: 234-9-3142216-7
Fax:234-9-314229
http://www.ptdf.gov.ng/

School of Marine Science and Technology
Newcastle University Newcastle upon Tyne
NE1 7RU
United Kingdom
Tel: +44 1912225533
GSM: +44 7930347332
http://www.ncl.ac.uk/marine

to ***Wise, Wyman and Winnie***

Certificate of Originality

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgments or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a higher degree.

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Author's signature

Supervisors:

Dr Julia Race
Professor Richard Birmingham

……

Examiners:

Professor Chris Brunsdon
Dr Stuart Barr

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ADEWUMI Rowland (B.Eng., MSc.)

B.Eng in Civil Engineering, Federal University of Technology, Minna-Nigeria, 2000
MSc in Geographical Information System with Remote Sensing, University of Greenwich-UK, 2006.

A thesis submitted to the Newcastle University in partial fulfilment of the requirements for the award of the degree of doctor of philosophy in Engineering Science in Marine Environment in the faculty of Science, Agriculture and Engineering.

School of Marine Science and Technology
Newcastle University, Newcastle upon Tyne
NE1 7RU, United Kingdom

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Nothing is accomplished in isolation.

ABSTRACT

In reported pipeline failures globally, third-party interference (TPI) has been recognised as a dominant failure mechanism in the oil and gas industry, although there has been limited research in this area. The problem is receiving considerable attention within the oil and gas industry, because of the industry threats (e.g. Al Qaeda's capabilities) and the natural vulnerability of pipelines because of their long distance network distribution. The ability to predict and secure pipelines against TPI is a valuable knowledge in the pipeline industry, and especially for the safety of the millions of people who live near pipelines. This thesis develop an understanding of the relationships between the many and various contributory factors leading to potential TPI, frequently resulting in mass deaths, economic losses, and widespread destruction to property. The thesis used GIS-based spatial statistical methodologies, first, based on hotspot and cold spot cluster analyses to explain pipeline incident patterns and distributions; and a geographically weighted regression (GWR) model to investigate the determinants of TPI and to identify local and global effects of the independent variables. Secondly, a generalized linear model (GLMs) methodology of Poisson GLMs and Logistic Regression (LR) procedures, by using a combination of land use types, pipeline geometry and intrinsic properties, and socioeconomic and socio-political factors to identify and predict potentially vulnerable pipeline segments and regions in a pipeline network. The GWR model showed significant spatial relationship between TPI, geographical accessibility, and pipeline intrinsic properties (e.g. depth, age, size), varying with location in the study area. The thesis showed that depth of pipeline and the socio-economic conditions of population living near pipeline are the two major factors influencing the occurrence of TPI. This thesis have prompted the need for selective protection of vulnerable segments of a pipeline by installing security tools where most needed. The thesis examined available literature and critically evaluated and assessed selected international pipeline failure databases, their effectiveness, limitations, trend, and the evolving difficulties of addressing and minimising TPI. The result of the review showed irregular nomenclature and the need for a universal classification of pipeline incidents database. The advantages and disadvantages of different detection and prevention tools for minimising TPI, used in the pipeline industry are discussed. A questionnaire survey was developed and employed, as part of the thesis, for the employees and managers in the pipeline industry. The results of the data analysis has contributed to the body of knowledge on pipeline TPI, especially the industry perceptions, prevention strategies, capabilities and complexities of the various application methods presently being implemented. The thesis also outlined the actions that governments and industry can and should take to help manage and effectively reduce the risk of pipeline TPI. The results of this study will be used as a reference to develop strategies for managing pipeline TPI. The results of the thesis also indicated that communications with all stakeholders is more effective in preventing intentional pipeline interference, and that the government's social responsibility to communities is the major factor influencing the occurrence of intentional pipeline TPI.

USED ACRONYMS / ABBREVIATIONS

9/11	September 9th 2001
AE	Acoustic Emission
AHP	Analytic Hierarchy Process
ANN	Artificial Neural Network
ANOVA	ANalysis Of Variance
APDM	ArcGIS Pipeline Data Model
APIA	Australian Pipeline Industry Association
APPEA	Australian Pet. Production and Exploration Association
Bbl/d	Barrel per day
CCTV	Closed-Circuit Television
CCVR	Closed Circuit Video Recording
CONCAWE	CONservation of Clean Air and Water in Europe
CSCAP	Council for Security Cooperation in the Asia Pacific
DHS	Department of Homeland Security
DPR	Department for Petroleum Resources
DPR	Department for Petroleum Resources
DSS	Decision Support System
DTM	Digital Terrain Models
EGIG	European Gas Pipeline Incident Data Group
EIA	Environmental Impact Assessment
ESRI	Environmental Systems Research Institute
FA	Factor Analysis
FEPA	Federal Environmental Protection Agency
FMENV	Federal Ministry of Environment
GDI	Gender-related Development Index
GDP	Gross Domestic Product
GEM	Gender Empowerment Measure
GIS	Geographic Information System
GLMs	Generalised Linear Models
GPS	Global Positioning System
GWR	Geographically Weighted Regression
HDI	Human Development Index
HPI-1	Human Poverty Index for developing countries
HT	High Tensile
HTML	Hyper Text Markup Language
IDW	Inverse Distance Weighted
IFO	Fibre Optic Sensors
ILL	In-Line Inspection
IRA	Irish Republican Army
ISAT	Integrated Spatial Analysis Technology
ISPDM	Industry Standard Pipeline Data Management
LEI	Life Expectancy Index
LGA	Local Government Area
LR	Logistic Regression
MAUP	Modifiable Areal Unit Problem
MCA	Maritime and Coastguard Agency
MDS	Multidimensional scaling

MEND	Movement for the Emancipation of the Niger Delta
MLE	Maximum Likelihood Estimation
NASRDA	National Space Research and Development Agency
NB	Negative Binomial
NDDC	Niger Delta Development Commission
NEB	National Energy Board
NNPC	Nigeria National Petroleum Corporation
NOPSA	National Offshore Petroleum Safety Authority
OLS	Ordinary Least Square
PCA	Principal Component Analysis
PODS	Pipeline Open Data Standard
PPMC	Petroleum Product Marketing Company
PRCI	Pipeline Research Committee International
ROW	Right of Way
SPSS	Statistical Package for the Social Sciences
TPI	Third-Party Interference
UKOPA	United Kingdom Onshore Pipeline Association
UNECE	United Nations Economic Commission for Europe

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GLOSSARY OF TERMS

Oil and Gas Pipelines:	Includes crude oil pipelines, refined products pipeline, and natural gas pipeline. Comprising: chemical liquids pipelines, natural gas liquids (NGL) pipelines, liquefied petroleum gas (LPG); and gathering, mains, transmission and distribution lines.
Third-party Interference:	A failure resulting from an action by a third-party either intentional or Unintentional (accidental). This also includes damage undetected when it occurred and resulting in a failure at some later point in time; and sabotage, theft, terrorism threats to pipelines.
Dependent Variables	A variable is any characteristic that is recorded for a subject in a study. The dependent variables are outcome variable on which comparisons are made
Independent Variables	The independent variables define the groups to be compared with respect to values on the dependent variables. "If x is given, then y occurs", where x represents the independent variables and y represents the dependent variables.
Pipeline System	All component part through which petroleum product moves during transportation including pipe, valves, compressor units, metering stations, regulator stations, delivery stations, holders and other fabricated assemblies.
Detection	The process of obtaining an inspection signal recognized as coming from a pipeline defect that produce signals that are both measurable and distinctive.
Mitigation	Procedures to alleviate, reduce the severity consequences of failure.
Prevention	Activities and procedures initiated to prevent pipeline damage or failure.
Right-of-way	Corridor width over another person's property along a typical pipeline with a legal right of passage granted, and acquired for usage by pipeline operator.
Euclidean	Any two points can be joined by a straight line, or a a straight line segment can be extended indefinitely in a straight line
Z-Score	A statistical measure in data analysis that quantifies the distance (measured in standard deviations) a data point is from the mean of a data set.
Multicollinearity	A statistical phenomenon in regression analysis describing, because of the high degree of correlation between two or more independent variables, the difficulty to accurately separate the effect of each individual independent variable upon the dependent variable.

1 INTRODUCTION

1.1 Background Information

It is predicted that the global energy demand will rise by as much as 54 per cent over the next two decades and oil consumption constitutes 40 per cent of this energy demand (EIA, 2008). This increased demand for more oil encourages exploration and production of more petroleum resources and therefore more pipelines are required to transport the oil from the production to the processing facility and on to the end user. These pipelines are generally designed, installed, and maintained using the best available engineering technology in order to comply with regulatory requirements. However, despite being one of the safest forms of oil transport, pipelines are still prone to several threats, which if not effectively managed can lead to failure, e.g. environmental damage, external and internal corrosion damage, defects, and third-party interference (TPI). The form of TPI include sabotage, theft, cyber-attacks on control systems, and terrorism threats (Van Den Brand and Kutrowski, 2006b, Day et al., 1998).

Presently, the study of TPI is of considerable interest in the oil and gas industry, especially in the current world oil and gas economy (Augusto et al., 2010). In all forms of pipeline failures reported all over the world, TPI has been recognised as one of the most dominant failure mechanism in the pipeline industry and yet it does not attract the attention of the research community. TPI is one of the major classifications of pipeline failures, generally classified into six cause categories, namely: (i) TPI, (ii) corrosion, (iii) design and construction defects, (iv) natural hazards, (v) operational error, and (vi) unknown causes (Miesner and Leffler, 2006, Bolt, 2001, Jones et al., 1996, Kiefner et al., 1994).

International efforts to improve pipeline security, because of terrorism; and the continuous fluctuation of the oil price, which can be attributed to intentional attacks against pipeline installations, now requires more emphasis on TPI research than ever before. These threats (e.g. Al Qaeda's capabilities) have made pipelines naturally vulnerable because of their long distance network distribution nature, especially the opportunities the long stretch provides for TPI. For example, prior to September 11, 2001 (9/11), risk assessments in the pipeline industry focused less on TPI and more on other factors, but the terrorist events of 9/11 have changed the outlook significantly (Parfomak, 2008, Lorenz, 2007, Baybutt and Ready, 2003, Baybutt, 2002). However, terrorism is not the only factor involved in pipeline TPI; many other factors could influence the occurrence. These other determinants factors are land use, environmental factors, socioeconomic and socio-political aspects, population density, and pipeline intrinsic properties (Lorenz, 2007, Miesner and Leffler, 2006, Muhlbauer, 2004, Mather et al., 2001, Macdonald and Cosham, 2005, Jager et al., 2002, Frisbie and Minnesota, 1977). The ultimate consequence of these determinant factors is the risk to human lives and properties, particularly with worldwide increasing lengths of pipelines.

Consequently, the ability to predict and secure pipelines against TPI is valuable knowledge in the pipeline industry, especially for the safety of the millions of people who live near pipelines. Hence, there is the need for a prediction, monitoring and preventative methodology that can identify the most vulnerable pipeline segments in an overall network. This will inform the expert deployment efforts more efficiently (e.g. to high consequence areas), reduce response times, and help develop strategies for a well-functioning pipeline policing approach (Parfomak, 2008). Therefore, this thesis is aimed at predicting future occurrence of TPI and examines potential relationships between TPI, land use, environmental factors, socioeconomic and socio-political variables, population density, and pipeline properties using hybrid multivariate statistical methods and spatial analysis. This thesis will also allow for the effective allocation of preventative measures by identifying patterns and trends of TPI.

1.2 The Study Area

The above factors make the study area, Niger Delta, Nigeria, the most suitable choice, because of the prevalence of pipeline TPI in that region. The study area is the oil and gas producing region of Delta State, in the Niger Delta of Nigeria. Overall, the country has a network of over five thousand kilometres (5000km) of oil pipelines with an oil reserve estimated to be over 20 billion barrels and which has risen steadily to host the world's 10th largest reserves at about 25 billion barrels (NNPC, 2005). The oil and gas industry is the backbone of the Nigerian economy, accounting for the majority of the total foreign exchange revenue. However, pipeline TPI is a daily concern, and has continuously put the general environment, economy, ecosystem, and public health in danger. The avowed intentions of ethnic guerrilla groups such as the Movement for the Emancipation of the Niger Delta (MEND) and similar shadow gangs, have continuously threatened oil and gas operations in the region. Such groups have captured hostages, destroyed pipelines, and threaten oil and gas installations. This thesis will examine the motivation for TPI and investigate the link between political instability, poverty and socio-economic deprivation and whether this results in third-party pipeline damage becoming a more common occurrence in the study area.

1.3 Pipeline Third-party Interference

Pipeline TPI is a term frequently used in the literature, but to date there is no consensus about its definition. TPI is simply any action taken to obstruct or tamper with the functional operation of energy infrastructures by an individual or group of people not directly (or indirectly) related to or hired by the operator of the utility (Muhlbauer, 2004). TPI within the context of this research means some form of system failure resulting from an action by a third party either intentional or unintentional (accidental). This includes damage that may have been initially undetected when it occurred and subsequently resulting in a failure at some later point in time. The term also includes sabotage, theft, and terrorism threats to pipelines.

Sometimes, the knowledge of the past helps understand the present; TPI is one of the oldest pipeline problems dating back to the 1880s, and the threat posed by the Brotherhood of Pennsylvania Oil Haulers in the 1880s, in Pennsylvania, USA (Miesner and Leffler, 2006, Papadakis et al., 1999). While various definitions of TPI are found in the literature and several failure databases, they all recognise it as one of the most prevailing cause of pipeline failure. For example, Wan and Mita (2010), Focke (2009), Seevam (2009), Williamson and Daniels (2008), Ai et al. (2008), and Cao et al. (2007) have all classified the most common causes of pipeline failures as being TPI and corrosion. Whilst there is much research regarding the threat of corrosion resulting in numerous research publications and data, there are very few studies concerned with TPI. Recent research in this area is concern on the development of remote sensing and surveillance technologies, in addition to models for pipeline hazard risk analysis. Nevertheless, with regard to current technologies, and taking advantage of the limited literature, TPI can be classified into the following two main categories: (1) Intentional, and (2) Unintentional. The following sections describe in more detail what is meant by intentional and unintentional pipeline interference.

1.3.1 Intentional Pipeline Third-party Interference

In the literature, the term intentional TPI tends to be used to refer to the deliberate and illegal intrusion into a pipeline network without the operators' given consent and permission. In global terms, activities of intentional TPI include vandalism, smuggling, trespass, conspiracy, pilfering, sabotage and terrorism. It could also be in the form of piracy, intrusion, hijacking, bunkering, political extremism, false alarm, and guerrilla warfare. Intentional TPI also includes the use of mechanical equipment, firearms, and explosives to cause physical damage, for example, Figure 1-1 shows activities of TPI in the study area.

Figure 1-1: Activities of pipeline TPI (intentional): Left picture: Saboteurs' typical illegal installed valves to steal oil from pipelines; Right-picture: Theft of pipeline product, a common occurrence in the study area (Watts and Kashi, 2008).

Moreover, cyber (internet) attacks on pipeline network and the operation of monitoring control systems are also other forms of TPI, this is in addition to robberies, militia groups, hostage taking and kidnapping that now accompany pipeline TPI. This shows a need to be explicit about exactly what motivates intentional TPI, and makes pipelines vulnerable. This thesis hypothesises that these actions and threats are strongly influenced by environmental, physical, social and economic conditions.

Intentional pipeline damage resulting from TPI is criminal. For example, the Royal Dutch Shell Company, the largest oil producer in Africa cut production by 500,000 barrels per day in 2006 (Watts and Kashi, 2008). This resulted in a revenue loss of about $35 million daily and was caused when kidnapping and attacks on facilities by militants and vandals became unbearable. In addition, vast volumes of oil are lost due to theft at oil flow monitoring stations; between 275,000 and 685,000 barrels of oil are on average each day stolen in Nigeria (NNPC, 2005). A total loss of between $1.5 and $4 billion annually are lost to the illegal *hot-tapping* of pipelines. Globally, the oil and gas industry is currently under pressure to take a more proactive role at curbing such intentional pipeline damage (Parfomak, 2008).

1.3.2 Unintentional Pipeline Third-party Interference

Unintentional third-party interferences are external events and activities unexpectedly leading to the accidental damage of pipelines, and which could have been prevented if protective measures had been taken prior to their occurrence. The term embodies a multitude of possibilities; however, the activities are mechanical failure, operation error, control system failure, and also by humans and natural hazards, for example, road construction, farming, drilling, mechanical error, landslides, erosion, and earthquakes (James and McKinley, 2007, Houreld, 2007, Gale, 2006).

Figure 1-2: Aftermath of pipeline TPI in Ghislenghien, Belgium, on the 30th July, 2004. Over 20 fatalities and 33 people severely burned were reported (Papadakis, 2005).

Recently, Nigeria (the study area) experienced a major disaster when an earth-moving vehicle accidentally collided with a petroleum pipeline. The resultant inferno raced through the neighbourhood, killing over 100 persons, including schoolchildren in a nearby nursery school (Nwankwo and Ezeobi, 2008). Similar pipeline disasters, as reported worldwide, are sometimes catastrophic and often result in mass deaths and widespread destruction of properties. For example, the Department of Justice (2007) and Papadakis (2005) reviewed a tragedy that involved various deaths, several serious casualties, and others who were hospitalised with severe burns when a Major Accident Hazard Pipeline (MAHP) near Ghislenghien in Belgium, that operated at a pressure of 70 bars, failed due to third party activities (Figure 1-2). For these reasons, there is the need to limit the consequences of pipeline TPI, especially since TPI can cause immediate pipeline failure, as well as future failure in undetected rupture and damage.

1.4 Objectives and Scope of the Thesis

TPI is a serious threat to the integrity of the pipeline industry and with limited attention to it given within the research literature and few studies addressing theoretical and methodological issues, especially with respect to intentional pipeline TPI. However, this thesis, as described earlier, will develop an understanding of the relationships between the many and various contributory factors leading to TPI. In addition, the thesis will allow pipeline operators to effectively manage resources by the selective protection of vulnerable segments of a pipeline by installing necessary security.

This thesis could be used to minimise the cost per mile of pipeline installations against possible TPI. Therefore, it could complement other solutions (as discussed in chapter 3), and considerably reduce the huge investment involved in protecting pipelines. The aim of this thesis, therefore, is to determine and explore relationships between land use, environmental factors, socioeconomic and socio-political factors, population density, and pipeline properties by using hybrid multivariate (and spatial) statistical methods and the subsequent design of a prediction model for pipeline TPI. The main objectives of this thesis are thus to:

1. Develop an understanding and description of pipeline TPI, and investigate the many possible influencing factors, especially for intentional TPI, in developing, politically complex countries such as Nigeria.

2. Review the available literature and critically evaluate and assess selected international pipeline failure databases, their effectiveness, limitations, trend, and the evolving difficulties of addressing and minimising TPI.

3. Study the aspects of safety and effectiveness of various detection and prevention tools and approaches for minimising TPI, with their corresponding advantages, limitations and disadvantages; especially, the various ways for combating TPI that are currently implemented.

4. Conduct a questionnaire based survey for participation of the employees and managers in the pipeline industry, to investigate perceptions regarding TPI and the

efficacy of prevention strategies, capabilities and complexities of the various application methods presently being implemented in the industry.

5. Identify the significant factors of geographical accessibility to pipelines and vulnerable segments with alternative methodologies based on: (a) point pattern analysis to describe the spatial distribution of third-party damages in the study area; and (b) a geographically weighted regression model to show spatial variations in the relation between the occurrence of TPI and selected exploratory independent variables.

6. Determine the factors in particular that affect the occurrence of pipeline TPI, in a measurable way, and the relationship patterns among the variables undertaken by using Factor Analysis (FA) approaches, in addition to identifying the most significant variables for subsequent use in prediction models.

7. Develop a statistical prediction model with Generalised Linear Models (GLMs) to predict and estimate the likelihood of TPI in the future at postulated vulnerable pipeline segments, by modelling a combination of land use types, pipeline geometry, failures count data, socio-economic, socio-political and pipeline variables.

8. Review the limitations of the tools and modelling approach and make recommendations for further research.

9. Investigate the possible contribution of the thesis findings into the current pipeline safety policy in the study area, Nigeria.

1.5 Structure of the Thesis

In summary, this thesis provides a critical examination of pipeline TPI, and deals with the fundamental concepts of best approaches to prevent and manage the problem. This thesis consists of a general introduction; a detailed literature review of pipeline TPI issues; detailed review of pipeline failures and of various preventive measures; a description of various methodologies adopted and applied for the thesis; and a discussion and conclusion of the results obtained.

Specifically, Chapter 1 presents basic definitions and covers background research materials described in subsequent chapters. The chapter provides an overview of the meaning of pipeline TPI, with a review of theories of major contributory factors leading to TPI. The chapter presents the thesis's overall objectives, and concludes by describing the structure of the thesis, followed with a summary.

Chapter 2 discusses TPI in detail and reviews pipeline failures especially intentional and unintentional TPI. The chapter then focuses discussion on previous work on pipeline TPI. The chapter concludes with a presentation of an extensive description of general security and policy issues, regulations and legislations concerning pipelines.

Chapter 3 describes and reviews various international pipeline failure databases. The chapter focused on the Nigeria National Petroleum Corporation (NNPC); European Gas Pipeline Incident data Group (EGIG); Office of Pipeline Security (OPS), U.S; Conservation of Clean Air and Water in Europe (CONCAWE); United Kingdom Onshore Pipelines Operators Association (UKOPA); and National Energy Board of Canada (NEB). The chapter concludes with a discussion on the findings of the review. The chapter concludes with commentary on the reviewed pipeline database as well as suggestions for proper definition of TPI in the databases.

Chapter 4 provides an extensive description of the various detection and prevention tools that are available for undertaking third-party damage control, with their corresponding advantages, disadvantages and limitations. The review was based on review of literatures, and was divided into three broad categories: pre-installation, during-installation, and post-installation.

Chapter 5 discusses factors that affect and influence the occurrence of pipeline TPI. It starts by defining and discussing the characteristics of the individual factors, with reference to the Nigeria study area. The following factors influencing TPI are discussed in this chapter: land use, socioeconomic factors, Human Development Indicators (HDI); socio-political factors; population density; geographical accessibility; pipeline intrinsic properties; topographical and geological factors.

Chapter 6 catalogues the overall methodology adopted for the analysis and development of the TPI models in the thesis. The following are described: the hot spot spatial approach and modelling; and model development with Multivariate Statistics. Chapter 6 also describes the various tools of multivariate statistical analyses and the application of Geographical Information System (GIS).

Chapter 7 describes the results of the GIS hot-segment analyses from the Gi* and Gi statistics and the Geographical Weight Regression (GWR) based procedures. The chapter identifies a set of influential and significant factors using: (i) point pattern analysis of pipeline incidents to describe their spatial distribution; (ii) hotspot and cold spot cluster analyses to explain pipeline incident patterns and distributions; and (iii) GWR model, that showed spatial variations and relationship between the pipeline incidents, proximity access, and pipeline intrinsic properties (e.g. depth, age, size) as explanatory variables.

In Chapter 8, the analyses and results of TPI activities from the study area using multivariate statistical analysis from Generalised Linear Model (GLMs) of Logistic Regression (LR) analysis are presented. The result obtained is by using a combination of land use type, pipeline geometry, socio-economic, socio-political and pipeline intrinsic properties to identify and predict potentially vulnerable pipeline segments. This chapter answered some of the most important questions involving TPI. Why are particular segments of a pipeline experiencing increased level of TPI? What might be causing this? What factors are contributing to higher than expected levels of interference?

Chapter 9 outlines and discusses the significance of the questionnaire survey as part of this thesis. The chapter discuses the methodology for the administration of the survey, constructed to identify and investigate perception of various organisations that are involved in the pipeline industry and then compared them to the industry standards and requirements. It describes the most suitable research design and methods used to collect and analyse the questionnaire survey data collected. The chapter further discusses the considerations, sample size and limitations of the questionnaire survey.

Chapter 10 presents the results, analysis, and discussion of the assembled and analysed questionnaire. The chapter summarizes the findings from the survey, concluding with a recommendation resulting from the analysis.

Chapter 11 presents a general discussion, in which the major conclusions are summed up, the chapter also reinforced the connections between various results obtained, in particular, describes how individual underpinning factors described in Chapter 5 contribute to the understanding and interpretation of the results. Limitations of the thesis are then presented,. Finally, potential future research directions and recommendations for future work are explored.

Chapter 12 presents the overall conclusions of the work undertaken and presented in this thesis, their implications, and draws comparisons with the theories discussed in the opening literature review (Chapter 2). This is followed by an appendix containing the questionnaire survey sample, selected GIS and statistical outputs and correspondence presentations given by the author during the period of development of this thesis. The appendix also presented the elicited critical remarks from the respondents.

1.6 Summary

Current knowledge about TPI lacks a deep understanding of the interaction effects of the various factors influencing the occurrence. In summary, this chapter gives a brief introductory context of TPI, the objectives and scope of the study; and the structure of the thesis. Specifically, Section 1.2 provides an overview of the study area. It describes the characteristic of the pipeline network across the study area in a national context. Section 1.3 describes intentional and unintentional pipeline TPI. The objectives and scope of the study are given in Section 1.4, followed by a description of the general organisation of the thesis in Section 1.5. The next chapter provides background and literature information necessary for understanding the concepts of pipeline TPI, and presents an evaluation of several studies about pipeline TPI, the theoretical and practical considerations of such studies, and an overview of previous research regarding pipeline TPI.

2 PIPELINE THIRD-PARTY INTERFERENCE, SECURITY, AND GIS-BASED STATISTICS

2.1 Introduction

The negligence of pipeline third-party interference (TPI), especially aftermath of September 9th, 2001 (9/11) could further put the pipeline industry and the local populations in serious danger. The negligence have resulted in disruption of business activity, grave casualty, and economic loss in various oil and gas producing region of the world (Baybutt, 2002, Baybutt and Ready, 2003, Parfomak, 2008). The review of literature have shown that TPI is responsible for high failure rates for all types of pipelines, for example, longitudinal studies of pipeline failures by Conservation of Clean Air and Water (CONCAWE), reports that TPI is responsible for the increase in failure rates for crude oil pipelines in Europe (CONCAWE, 2000, 2006, 2007).

General pipeline failure and the behaviour has been the subject of considerable study over the past forty years, according to Macdonald and Cosham (2005), with a large number of full-scale tests, various analyses and other related work having been undertaken. Literature reviews of pipeline failure studies confirm the growing number and complexity of the available mathematical and scientific models; while, specifically, TPI, a subject that is both technical, social, political and economic has been the subject of fewer studies. For instance, many authors (e.g. Hongqing (2005); Macdonald and Cosham, (2005); and Hopkins et al. (1999)) have all studied pipeline TPI from compiled historical data without consideration and proposals to mitigate damage caused by TPI.

This chapter discusses and examine TPI in detail and reviews pipeline failures, especially intentional and unintentional TPI. The chapter focuses discussion on previous work in mitigating pipeline TPI. The chapter also introduces the application of statistical method and Geographic Information Systems (GIS) in the analysis of pipeline failure, and concludes with a presentation of an extensive description of general security and policy issues, regulations and legislations concerning pipelines.

2.2 Review of Pipeline Third-party Interference

Energy infrastructures, for example, pipelines, truck tankers, refineries and oil and gas terminals are potential targets for terrorists and saboteurs. Many studies and reports have indirectly identified this potential (e.g. Nwankwo and Ezeob, (2008); Parfomak, 2008; James and McKinley (2007); Houreld (2007); and Gale (2006)). For example, rebels have bombed the Caño Limón oil pipeline in Colombia over 600 times since 1995 and similarly have detonated several bombs along Mexican natural gas pipelines in July 2007. The U.S President's Commission on Critical Infrastructure Protection (1997) and Parfomak (2008) both report how London police foiled a plot by the Irish Republican Army (IRA) to bomb gas pipelines and other utilities across the city. Similarly, in June 2007, the U.S. Department of Justice arrested members of a terrorist group planning to attack jet fuel pipelines at the John F. Kennedy (JFK) International Airport in New York.

The successes of any intentional or unintentional interference on oil and gas pipeline have grave consequences that can be devastating for the local people and the environment. This is more probable, especially, considering numerous pipeline companies that are continually digging thousands of kilometres of construction holes to meet with the upsurge in technological advancement. For example, a pipeline TPI tragedy that occurred in California in 2004 resulted in the death of five utility workers. This was caused when an excavator, accidentally ruptured a high-pressure petroleum pipeline (Parfomak, 2008). There are other various records of similar occurrences in several international pipeline failure databases.

CONCAWE (2000) detailed how 500 people died in 1998 when an attempt to remove oil product from a pipeline under its jurisdiction failed. In addition to this, it also recorded how, in 1993, 51 people were burnt to death when a gas pipeline failed in Venezuela. The US Department of Transportation, in 1995, estimated that 50 people were seriously injured in 1994, when a 36-inch pipeline in New Jersey (USA) failed as a result of TPI. Parfomak (2008) also reiterated how *"a 1999 gasoline pipeline explosion in Bellingham, Washington, killed two children and an 18-year-old man, and caused $45 million in damage to a city water plant and other property. In 2000, a natural gas pipeline explosion near Carlsbad, New Mexico, killed 12 campers, including four children"*.

The early developmental history of what by now has cumulated into the above cases of TPI can be traced back to the nineteenth century. In 1806, the London Westminister Gas Light and Coke Company (LWGL&C) laid the first gas mains amidst protest from third parties. In 1850, the Brotherhood of Pennsylvania Oil Haulers vandalised pipes and pumps, and interfered with production in the U.S. Similarly, in the 1880s, there were several monopolistic activities, blackmail of pipeline operators and saboteurs of pipeline as the industry and networks expanded. In the twentieth century, in 1906, the Hepburn Act deemed all interstate oil pipelines to be regulated common carriers, this was amidst various third-party protest and attempted attacks. The Levant pipeline built in 1932 to 1952 from Iraq through Israel to the Mediterranean has been held hostage several times for complex political and economic reasons. In 1950, the Tapline built from Saudi Arabia through Lebanon and Syria was closed down several times due to political reasons and TPI (Miesner and Leffler, 2006). Hence, pipeline TPI is as old as the history of oil exploration itself.

2.2.1 Pipeline Third-Party Interference in Nigeria

In Nigeria, militants have repeatedly attacked pipelines and related facilities resulting in great loss of life and property. The country has the highest cases of pipeline TPI in the world. This is combined with record high cases of hostage taking and extortion of money from oil companies, to avoid attack on pipelines. The Petroleum Product Marketing Company (PPMC), a subsidiary of the Nigerian National Petroleum Corporation (NNPC), documented over 12,770 cases of vandalism between 2000 and 2007. The number is alarming compared to the 450 cases of rupture for the same period (Figure 2-1) (Nwankwo and Ezeobi, 2008).

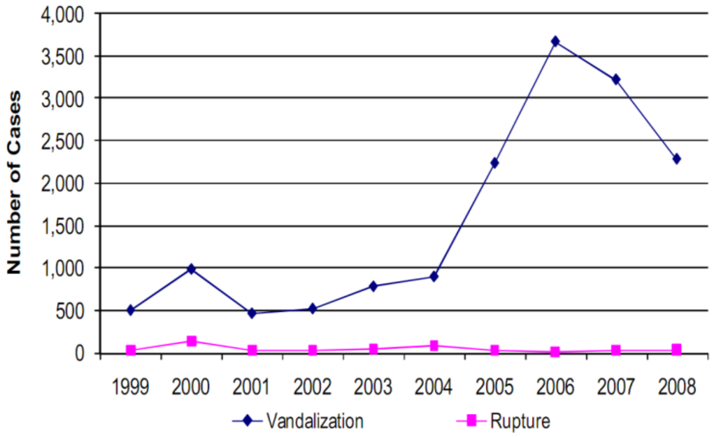


Figure 2-1: Vandalism and rupture rate on pipelines in Nigeria from 1999 to 2005; from 2005 the trend and numbers of cases have been upwards (NNPC, 2005).

In January 2010, some unidentified group in the study area blew up Chevron's *Makaraba-Utonana* pipeline; this forced the company to reduce the production of crude oil by 20,000 barrels, per day. Earlier, in July 10, 2000 it was estimated 250 villagers were burnt to death in Jesse, Delta State, while pilfering fuel from vandalised pipeline. This was followed by a TPI of a pipeline that caught fire near the fishing village of *Ebute* near Lagos, killing over 60 people in November 2000.

Figure 2-2: Scenes of pipeline failures in the study area that burnt to death hundreds of people in *Abule Egba*, a suburb of Lagos in 2006 (Source: Unknown archive newspaper clip, 2007).

A pipeline explosion at *Inagbe* Beach on the outskirts of Lagos resulted in the deaths of 250 people in May 12, 2006. Pipeline TPI reached a new height in 2006, when on December 26, 2006, about 269 recovered burnt bodies from the scene of pipeline fire in *Abule Egba*, a suburb of Lagos, make news headlines (Figure 2-2).

Figure 2-3: Consequences of pipeline failures in Nigeria: (A) Shows various attempts by people siphoning oil from a vandalised pipeline; (B) Aftermath wide destruction of properties from a vandalised pipeline in Lagos, Nigeria; (C) Fire outbreak from a damaged pipeline; and (D) Humans burnt to death as a result of a pipeline explosion caused by a TPI (compiled from bbc.com).

Similarly, on June 19, 2003, a failed attempt at oil theft led to the explosion of pipelines in a village near *Umuahia*, Abia State; in this incident, 125 people died (Figure 2-3(b)). This was followed, in September 2004, when dozens of people died in a pipeline explosion in Lagos after thieves had tried to siphon oil product (Figure 2-3(C)). In addition, Nwankwo and Ezeob (2008) recount how Nigeria experienced increased pipeline vandalism including a simultaneous bombing of three oil pipelines in May 2007. In addition, on December 26, 2007, over 45 people burnt to death in Lagos when fuel they were siphoning from a buried pipeline caught fire (Figure 2-3(D)). In May 2008, at least 100 people died and hundreds were injured when fuel from a pipeline ruptured by an earthmover exploded in a village near Lagos.

Overall, attacks made on the pipeline inevitably disrupt oil production eventually, having a multiplier effect on the international oil price. For example, the total destruction of oil pipelines in *Isaka* and *Abonema*, both in Rivers State barely 72 hours after crippling the *Adamakri* crude flow line belonging to Shell Petroleum Development Company (SPDC) affected the international price of oil barrel (Nwankwo and Ezeob, 2008). Environmental pollution (water, air and solid waste) also results from these pipeline attacks and can be attributed to lack of/and or enforcement of regulatory standards. The activities of the oil companies in the study area have destroyed much of the land cover, for example, and as confirmed by the review of the NNPC database, thousands of oil spills occur yearly. The inadequacy of the oil companies to redress this issue, together with the destruction of livelihood, does lead people to vandalize and pilfer from the oil infrastructure, as a way of revenge and obtaining compensation. More worrisome are the large-scale attempts of armed groups against government reprisals, thus deepening pipeline TPI.

2.3 Third Party Interference: Previous Research Studies

Since the discovery of oil and its transportation by pipeline, only few studies have been conducted to examine pipeline TPI. This is in addition to the many questions that remain unattended to about unifying the various complex contributory factors influencing the occurrence of TPI. Particularly, the problem of intentional TPI and the ability to quantify and measure the salient factors, for example, geographical accessibility, socio-political and socioeconomic factors. These factors have not been adequately treated, especially the combined effect. These factors are imperative in developing an understanding of pipeline TPI. Although more studies and articles have been written, for example, on unintentional

TPI, no studies have attempted to resolve the contradiction between intentional and unintentional TPI. The results of various representative studies relating to TPI are described in the following sub-sections.

2.3.1 Depth of Pipeline

It has been hypothesised that the deeper a pipeline is buried, the lower the risk. A pioneering study by Knight and Grieve (1974), cited by Mather et al.(2001) provided a comprehensive (although not exhaustive) overview of the influence of depth of cover on TPI. It complements the companion review by Neville (1981), also cited by Mather *et al.*, (2001); although no data existed to confirm this, the study concluded that increasing the depth of cover will bring about a reduction in pipeline TPI. The two papers share the same understanding, which provides a description of the influence of depth of cover of pipelines; which today is still one of the major factors for third party damage risk reduction.

Chen and Su (2009) studied the relationship between the depth of pipeline, geological fault, pipe-soil friction, and accidental pipeline damage using the predictive capability of Artificial Neural Network (ANN). The occurrences of the pipeline damage are assumed nonlinear in the analysis, and the numerical simulation of the model adequately produced an optimum structured network. However, this study has not treated pipeline damage from accidental interference in much detail. For example, the study did not capture the effects of the number of previous damages has on future probability of reoccurrence and on the model. The reliability and practical evaluation of the study would have improved if the author had not overlooked the fact that history of pipeline damages contributes to reliable prediction of future occurrence and to understanding TPI.

2.3.2 Human Activities and Pipeline Third-party Interference

One of the greatest single challenges to safe operations of pipelines is the accidental interference caused by human activities (Day et al., 1998). Geyer et al. (1990) investigated how organisations, management procedure, and human related factors might be quantified and included into pipeline risk assessments and safety procedures. Their study is a socio-technical analysis of pipeline failures, taking into consideration various factors ranging from management procedures, design for preventive measures, engineering reliability, and human error as direct contributors of pipeline TPI. Their findings provide satisfactory explanation to understanding the effect of general human factors to occurrence of TPI, however, the study failed to explore the association between population proximity and land use in reducing impacts. These two factors he failed to consider are basic significant human factors to understanding the occurrence of TPI.

The availability of historical data further prompted Sljvic (1995) to study relationships between human activities and their contribution towards pipeline failure. He also recognised TPI as the single most probable cause of pipeline failure arising from, but not limited to, landowners, utility companies, contractors, and local authorities. It, however, conflicted with a companion paper (Hovey and Farmer, 1993) who contended that the probability of a spill, from TPI, along a pipeline is the responsibility of the risk managers and not socio-economic factors. The Sljvic's (1995) study, subsequently examined by Hongqing (2005), further encourages increased contact by pipeline operators with potential third parties through quality dissemination of information. However, a review and examination by Pipeline Safety Regulations (PSR) of 1996, aimed to make pipeline safer, with particular reference to TPI further concluded and points out that people who intentionally interfere with pipelines are responsible and liable for the consequences of their actions. These results are suggestive, it is expected that any TPI should be the collective responsibility of the owners of the pipeline and the third parties causing the interference.

Furthermore, many analysts now argue that the strategy of involving all stakeholders in the prevention of TPI has been successful. Hongqing (2005), for example, argues that the differential impact of primary causes of TPI is community based. He therefore reinforced the need for traditional prevention of pipeline TPI (e.g. patrol and periodical survey). It can be concluded that geographical inequalities in infrastructural development and facilities between urban and rural areas also induced a high rate of migration into the urban areas from the rural areas, putting considerable pressure on the urban centres to gradually encroach into pipeline right-of-way (ROW). However, the study concludes that inadequate communication between pipeline operator and local inhabitants caused most TPI. In order to guarantee pipeline safety and security, he also investigated how pipelines can be protected from TPI using methods of GIS, Remote Sensing (RS) and direct surveillance by developing a model to fit similar data. The probabilistic model measuring failure rate of third-party pipeline damage was designed using historical data and structured opinion survey of experts. Pipeline characteristics and environmental factors were also considered in the probability model.

2.3.3 Researches on Mechanical Methods for TPI

Previous studies have reported how to remotely monitor any on-going TPI on an oil and gas pipeline using signal detection and classification (e.g. Wang et al. (2006) and Leis et al.(1998)). They tested for the effect of pipeline drilling, excavation, and mechanical hammering under normal typical working conditions. However, the model they employed failed to significantly identify and filter out false alarms and environmental noises that are common with signals detection using the acoustic method as demonstrated by Cao et al. (2007). Similarly, Nikles (2009) showed how fiber optic sensing technique was used to measure strain and temperature for cross-country pipeline. The system is able to monitor pipeline ground movement, interferences and detect leakages. The system was corroborated by case studies and practical field data test. Notwithstanding these results, it is unclear from these studies whether what was learned in one area could be applied to another. In addition, the main weakness of the study is the failure to address high investment cost and expensive optical line transmitters and receivers this method will incur, besides lacking industry standardisation (at least for now) and the limited acceptance in pipeline project procurement.

Nam et al. (2006) introduced an on-line monitoring system for TPI for underground natural gas pipelines using accelerometers installed along pipeline, which could detect a propagated acoustic pressure and pulse from any pipeline interference. The model was validated with third-party damage simulation using hammer, drilling, etc. The study is similar to the one carried out by Wang et al (2006). However, all the studies reviewed so far, suffer from the fact that (according to Hopkins (1993)), over 80% of oil and gas pipeline are onshore, long haul and laid cross-country. Hence, a system that's cheap to implement and target vulnerable pipeline segments driven will do the industry good in term of resources management, although the advance security technologies are welcomed, and could be suitable in vulnerable segments of pipeline network.

2.3.4 Application of Statistical Method in Pipeline Failure

One area in which statistical approaches are commonly applied in pipeline failure are model-based procedures to investigate the influences of multiple variables. For example, Wan and Mita (2010) presented a methodology for early warning of hazards to pipelines using Eigenvalues derived from Principal Component Analysis (PCA), as unique prediction signature, coupled with acoustic information applied to pipelines from third-party activities. The effectiveness of the method was investigated using an on-site application to a pipeline that indicated possible determination of early warning for pipelines.

Cagno et al (2000) uses the Analytic Hierarchy Process (AHP) and Bayesian approach to investigate the pipeline failures and assess the probability of failure of low-pressure cast-iron pipelines. The integration of historical data and knowledge of company experts to aid accurate rehabilitation policy was employed in the study. Expert opinion using the AHP to develop a Decision Support System (DSS) was also used by Dey (2004) to determine priori distribution of gas pipeline failures coupled with a DSS. However, there are several drawbacks of using this method. First, humans are not very good probability estimators (Paulson and Zahir, 1995). While Dey (2004) recognises pipeline risk analysis as a group effort, the unequal length of pipeline stretches (segment) used lacks homogeneity requirement and thus may negate unequal sample size, and lead to a loss in inference efficiency. This method is mostly based on the worst-conditions-first approach, which may not be the most cost-effective approach in pipeline risk management. Secondly, the Bayesian method by Cagno et al (2000) is vulnerable to a poor choice of factors for consideration. This is evident considering the inappropriateness of the *in- house* experts to give and determine adequate descriptive statistics for failure density.

Limited research to date dealing with third-party pipeline damages using statistical techniques have also failed to consider many essential factors that affect the susceptibility of a pipeline network. Mather et al. (2001) for example, developed a predictive model, which can be used to assess the likelihood of pipeline failure caused by TPI using such factors as pipeline diameter, wall thickness, geographic location, and depth of cover. The EGIG and BG Transco data were used in the analysis. The Mather et al. (2001) analysis with reliance on these factors may be subjected to certain error in the prediction of frequency of TPI. This was evident in comparison of predicted failure frequency values derived from EGIG and BG Transco data investigated that showed a marked difference in the result. This approach of drawing inferences concerning TPI from the failure history and pipeline depth of cover rests on the assumption that vulnerability of pipeline is depth related. However, it has been shown that a significant proportion of TPI activities do not depends on the depth of cover. Activities such as drilling and seismograph activities involving underground detonations are influential irrespective of pipeline cover (Muhlbauer, 2004).

2.3.4.1 Advance Linear Statistical Model

Previous research has usefully used the simple t-tests and least squares regressions methods for pipeline failures, assuming normal distributions of the pipeline data (e.g. Barteneva (1996)). However, many authors (e.g. Tabachnick and Fidell (2007)) question the ability of these assumption, by pointing out that assuming normal distributions of pipeline incident is an inappropriate approach. Perhaps the simplest approach to evaluate patterns of TPI measured by point counts is to use statistical tests that are more flexible about the distributional properties of the data, especially to make statistical inferences. Some authors add that approach and methods involving the use of exponential distribution families including the Poisson and Negative Binomial models to address the issue are more appropriate.

In addition, many previous research in various studies in transportation, biology, physics, medical sciences, and marketing using least squares (e.g Jovanis and Chang (1986); Joshua and Garber (1990); and Miaou and Lum (1993)) indicates the inappropriateness of these techniques to modelling failure frequencies and recommends the employment of the Poisson distribution. The Poisson distribution, however, also suffers from variance disparity, where the variance is greater than the mean (over-dispersion) or when the variance is less than the mean (under-dispersion) (Hinde and Demetrio, 1998). This mean and variance equality constraint can leads to biased coefficient estimates. A more general distribution, such as the Negative Binomial has been employed in such situations to relax the issue. However, recent research shows the inadequacy of this approach. The authors also show the misinterpretation of the inverse dispersion parameter when a sample size becomes small and the samples mean value is low (Maher and Summersgill, 1996, Wood, 2002).

Consequently, since these methods can lead to erroneous inferences and coefficient estimates, the Generalized Linear Models (GLMs), in which non-normal distributions can be specified, is appropriate because it relaxes the Poisson's mean-variance equality constraint. The GLMs are "*a broad class of models that include ordinary regression and analysis of variance for continuous response variables, as well as for categorical response variables*"(Agresti, 1990). Several studies have attempted to use GLMs in varying degrees to model utility network (e.g. power transmission and water pipeline). Guikema et al. (2006) developed a model for infrastructure reliability of electric power system outages with Poisson GLMs, a Negative Binomial GLMs. The models include predictor variables that were used to measure the impacts of tree trimming on electric power system outages under normal operating conditions.

2.3.4.2 Geographically Weighted Regression (GWR)

Geographically Weighted Regression (GWR) is a technique pioneered at the Department of Geography of Newcastle University (UK) by Stewart Fotheringham, Martin Charlton and Chris Brunsdon. The technique, in recent years has experienced increasing interest in many science researches. One major theoretical issue that has made GWR dominated the field of linear statistics concerns the limitations of the ordinary least squares regression analyses. Ordinary Least Squares (OLS) regression analyses produce only global statistics with assumptions that relationships between variables are same in a given study area. The objective of using GWR is first, to investigate the spatial correlation between neighbouring geographical locations and the local contribution of the independent variables, especially how they influence the dependent variable's outcomes. Secondly, to examine how spatially consistent relationships between the dependent variable and each independent variable are across a given study area. This is simply to reveal where and how much variation is present in a model.

A large and growing body of literature has investigated the use of GWR for different types of crime related analysis, for example, Malczewski and Poetz (2005) used it to explore the relationship between residential burglaries and neighbourhood socioeconomic context in London. Recent evidence suggests the applicability of GWR in socioeconomic context; for example, GIS based spatial analysis and modelling of land use distributions, and transport analysis as demonstrated by Dendoncker et al.(2007) and Paez (2006). Previous studies have also reported the use of GWR as a suitable method for understanding the occurrence of accidents (e.g. pipeline incidents), for example, Adhikari (2006) applied GWR to improve the predictability of urban intersection vehicle accidents. These approaches with GWR are applied to pipeline TPI, especially intentional TPI in this thesis.

2.3.4.3 Logistic Regression

Logistic Regression (LR) is a form of GLMs, and since its conception, it has been used exclusively in the clinical, botany, biology, geology, and psychology disciplines for the purpose of predicting events occurrence. In recent years, the use of LR in many engineering, environmental and social applications is very popular. Tabachnick and Fidell (2007) recount how it is now one of the most widely used statistical methods for probability prediction of dependent and independent variables. The suitability includes predicting landslide, earthquakes, rockslide, and in manufacturing process. However, at present there is relatively little research published on the application of LR in the analysis of petroleum pipeline failure. This limitation is probably due to inadequate data obtainable, compared to other field where data can be reliably gathered successfully. Hence, this thesis presents a novel methodology of multivariate statistical techniques using the LR to investigate the failure characteristics of TPI. It hypothesised that the factors influencing TPI are environmental, socioeconomic, socio-political, and the pipeline geometry.

2.4 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) first introduced in the 1960s in Canada is referred to as a computerised system for mapping (Longley et al., 2005). The technology is now being widely accepted for the exploration of oil and gas in today's multi-billion pound oil business; when geoscientists, engineers, and geologist look for oil they implement GIS (Day, 1998). GIS helps collect, store and integrate spatial data for analysis to generate new information in a map-based, database and graphical model formats. Cowen (1988), Parker (1988), DoE(1987), and Burrough (1986) have defined GIS as: *"a decision support system involving the integration of spatially referenced data in a problem solving environment"; "an information technology which stores, analyses and displays both spatial and non-spatial data"; "Integrated computer systems for capturing, storing, checking, manipulating, analysing and displaying data which are spatially referenced to the Earth's surface"*; and as "*a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world"* respectively.

The advent of GIS coupled with readily available various dataset in environmental studies has made GIS increasingly useful in environmental assessment and monitoring. This is because of its statistical and spatial analytical ability. It also enables decision-making capability and the detection of complex spatial relationships within various factors for consideration (Augusto Filho et al., 2010, Facchinelli et al., 2001, Malczewski, 1999, Rigina, 1998). Researchers have used the statistical capability of GIS for analyses in diverse industrial applications. Josi and Iraokhahi (2010) used GIS-based AHP procedure to classify and assess numerous types of environmental risks to petroleum pipelines. The study showed that the most significant influencing factors to the occurrence of third-party damage in their study area are the local population and human activities. Partovi et al. (1999) used it for operations management decision-making. Dey et al. (1999) used it in managing the risk of projects. The methodology of this thesis relies on application of GIS-based statistical analysis to predict vulnerable segments and regions of a pipeline network. This hybrid approach can identify and rank pipeline segments with potentially high risks for TPI so that preventive actions can be taken to reduce the risks in these segments.

2.4.1 GIS Application in Pipeline Management

Malczewski (1999) identified GIS as a decision-making tool, using different data from various sources for solving spatial problems through spatial analysis and modelling. In the pipeline industry, Augusto et al. (2010); Kneller (2007); Hutson (2006); Luettinger and Clark (2005); and Gale (1999) have used GIS as a decision making tool for optimum pipeline route selection and for related oil and gas facilities. Characteristically, the technique used involves the analysis of spatial data using data captured by remote sensing; and these studies have only focussed on environmental impacts, risk management and construction costs factors. For example, Augusto et al. (2010) used GIS to developed qualitative models of pipeline hazard risk analysis using multicriteria decision investigation. The study indentified pipeline segments vulnerable to failure. TPI, geotechnical and environmental risks were considered. Although, despite the few research carried out on pipeline TPI, no single study exists which adequately covers extensive factors (e.g. socioeconomic, socio-political, geographic accessibility, and human factors), and combined with primary questionnaire survey to exploit opinion of the industry experts. De Albuquerque et al. (2002) is critical of the conclusions that various authors draws about unavailability of data to fully exploit other factors for consideration. He reviewed how GIS could exploit online data and how decision-making process can be taken to the internet where pipeline data and other multimedia documents via a computer network can be distributed and shared.

Wild et al. (2002) reassessed how Conoco Inc. used GIS technology in pipeline project development for sustainability growth of its asset by linking diverse organisations and key players together on the internet. They showed how sustainability and continuous use of GIS from planning to pipeline operation is beneficial to a decision-making framework, especially the consideration for eco-efficiency, socioeconomic, and socio-environmental factors. However, it is perceived that the growing advent of cyber security requires caution be taken in any implementation of pipeline web mapping. This is important, to avoid *e-hijack* of a company's server or database, a form of third-party interference.

An integrated use of GIS, for pipeline projects is useful in installation management, emergency prevention, preparedness, and response. A European leading oil and gas company, OMV, uses GIS for oil exploration and production workflow. They have used GIS to create analysis tools, reduce data redundancy, and allow easy manipulation and access to data, in addition to creating seismic navigation maps for oil exploration. The company built a prototype GIS-enabled internet system where remote operators and employees can view, query, interact with essential data online (Kamelger et al., 2006).

Shields (2006) reviewed how Earth Science Associates (ESA), uses GIS to predict the impact of hurricanes on oil and gas production in the Gulf of Mexico between 2004 and 2005. The combined impact of hurricanes *Katrina*, *Rita*, and *Wilma* implicitly "affects 105,889,263 barrels of oil, an equivalent of approximately 19 per cent of the Gulf of Mexico's yearly oil production". Particularly, GIS integrated with pipeline networks and 50,000 wells were used to develop a comprehensive risk analysis and recovery operations planning.

The holder of the world's largest oil reserves, the Saudi Arabian Oil Company explores the advantages of GIS. They used GIS to plan pipeline route surveying projects and develop a safety and emergency response system with a web based gas leak emergency response system. A land management system to manage land use permit and monitor encroachment in to the company's facilities was also developed with GIS (Saudi-Aramco, 2003). In addition, Petróleos de Venezuela S.A. (PDVSA), a Venezuelan petroleum company is using GIS to manage its operations of hydrocarbon transportation and distribution facilities. According to Leon et al. (2003), the GIS system developed manages Venezuela's 6,000 kilometres of pipelines. Integration of satellite images, basic cartography, petroleum pipeline data, well locations, and seismic data has improved oil and gas exploration and production (Leon et al., 2003).

Gin et al. (2002) and Wild et al. (2002) reviewed an industry-based role of GIS in the sustainability of pipeline integrity. They reviewed that the role of GIS in pipeline assessment and management provides the ideal tool for mapping pipeline attributes, content movement, and spatial analysis. They further claimed it is taking over from the traditional cartography and statistical methods. However, applications of GIS to socio-political and socioeconomic characteristics is been poorly integrated with these advance techniques. Proper understanding of human activities and its relationship with the environment is very important to produce accurate representation of a phenomenon (Martin and Bracken, 1993). Thus, for a good analytical GIS analysis for petroleum pipeline, it is important to recognise the many different roles various factors considered in this thesis play in supporting pipeline failures.

2.4.2 GIS and Pipeline Security

The rapid population growth worldwide is pressuring the energy infrastructure to a breaking point and resulting in high failure rates of pipeline. Such problems are not unique to developing countries. Developed countries that have had similar experience are currently using GIS tools to solve these problems by realising that GIS is a powerful tool for law enforcement, crime prevention and in risk assessments. Singularly, by applying GIS technologies, crimes (for example, intentional TPI) can be geo-located to reveal significant trends and relationships, thus helping in law enforcement planning and more effective resource allocation, to avert subsequent reoccurrence (De Albuquerque Vasconcelos et al., 2002, Ratcliffe and McCullagh, 2001). This application of GIS is an indispensable tool in preventing TPI. In brief, the following are the main tasks that a GIS-based model can accomplish in protecting pipelines against TPI (Chainey and Ratcliffe, 2005):

- Generate reports and hardcopy maps for different type of queries enabling the law enforcement agencies to visualise TPI patterns.

- Show the hotspots in a typical pipeline segment (i.e. the areas with high rate of TPI) on a map to assist with resource allocation more efficiently.

- Show TPI in buffer zones around institutions like schools, villages, petroleum facilities. This zones can be use to map repeat calls where applicable, and also identify trouble spots and TPI prone areas.

- Cross-reference the location of TPI with list of suspected vulnerable region to have an approximate idea about the operation area of susceptible regions. This can help prepare police patrols for quick response to maximise limited resources in combating TPI.

- Customised GIS crime analysis model will provide the law enforcement agencies and pipeline operators capability to create density maps of TPI and analyze trends over time.

- Compare TPI data to demographic data and analyse the probability and location of future TPI using the expected range of TPI activity.

2.5 Pipeline Security: Policy Issues

2.5.1 Pipeline Regulation and Legislation

In the last few decades, environmental, political and financial awareness and consciousness concerning the negative aspects of pipeline failures have led to the development of various national policies to alleviate the consequences and probabilities of such failures. Consequently, different legal frameworks and many actions have been taken to implement a number of appropriate environmental protection laws. This legal initiative also aims to harmonise the existing protection legislation, and make it a constitutional duty of any responsible government at all levels to safeguard oil and gas pipelines. Pipeline failures not only influence the world energy supply of oil, but also cause serious environmental damage and pollution (Wolf and Stanley, 2003). Therefore, the importance of effective regulation and legislation for the prevention and remediation of pipeline damage cannot be over emphasised. In countries where terrorism persists, pipeline protection is given the utmost attention and no amount of money or research is considered too much in ensuring their protection and safety.

The European Council and the parliament, have, over the past few years, reviewed regulations regarding pipeline accidents (and related petrochemical hazards) and the need to follow strict international protocols to curb this global issue and which clearly indicated the *'major accident hazard'* potential of pipelines. Thus, the Seveso II Directive 96/82/EC of 1999 became necessary considering the increase in the rate of environmental damage resulting from pipeline TPI. Papadakis et al. (1999) further points out that a number of guidelines and regulations on managing the environment and preventing pipeline failures in Europe are stipulated by various organisations, departments, ministries and international organisations that existed at that time. However, the platforms on which these numerous legislations operate form the framework of planning decisions, and are mostly, inadequate and limited in application. They do not have a comprehensive and undeviating 'major accident hazard' legislation in place for minimizing pipelines failures from third-party interference (Wolf and Stanley, 2003).

2.5.1.1 Pipeline Safety Legislation

In the United Kingdom, the consequences of pipeline TPI and the continuous development of a nation's economy and human subsistence has been acknowledged since 1996 and have prompted the implementation of the Pipeline Safety Regulations (PSR) of 1996 statutory regime (Fisher, 1997). This statutory law is applicable to onshore and offshore pipelines throughout the entire life cycle of a pipeline, covering the following activities: planning, design, construction, operation, maintenance, and rehabilitation (Fisher, 1997; cited by Mather et al., 2001). Prior to the PSR of 1996, several legislations have addressed the control of accidents and hazards from pipelines. In England and Wales the Maritime and Coastguard Agency (MCA) is the authority regulating the potential for pollution from shipping and offshore installations, for example pipelines. In addition, the Merchant Shipping Act (1995) is responsible for offshore installations to avoid pollution by implementing necessary command and control actions.

However, the PSR of 1996 statutory regime deals rather poorly with the issue of potential TPI in terms of the requirements laid down under its regulations. Regulation 15 for example states: *'No person shall cause such damage to a pipeline as may give rise to a danger to persons'*, and Regulation 16 states: *'For the purpose of ensuring that no damage is caused to a pipeline, the operator shall take steps to inform persons of its existence and whereabouts as are reasonable'*. This command-and-control statutory regime does not prescribe the form of protection to be used during pipeline construction, and only recommends that reasonable steps are to be taken to inform people (owners and occupiers of land in close proximity to a pipeline) of the existence of the pipeline followed by periodic surveying of the pipeline's alignment (Mather et al., 2001). This inadequacy prompted Zywicki (1995) to put forward many arguments challenging such wide and general regulations, in that the distinction drawn by such regulations are sometimes narrow, political and unsocial; that choices in regulation affecting environmental damages and pollution (for example, resulting from pipeline damage) reflect political influence and interest. Zywicki's argument is that a more categorical statutory regulation is required for factors contributing toward the growing environmental problems like TPI.

2.5.2 Legal and Administrative Framework in Nigeria

The present trend of third-party interference in Nigeria has confirmed that more effort is required in establishing firm regulatory laws. In recognition, the federal government of Nigeria established the Federal Ministry of Environment (FMENV) with an overall directive to monitor, protect, and preserve all ecosystems of the country. Today, the FMENV is trying to implement the policy on the environment, coupled with some assistance from environmentally friendly organisations and non-governmental organisations, especially in creating the awareness for environmental consciousness regarding TPI.

A number of pipeline safety guidelines and regulations have been stipulated by various national organisations, for example the Department of Petroleum Resources (DPR), various State ministries of environment and various international organizations such as the World Bank. According to FEPA (1991), these legislations now form the framework on which planning decisions are being made for pipeline installations in Nigeria. However, national policies on pipeline safety and environmental protection require companies to manage their pipeline networks in a socially responsible and ethical manner, in order to protect and ensure the safety and fitness for purpose of pipeline. Federal laws have since backed the initial guidelines produced by FEPA. For example, paragraph 15(2) of the new regulations S.1.9 by FEPA states clearly *'No oil, in any form, shall be discharged into public drain, rivers, lakes, sea, atmosphere or underground injection without a permit issued by the agency (FEPA) or an organization designated by the agency".* Paragraph 17 of the same legal instrument states *"an industry or a facility which is likely to release gaseous, particulates, liquid or solid untreated discharges shall install into its system appropriate abatement equipment in such manner as may be determined by the Agency"* (FEPA, 1991).

The overall objective of the foregoing legal instruments, regarding oil and gas related activities in Nigeria is to regulate operational environmental damage, for example, accidental spills of oil and gas from pipelines or processes within the territorial waters of the country. These guidelines, issued by FEPA, stipulate minimum required standards for all industrial waste, either operational or accidental. In addition, it is required that managers and operators of oil and gas pipelines must comply with the regulation, in order to improve the quality of the service delivery and other environmental hazards. However, literature review shows that the prevention of TPI and general management practice within each pipeline operator in the study area are been guided by environmental standards including those imposed by legislation and those established by self-regulating industrial codes of practice, industry standards and company policy. In general, some other related laws in Nigeria, albeit pipeline operator's policy, include pollution mitigation and industrial waste from the activities of the oil and gas company, and include the following:

- The Harmful Wastes (Criminal Provisions) Decree No. 42 of 1988
- Pollution Abatement in industries generating Waste Regulations: S.1.9 of 1991
- Solid and Hazardous Wastes Management Regulations of 1991
- 1992 National Guidelines and Standards for Waste Management

2.5.2.1 National guidelines for pipelines in Nigeria

Department of Petroleum Resources (DPR): The Department of Petroleum Resources (DPR), among its other duties, is responsible for regulating the activities of the oil and gas industry in Nigeria. It also ensures strict compliance with relevant regulations in the industry. The DPR has published the environmental guidelines and standards for the petroleum industry, which stipulate the manner by which pipelines should be protected against TPI (FEPA, 1991). The methods include regular patrol of right-of-way and detail Environmental Impact Assessment (EIA) of pipeline projects.

Federal Ministry of Environment: The FEPA (1991) Guidelines and Standards for Environmental Pollution Control in Nigeria (now the Federal Ministry of Environment) provide and regulate the permissible boundary and limits that will help to prevent indiscriminate discharge of oil and gas product, for example, products from pipeline rupture, into the environment and coastal waters. These frameworks are also applicable to the maintenance and rehabilitation of oil and gas pipelines (FEPA, 1991).

State Legislation: The Nigeria constitution allows States to make legislation, laws, and edicts on the environment. For example, the EIA Act No. 86 of 1992 recommends the setting up of state environmental monitoring agencies to corroborate the efforts of the federal government in regulating the consequences of all oil and gas pipeline related project development. For example, the edict setting up the Delta State Environmental Protection Agency (DELSEPA), in the thesis study area outlines the primary responsibilities of the agency, which is to protect and monitor all oil and gas activities with the potential to disrupt the general environment of the study area (FEPA, 1991).

2.6 Summary

This chapter provides a summary of the review of existing information about TPI and discussions on legal and administrative framework, in addition to a very detailed description of pipeline TPI. The chapter suggest the need for developing critical legislation in addition to technical capabilities to curb pipeline TPI. Specifically, in the study area, it was found that pipeline TPI experienced a high rate of failure commencing from 2005 to 2009. The chapter also discusses several techniques in the literature that have been developed in the past to study and understand pipeline TPI. The following chapter, Chapter 3 presents the review of major international pipeline failure databases in Europe, America, Africa, Australia, and Asia.

3 REVIEW AND COMPARISON OF PIPELINE FAILURES DATABASES

3.1 Introduction

This chapter reviews and compares the major international pipeline failure databases in Europe, America, Africa, Australia and Asia. This comparative analysis of major pipeline incident databases is aimed at exploring the differences and similarities in order to understand the background frequencies estimation of pipeline third-party interferences (TPI), and contribute to literature, as a potential references for future development of pipeline incident database. The databases under comparison include:

- Australian Pipeline Incident Database (APIA)
- Conservation of Clean Air and Water in Europe (CONCAWE)
- European Gas Pipeline Incident data Group (EGIG)
- Office of Pipeline Security (OPS)
- National Energy Board (NEB)
- United Kingdom Onshore Pipelines Operators Association (UKOPA)
- Russian Association for Licensing (JSC Gazprom/Rostechnadzor)
- Nigeria National Petroleum Corporation (NNPC)

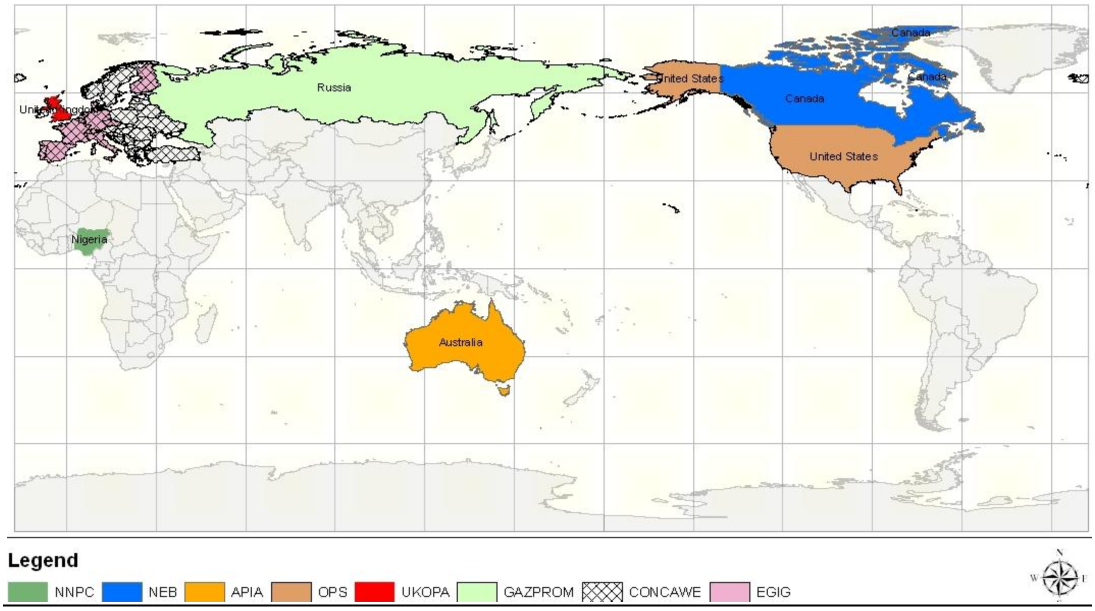


Figure 3-1: Map showing the major international pipeline failure databases review in this thesis, in Europe, America, Africa, Australia, and Asia.

Figure 3-1 illustrates the databases identified and reviewed for this thesis; however, only databases with its data in public domain, and are major world producers of oil and gas products were reviewed. However, while the databases under consideration have catalogued different causes of pipeline failures, this thesis is limited only to pipeline TPI in these databases.

3.2 Australian Pipeline Incident Database (APIA)

The safety of over 21,000 kilometres of high-pressure transmission pipelines and related facilities in Australia is the responsibility of the National Offshore Petroleum Safety Authority (NOPSA), a section of the Department of Industry, Tourism and Resources, responsible for monitoring all pipelines and administering safety legislation. These responsibilities include managing Australia's natural gas resources, which account for approximately 1.6% of the world combined oil and gas demand (Kimber, et al., 2003).

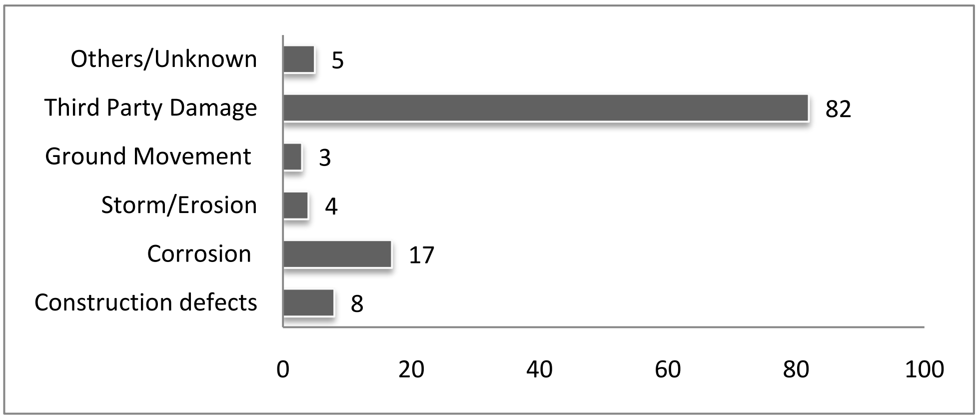


Figure 3-2: Summary of pipeline failure from APIA's database from1987 to 2002. TPI damage is significant, and account for over 60 per cent of the entire occurrences (Kimber, et al., 2003).

APIA defined TPI as any incident resulting in loss caused by land disturbance activities, for example, excavation, boring activities, and unauthorised activities in close proximity to pipelines. Some analysts (e.g. Kimber et al., 2003) have attempted to draw attention to the fact that pipeline TPI in Australia is low when compared to that of other countries with similar oil and gas statistics (EIA, 2008). For example, no fatalities have occurred since the 1970s, and statistically, only one fatality per 60 years for the transmission system is expected. However, TPI is the leading cause of pipeline damages in Australia, and this has been confirmed by the 82 incidents of TPI between 1987 and 2002, 60 per cent of the total number of incidents in that period (APPEA, 2008, Kimber et al., 2003). By way of illustration, Figure 3-2 presents the overall pipeline failure statistics between 1987 and 2002 in Australia, and shows how TPI dominates causes of pipeline failures.

Many analysts argued that the strategy of NOPSA for protecting pipelines from damage, especially TPI, has been successful. Kimber et al. (2003), for example, argue that the reason for this is that pipeline research and schemes (for example, the Australian Standard for pipelines (AS2885) and the Australian Pipeline Industry associates annual conference) in Australia has focussed on preventing TPI through public awareness programmes. This strategy, according to Kimber et al. has worked successfully in minimising the occurrence of TPI in Australia. In other major studies in Australia (e.g. Brooker, 2002), objective measures have been shown to be very efficient compared to physical measures in protecting pipelines against TPI. Kimber (2001) for example, showed that using the maximum wall thickness as prescribed by the design standards, does not guarantee protection of pipelines against direct drilling or other cutting actions by third parties.

The above studies corroborate the findings of a questionnaire survey, conducted as part of this thesis and described in Chapter 9, and the recommendations of the Australian Standard for pipelines (AS2885.1-1997) supporting the use of pipeline awareness programmes and risk based approaches in preventing TPI. For example, a respondent to the questionnaire states that *"In Australia TPI is brought about by deficiencies in the risk assessment in the first instances failing to identify the threat and relevant controls of such interference. I disagree that third parties would intentionally seek to damage a pipeline; unless of course it is in a politically unstable environment e.g. Iraq and Afghanistan."* However, Roach (2003) points out that Australia's success in reducing TPI incidents lies in a systematic evaluation of each threat and proposing appropriate immediate action to eliminate such risk, in addition to remotely locating potential pipelines vulnerable to TPI.

Figure 3-3 shows summarised plots of failure rate of all the databases reviewed in the thesis. Table 3-1 showed the trend calculations for pipeline failure statistics between 1998 and 2007 where simple forecast analysis are implemented to show the trend of third-party interference in the APIA database, and other databases reviewed in this thesis. The percent change if the numbers of incidents changes from P_1 to P_2 is calculated by:

$$\frac{P_2 - P_1}{P_1} X\,100 \qquad \text{(Equation 3.1)}$$

In equation 3.1, P_1 is numbers of incidents last year and P_2 is the current's years numbers of incidents, for example, APIA had 8 numbers of incidents in 1998 and 7 incidents the following year. Therefore, the percent change from 1998 to 1999 is calculated by subtracting *7* from *8*, divided by *8*; this give *0.125* that is further multiplied by 100. Therefore, the number of incidents at APIA's database went down 12.5 per cent from 1998 to 1999. This same procedure applies to tables in this chapter showing trend calculation of pipelines incidents.

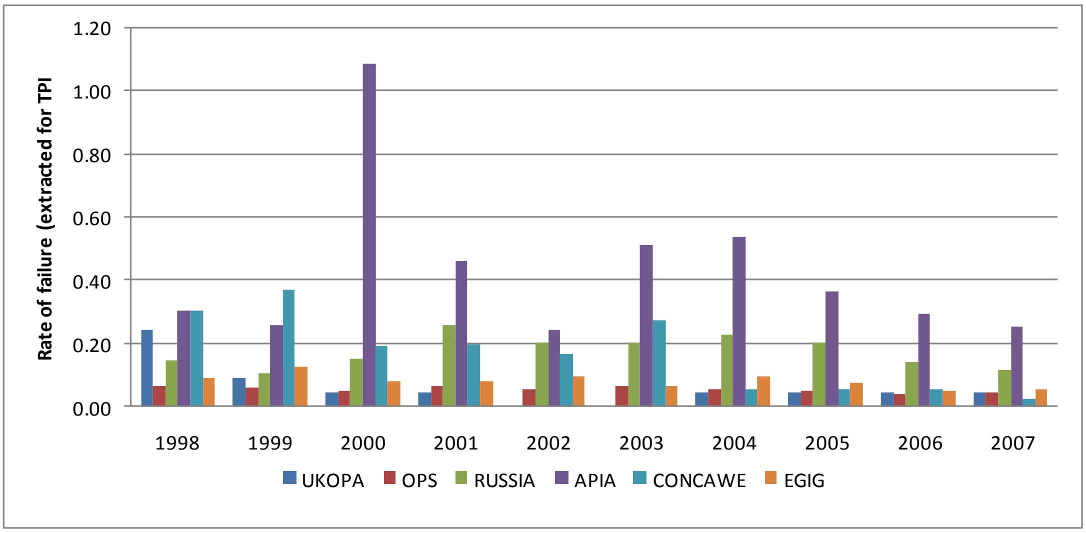


Figure 3-3: A plot of failure rate calculated from the procedure described above, showing the trend comparison of pipeline incidents for the databases reviewed, from 1998 to 2007.

The rate calculation in Table 3-1, for the various databases under consideration is by dividing the numbers of pipeline incidents by the total length of the pipelines, and expressed as a ratio. However, some missing data, for example, length of pipelines for certain period of time where determined by using existing values, assuming the data values increase or decrease at a steady rate. The simple linear equation was used to calculate the least squares fit, and to predict subsequent estimated length of pipeline.

Australia's relatively low rate (as can be seen in Table 3-1) of pipeline failure is probably because of the failure to address the voluntary provision of data by pipeline operators. Although, this is not a regulatory requirement, as provision of major pipeline incidents in

Australia is voluntary, according to Bolt (2006). This might explain the low failure rate, because as Bolt (2006) argued that not only does the voluntary submission of dataset provide an accurate measure of the Australia rate of pipeline failure, but also, Australia's low population density and relatively young age of most of its pipelines are other contributory subsequent estimated lengths of pipelines.

Table 3-1: Trend analysis of Australian pipelines incidents from 1998 to 2007.

Year	*No. of Incidents**	*% Change*	*Length (Km '000)***	*Rate*
1998	8		26.314	0.304
1999	7	-12.5%	26.778	0.261
2000	30	328.6%	27.604	1.087
2001	13	-56.7%	27.972	0.465
2002	7	-46.2%	28.512	0.246
2003	15	114.3%	29.109	0.515
2004	16	6.7%	29.666	0.539
2005	11	-31.3%	30.223	0.364
2006	9	-18.2%	30.780	0.292
2007	8	-11.1%	31.337	0.255

** Pipeline Spillages by TPI for year 1998 through 2003; **2005 to 2007 predicted using existing values*

3.3 Conservation of Clean Air and Water in Europe (CONCAWE)

Conservation of Clean Air and Water in Europe (CONCAWE) started in 1963, as a European organisation, comprising various oil and gas companies. The objectives are to monitor fuel quality, vehicle emissions, air quality, health, petroleum products, and cross-country oil pipelines. The organisation monitors a combined network (as at the end of 2006) of 35,390km onshore oil pipelines. They also produce annual statistical summary of reported spillages, in addition to records and reports of all the annual pigging inspection statistics of the participating seventy operating companies and agencies that provide data for its reports.

CONCAWE, unlike EGIG (Section 3.5), analyses pipeline incidents by causes, procedures and clean up costs of spillages (Davis et al., 2008, Restrepo et al., 2009). *"No spillage-related fatalities or injuries were reported in 2008. Over the 38 reporting years there have been a total of 14 fatalities in five separate incidents in 1975, 79, 89, 96 and 99. All but one of these fatalities occurred when people were caught in a fire following a spillage"*(Davis et al., 2009). Table 3-2 shows a summary output of a typical statistics from CONCAWE's database.

Table 3-2: Summary of failure statistic from the CONCAWE database of incidents on oil pipelines from 1971 to 2004.

Failure Statistics (CONCAWE)	***Number of Incidents***		***Percentage Gross Volume Spilled (m.cu/yr)***
	Average per Year (1971-2004)	Percentage (1971-2004)	1971-2004
Mechanical Failure	3	23.8	31.4
Operational	0.9	6.8	3.6
Corrosion	3.6	28.9	18.8
Natural Hazard	0.4	3.5	4.1
Third Party Activity	4.6	36.9	42.1

The most obvious finding to emerge from CONCAWE's statistics is the identification of TPI and corrosion as the two most prevalent causes of spillage incidents (Table 3-2). For example, Davis et al. (2010) recently review the published report of CONCAWE for 2010 that shows there were nine spillage incidents, and seven were attributed to TPI. This is an increase from Davies et al.'s (2008) recorded eleven spillage incidents in 2005, two of which were because of unintentional TPI. It is perceived the nine spillages that were caused by intentional TPI is an unanticipated finding in the database (Davis et al., 2009).

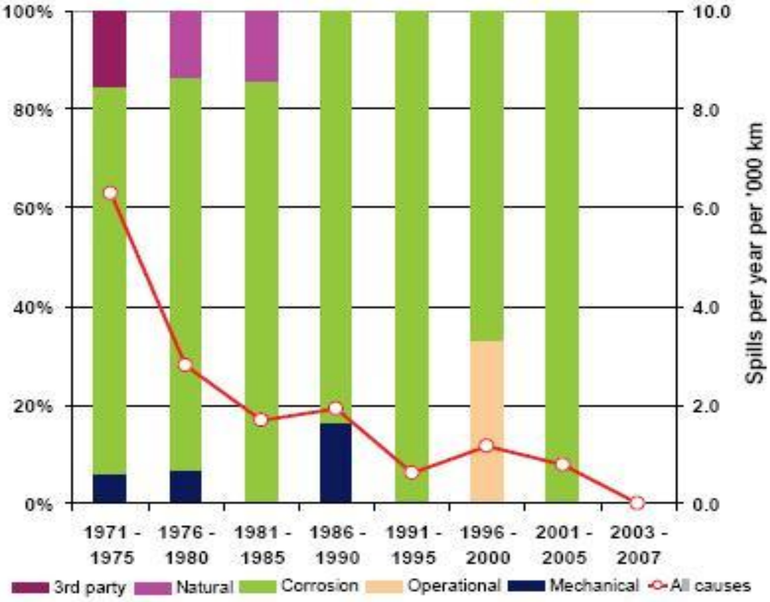


Figure 3-4: Pipelines spillage frequencies and distribution by major cause (CONCAWE, 2009).

CONCAWE's (2007) statistics of pipelines spillage frequencies and distribution by major cause indicates a reduction in the number of incidents caused by corrosion. These results are consistent with those given in other databases. However, in contrast to other pipeline incident databases (e.g. NEB), evidence of pipeline TPI declining was not reported by

CONCAWE, an implication of this is the possibility that third-party interference has been increasing in Europe, and a conclusion that can be drawn from Table 3-3.

Table 3-3: Trend analysis of CONCAWE pipeline spillages by TPI for year 1998 through 2003, and details from 2005 to 2007 were interpolated based on the previous year's values.

Year	*No. of Incidents*	*% Change*	*Length (Km '000)*	*Rate*
1998	9		29.670	0.303
1999	11	22.2%	29.450	0.374
2000	6	-45.5%	30.800	0.195
2001	7	16.7%	35.575	0.197
2002	6	-14.3%	35.592	0.169
2003	10	66.7%	36.422	0.275
2004	2	-80.0%	35.383	0.057
2005	2	0.0%	35.807	0.056
2006	2	0.0%	35.832	0.056
2007	1	-50.0%	35.858	0.028

Table 3-3 shows the calculated trend analysis, following the description given in Section 3.2.1, as part of this thesis, indicating the trend and rate of occurrence of TPI in the database for CONCAWE. It can be seen from the data in Table 3-3 that the year 1999 and 2003 reported significantly more numbers of incidents than other years. On average, it can be concluded that the trend of occurrence in the database is in the decline.

3.4 European Gas Pipeline Incident data Group (EGIG)

The European Gas Pipeline Incident Data Group (EGIG) comprises operators of gas transmission pipelines in twelve European countries (Figure 3-5). The overall objectives of the organisation are to communicate data regarding the safety performance of pipelines, and to provide a reliable and realistic picture of incident frequencies within member countries. Their other objectives are to prepare and maintain a database for statistical use in studies and research; periodically analyse the causes of incidents within members' network of pipelines; and recommend improvements for safety performance of pipeline networks. EGIG now collects data from over 130,000 km of pipelines and with an overall incident frequency of 0.37 incidents per year per 1,000 km from 1970 to 2007.

The EGIG database uses the following variables to compile data for their database: pipe diameter, pressure, year of construction, coating-type, pipeline depth, material grade, and wall thickness. The incidents reported by the EGIG are however categorised by detection method for failure, leak size, cause of incident, ignition, consequences, and incidents summary (Focke, 2009, Van Den Brand and Kutrowski, 2006a). These criteria, being use by the EGIG database records 1,172 incidents from 1970 to 2007.

Figure 3-5: The EGIG countries, comprising Belgium, the Czech, Denmark, Germany, Finland, France, Italy, Netherlands, Portugal, Spain, Switzerland, and the United Kingdom.

One interesting observation from the data presented in Figure 3-6 is that despite an increase in the number of European companies becoming EGIG members, the numbers of incidents are reducing although the pipeline network size is increasing. It is considered that further data is required before the association between the increased membership of EGIG and the relative decrease in the number of incidents can be clearly understood.

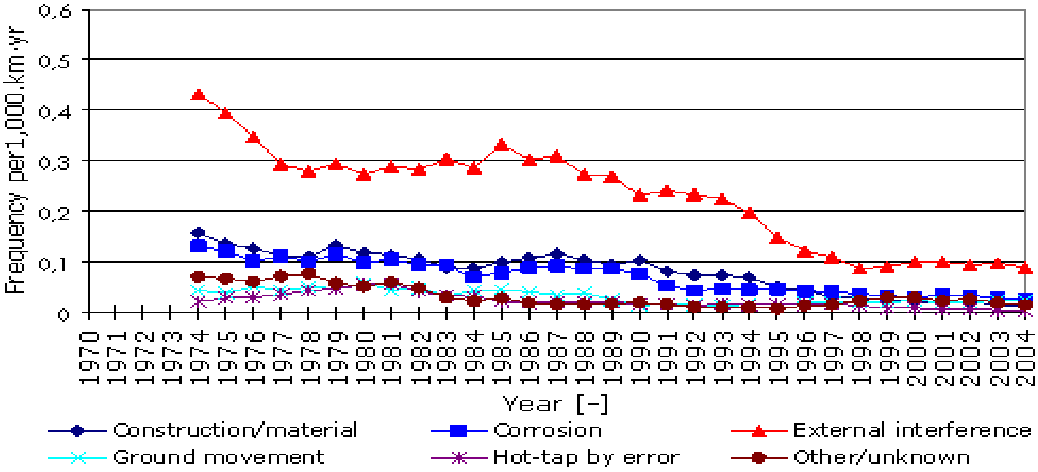


Figure 3-6: Primary failure frequencies per cause according to EGIG data. TPI, although decreasing, is the most dominant cause of pipeline failure in the database (EGIGI, 2005).

Table 3-4: The European Gas Pipeline Incident data Group (EGIG), showing the percentage rate changes of pipeline incidents according to the EGIG. The rate of pipeline incidents according to the EGIG database has decreased, and is decreasing in recent years.

Year	*No. of Incidents*	*% Change*	*Length (Km '000)*	*Rate*
1998	11		104.341	0.103
1999	15	42.0%	105.729	0.144
2000	9	-37.9%	106.761	0.089
2001	10	1.9%	109.980	0.088
2002	12	20.3%	111.125	0.104
2003	8	-31.5%	119.111	0.067
2004	12	48.1%	122.168	0.096
2005	10	-16.5%	127.696	0.077
2006	7	-30.3%	128.345	0.053
2007	7	2.3%	129.719	0.054

EGIG recognises the consequences of TPI, and their database is consistent with other similar databases that have also found TPI to be the leading cause of gas pipeline failures. Third-party interference accounted for over 50% of serious incidents in EGIG's database (Table 3-5). The database would be improved if EGIG had explicitly considered pipeline incidents with an intentional gas release. Although uncommon in Europe (until 9/11), intentional release cannot be entirely ruled out (Lords, 2010).

Table 3-5: Summary statistic of EGIG database of gas pipelines (1970 to 2007), between 1970 and 2004, the coverage exposure was 2.8 million km.yr km.

Cause	*Overall Percentage (%)*
External Interference	49.6
Construction defect/Material failure	16.5
Corrosion	15.4
Ground movement	7.3
Hot-tap made by error	4.6
Other and unknown	6.7

3.5 Office of Pipeline Security (OPS)

The Office of Pipeline Security (OPS) is part of the US Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA). They manage an estimated 244,000 km of petroleum pipeline products and 549,000 km of natural gas pipeline, as well as regulating over 2000 operators in the oil and gas industry. The OPS is responsible for the safety of pipelines by dissemination programs and practices to manage pipeline integrity and reduce the likelihood of pipeline failure (OPS, 2008).

Table 3-6: Trend analysis of pipeline incidence by Office of Pipeline Security (OPS) - US Department of Transportation from 1998 to 2007. The data is based on incidents of third-party incidence from OPS database for year 1998 through 2007.

Year	*No. of Incidents*	*% Change*	*Length (Km '000)*	*Rate*
1998	64		971.630	0.066
1999	59	-7.8%	1000.599	0.059
2000	54	-8.5%	1027.952	0.053
2001	65	20.4%	1003.602	0.065
2002	59	-9.2%	1034.131	0.057
2003	72	22.0%	1076.971	0.067
2004	58	-19.4%	1084.896	0.053
2005	58	0.0%	1094.138	0.053
2006	46	-20.7%	1105.795	0.042
2007	52	13.0%	1093.774	0.048

The September 11, 2001 (9/11) terrorist attack on United States has made the country one of the few countries that has taken serious precautions against all forms of intentional TPI. The Department of Homeland Security (DHS) and the pipeline industry are now jointly responsible for the security of pipeline systems against intentional pipeline interference (e.g. terrorist threats, cyber attacks and saboteur activities) in the country. The following are among the key initiatives taken to forestall the likelihood of TPI: (i) extensive communication systems, (ii) vulnerability assessments, (iii) consensus security guidance and development, and (iv) research sponsorships for detection technology and the continuous monitoring of rights-of-ways (Chen et al., 2007, Restrepo et al., 2009, OPS, 2008).

Table 3-7: Causes of pipeline failures according to OPS's failure database from 1985 to 1995, estimated from the raw data (OPS, 2006).

Cause of Failure	*Natural Gas (%)*	*Hazardous Liquids (%)*
Third Party	36	33
Corrosion	24	42
Weather related	11	3
Previously damaged pipe	4	8
Defective pipe seam	3	6
Defective girth weld	3	4
Defective fabrication weld	2	2
Defective pipe	2	3
Construction damage	1	0
Stress corrosion cracking	1	0

OPS identify the leading cause of pipeline incidents as being TPI (Table 3-7), and consequently encourage stakeholders to develop "Best Practices" for preventing damage to pipelines. For example, Common Ground Alliance (CGA), financed by OPS, ensures "Best Practices" are available to pipeline operators based on research findings and identifying emerging technology that is suitable for preventing pipeline damage (for example, the *Dig Safely* one-call programs). Evidence of the effectiveness of this initiative was ascertained in the questionnaire survey that was part of this thesis, when a respondent from the U.S stated that: *"For the past 15 years, the government has been involved helping our pipeline industry reduce excavation damage to our pipelines. Our efforts has resulted in reducing these damages by more than 50% while miles of underground pipelines have increased by more than 30%. This has been done by effective public education, use of technology and strong and fair enforcement".*

The U.S has been in the forefront of research in pipelines, and the incidents data analysed and classified by the PRCI of the OPS, grouped into 18 root causes pipeline failures (Table 3-8). The PRCI also classified TPI to include weather related and outside force. The framework of the classification is the most detailed characteristic of pipeline failures. A combination of factors could explained the extensive and thorough research into TPI by the U.S than that of any other country, for example, the dependence on energy per person than any other country, and perceived threats, especially following the event after 9/11.

Table 3-8: The classification of Department of Transportation classification of oil and gas pipeline failures grouped into 18 root causes. This data is extracted from OPS database (OPS, 2006).

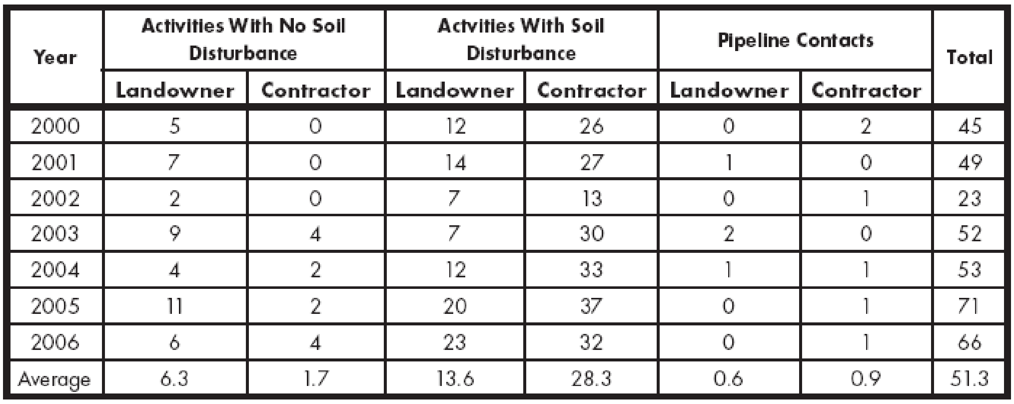
Main Causes	***Sub-divisions of the causes***		
Time Dependent	External Corrosion		
	Internal corrosion		
	Stress Corrosion Cracking		
Stable	Manufacturing Defects	Defective pipe seam	
		Defective pipe	
	Welding/Fabrication Related	Defective pipe girth weld	
		Defective fabrication weld	
		Wrinkle bend or buckle	
		Stripped threats and coupling failure	
	Equipment	Gasket O-ring failure	
		Control/relief equipment malfunction	
		Seal/pump packing failure	
		Miscellaneous	
Time Independent	Third Party/Mechanical Damage	Incorrect Operations	
		Weather related and outside force	Cold weather
			Lightning
			Heavy rains
			Earth movements

3.6 The National Energy Board (NEB)

The National Energy Board (NEB) is an independent federal agency with parliamentary powers that regulates about 45,000 km of pipelines in Canada operated by 104 companies. These companies compulsorily share their pipeline performance data with the NEB. The NEB attempts to ensure the proper functioning of pipelines by promoting safety and security, and thus ensuring an efficient energy infrastructure to the Canadian public. The NEB regulates the planning, design, construction, commission, and maintenance of all pipelines within Canada.

The NEB (2008) Pipeline Crossing Regulations define TPI as unauthorized activities with a potential to damage a pipeline or to prevent maintenance access to a pipeline. The NEB identified damage prevention as one of the key indicators that provide an understanding of safety performance of pipelines. The NEB further recognises unauthorized mechanical excavation; unintentional contact with a pipeline; and right-of-way encroachments as indicators of TPI (Jeglic, 2004, NEB, 2008).

Table 3-9: Third-party Interference on Rights of Way of NEB-regulated pipelines (NEB, 2008).



Year	Activities With No Soil Disturbance		Actvities With Soil Disturbance		Pipeline Contacts		Total
	Landowner	Contractor	Landowner	Contractor	Landowner	Contractor	
2000	5	0	12	26	0	2	45
2001	7	0	14	27	1	0	49
2002	2	0	7	13	0	1	23
2003	9	4	7	30	2	0	52
2004	4	2	12	33	1	1	53
2005	11	2	20	37	0	1	71
2006	6	4	23	32	0	1	66
Average	6.3	1.7	13.6	28.3	0.6	0.9	51.3

Unlike the OPS, EGIGI and UKOPA where TPI is found to be the leading cause of pipeline failures, NEB's leading cause of failures are corrosion (internal and external), followed by operational errors. While TPI still occurs, it is relatively uncommon in NEB-regulated pipelines (Figure 3-7). The NEB (2008) claim that for nine consecutive years (from 1998 to 2007), there were no fatalities involving employees, contractors, or third parties. In addition, there were no ruptures on regulated pipelines from 1991 to 2006. Therefore, considering the near zero fatality rate of the NEB database, illustrating the trend, for example, as shown in Table 3-6 is unfeasible.

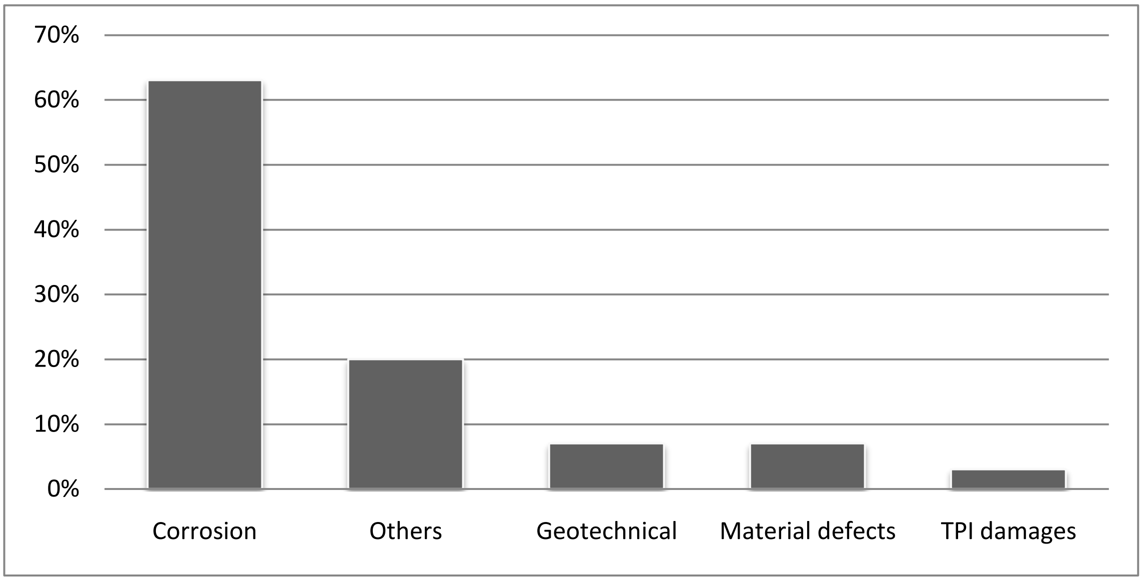


Figure 3-7: Causes of Failures on the NEB-Regulated Pipelines (1991-2006), pipeline third party is not the most dominant cause of pipeline failure.

The NEB has indirectly classified TPI as pipeline contacts (unauthorized activities), and 65 such activities on NEB-regulated pipelines were reported in 2006 alone (Table 3-9). These activities, however, do not necessarily result in failure and Canada's parallel economic and urban growth, especially near pipelines, could be largely responsible for these isolated cases in 2006. Compared to Europe, significant differences in local population density could explain the higher incidence of TPI in Europe and the U.S. (NEB, 2003).

The seven-year average of unauthorized activities of NEB-regulated pipelines is 51.3 (Table 3-9), 2006 experienced a decrease in unauthorized activities from 71 in 2005 to 66; although this is still higher than the seven-year average. In the questionnaire survey, that was part of this thesis, a respondent remarked about pipeline TPI that: *"In Canada we have not seen a large presence of terrorism or other types of activities related to pipeline damage. There have been some pockets of criminal activities within the pipeline community however the greatest threat we face is from within our own ranks. That is, a contractor or landowner who performs a ground disturbance without calling for locates and hits a pipeline or other buried infrastructure".*

3.7 United Kingdom Onshore Pipelines Operators Association

The United Kingdom Onshore Pipelines Operators Association (UKOPA) is the organisation responsible for the UK Onshore Major Accident Hazard Pipelines (MAHPs) that are operated by fourteen major UK pipeline operators. According to the Pipelines

Safety Regulations (PSR), the MAHP pipelines are high-pressure natural gas transmission and distribution pipelines and other pipeline systems transporting oils, chemicals and other gases (e.g. ammonia and ethylene). The MAHP's total pipeline network at the end of 2006 is 21,882 km, and 93% are crude oil and natural gas pipelines (UKOPA, 2008).

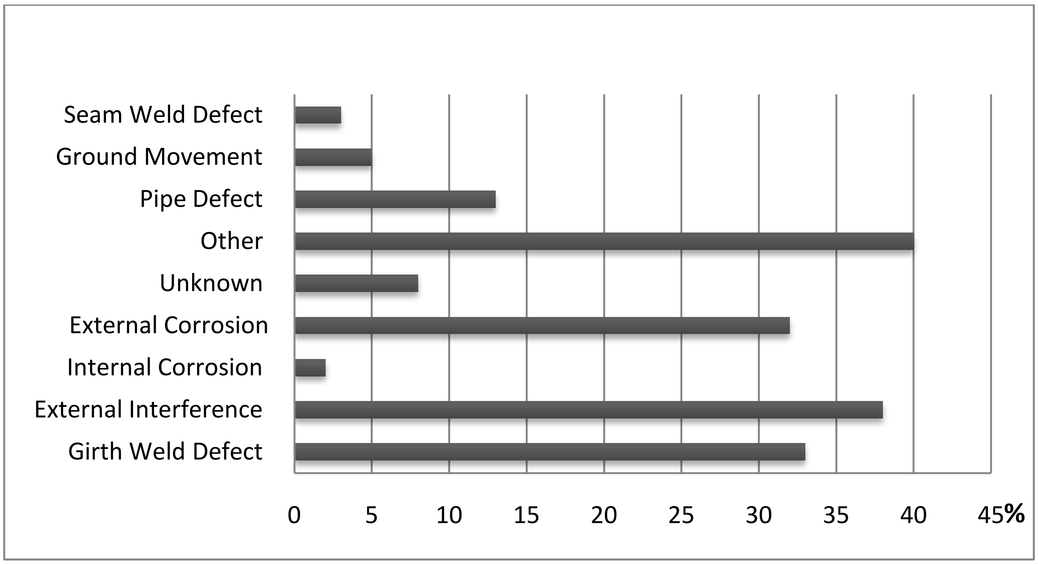


Figure 3-8: Summary of Failure Incidents by Cause from the UKOPA Database (1962-2006)

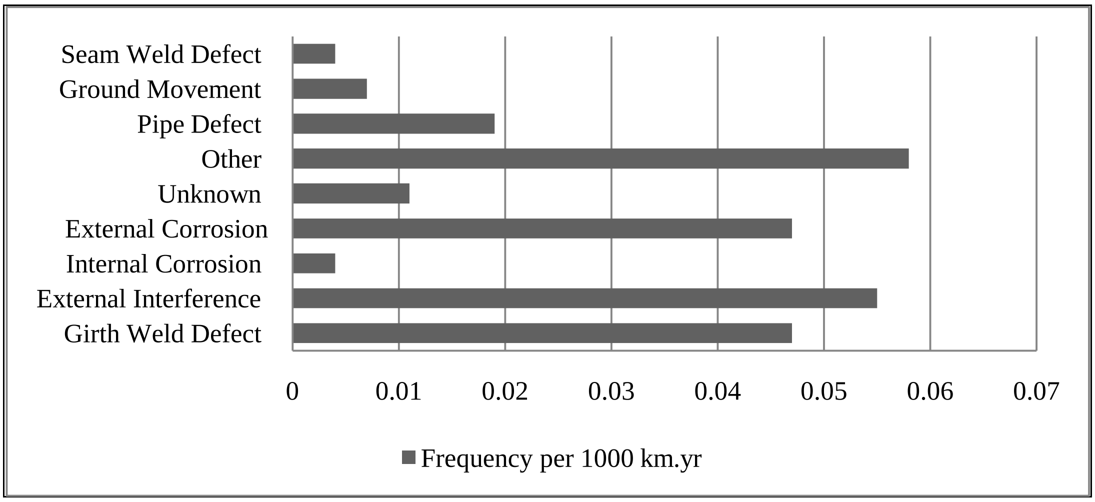
The UKOPA's database shows external interference (or TPI) as being one of the main causes of product loss in pipelines. The failure cause classified as *"others"* in the database includes internal cracking due to wet town gas, pipefitting welds, leaking clamps, lightning, soil stress, thread joint, and electric cable arc strike (Figure 3-8). Hobell and Stancliffe (2008) claim that third-party damage to utility companies (including the pipeline industry) costs £150 million a year. However, damage per 1000km since the early 1970s, according to the database, has been falling steadily; hence considering the £150 million a year, this translates to a lesser cost to the utility companies. For example, the overall failure frequency reduced by 0.015 incidents per 1000km from 2004 to 2006. However, despite these statistics, TPI is still the major single cause of product loss in the UK. The database shows the following average features from 1962 to date (UKOPA, 2008):

- In terms of failure frequencies associated with external interference and recorded by pipe diameter class, 0 to 4inch diameter pipelines have the highest failure frequency per 1000 km.yr. The failure frequency cause by external interference is inversely proportional to the diameter size of a pipeline-the lesser the pipe diameter the higher the failure frequency.

- The relationship between incidents caused by TPI and wall thickness shows that pipeline wall thicknesses of less than 5mm have the highest failure frequency of 0.22 per 1000 km.yr from 1962 to 2006. In absolute terms, *"the largest wall thickness for loss of product incident caused by external interference to date is 12.7mm"*. This is in addition to recorded incidents for wall thickness greater than this value.

- According to UKOPA (2008), the failure frequency of external interference by land use shows that suburban and semi-rural areas (population density greater than 2.5 persons per hectare, excluding central areas of towns or cities with a high population density) have the highest failure frequency of 0.156 per 1000 km.yr compared to mainstream rural areas that have a very negligible frequency.

Table 3-10: Failure incident frequency by cause over the period 1962- 2006 compared with the frequency from 2002-2006.



The UKOPA database does not have a standardised procedural methodology for the data collation of TPI. It also omits the age and length of the pipelines involved in the incidents. An accurate estimation of the age and length of a pipeline at the time of the incidents forms an important basis for the subsequent interpretation, evaluation and making of a comparison of pipeline failure risks. The lack of these technical parameters within the database could sully its intended performance record and claim of 'operations and integrity management of pipelines'. However, Lyons et al. (2009) identified how (UKOPA) is formulating additional procedures to the UK BSI PD 8010 code of practice for pipelines and the BSI PD 8010 by Institution of Gas Engineers. This is to provide a standardized approach for the design of quantified risk assessment. In the questionnaire survey, undertaken as part of this thesis, the findings showed that Europe employed awareness campaigns to all stakeholders, and the application of proper standards in the industry. This is evident, considering the steady trend of incidents in the database (Table 3-11).

Table 3-11: Trend analysis of UKOPA pipeline database and relationship between incidents and lengths of pipeline, the data is from UKOPA database for year 1998 through 2007.

Year	*No. of Incidents*	*% Change*	*Length (Km '000)*	*Rate*
1998	5		20.67	0.242
1999	2	-60.0%	21.34	0.094
2000	1	-50.0%	21.86	0.046
2001	1	0.0%	21.87	0.046
2002	0	-100.0%	21.83	0.000
2003	0	0.0%	21.73	0.000
2004	1	100.0%	21.73	0.046
2005	1	0.0%	21.80	0.046
2006	1	0.0%	21.88	0.046
2007	1	0.0%	22.13	0.045

However, there exists an ambiguous relationship between CONCAWE and UKOPA, because TPI is all-time in the decrease according Figure 3-4, and insignificant in UKOPA's database. It is difficult to explain this result; the most likely reason might be related to effective procedures of communication management in the United Kingdom. CONCAWE (2007), for example, states that *"Overall, some 65% of the third party accidental spillages would most probably have been prevented by proper communication to pipeline operators by the third parties, in addition to 35% of the spillages caused by lack of care or skill by the third party works management and machinery operators*". This confirmed earlier studies by Hongqing (2005), and Sljvic (1995) that proper communications between all stake holders can mitigate TPI.

3.8 Russian Association for Licensing (Gazprom/Rostechnadzor)

The Russian pipeline incident database is not information that is available for public or peer review. The only publicly available references for this thesis are from unofficial sources, for example, Det Norske Veritas's(2003) study on the causes of oil pipeline spills (Table 3-12) and unofficial published statistics from Lesikhina et al.(2007). EIA (2008) reviewed that: *"Russia holds the world's largest natural gas reserves, the second largest coal reserves, and the eighth largest oil reserves. Russia is also the world's largest exporter of natural gas, the second largest oil exporter and the third largest energy consumer"*. In all this, unofficial statistics estimate that oil leakages from pipeline accidents occur every two weeks in Russia (Lesikhina et al., 2007).

As in other countries with increasing pipeline infrastructures, TPI is always a concern, and Russia is no exemption. In Russia's North Caucasus region, pipelines have been regular targets of attacks, for example, the *Mozdok-Gazi-Magomed* gas pipeline has been attacked over a dozen times (Zhukov, 2006). Such incidents are monitored by the state owned Russian gas company (JSC Gazprom), using the federal law of *'Regulation of the Order of Technical Investigation of the Causes of Accidents at Hazardous Industrial Facilities'.* These are achieved by JSC Gazprom's use of a central alert system, as a diagnostic tool for monitoring pipeline networks, in addition to a real-time computerised recording of accidents (Bolt, 2006). However, in the event of an accident, a special committee headed by the Russian Federal Mining and Industrial Inspectorate (Rostechnadzor) - a central organ of federal executive power, performs technical investigation into the cause of the accident.

Table 3-12: Number of oil spills by cause in the former Soviet Union (FSU): 1986 to 1996. The cause categories are according to CONCAWE definitions (Det Norske Veritas, 2003).

Location/ Region	*Mechanical Failure*	*Corrosion*	*Operational Error*	*Third party Activities*	*Natural hazards*	*Unknown*	*Total Spills*
Azerbaijan	1	n/a	n/a	1	n/a	1	3
Belarus	n/a	n/a	n/a	n/a	n/a	1	1
Kazakhstan	n/a	n/a	n/a	n/a	n/a	1	1
Latvia	1	n/a	n/a	1	n/a	n/a	2
Russia	26	13	7	15	3	37	101
Ukraine	3	n/a	n/a	n/a	1	1	5
Total	31	13	7	n/a	4	41	113

Det Norske-Veritas's (2003) study on the causes of oil pipeline spills and recommendations for preventative measures, indirectly ascertain that eradicating pipeline failure in Russia is impossible. Singh (2010) also supports this view that *"pipelines stretch for thousands of miles and there are literally thousands of opportunities for accidents or sabotage. Often the pipelines go through politically unstable regions, areas of extreme poverty and desperation and incredibly harsh terrain. As such, it would appear that, for now, no single countermeasure can single-handedly protect and secure the Russian pipeline system."* However, Det Norske-Veritas identified that good risk management procedures and satisfactory regulations would reduce their frequency. The study identified TPI as being one of the main contributing factors to the causes of oil spills in the countries of the former Soviet Union (FSU) in their over 84,000 kilometres of pipelines in 1998 (76 per cent of which are located in Russia alone). In 2007, for example, about 1.3 million bbl/d of the almost 4.4 million bbl/d of crude oil exported by Russia were by the Druzhba pipeline supplying Central and Eastern Europe (Zhukov, 2006, EIA, 2008).

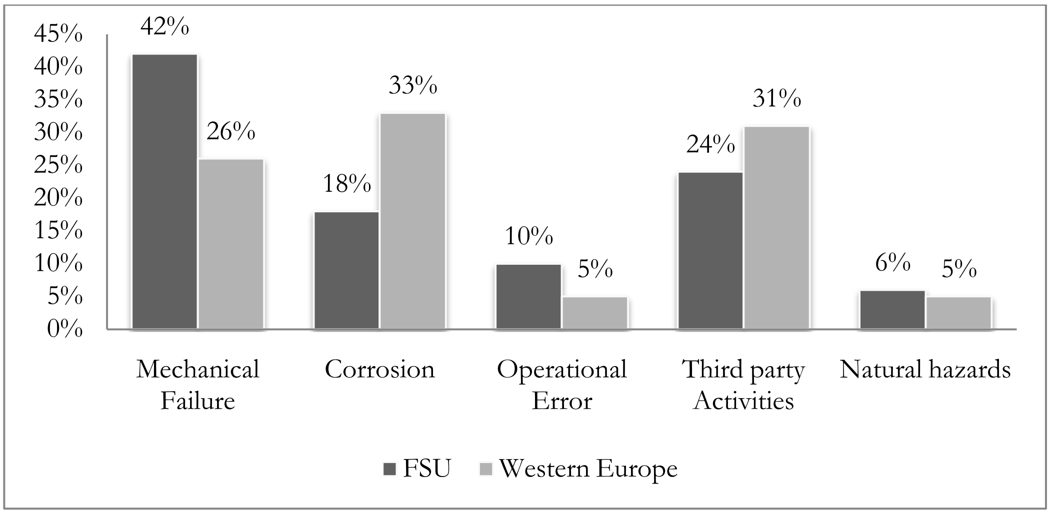


Figure 3-9: Comparison distribution of causes of pipeline failures in FSU and Western Europe, according to CONCAWE definitions during 1986–1996.

Det Norske-Veritas (2003) also observed that third-party activities accounted for 24 per cent of the total number of oil spills by known causes between 1986 and 1996, and with 88 per cent of this occurring in Russia alone (Figure 3-9). Mechanical Failure accounted for 43 per cent of the total number of oil spills. The difference in mechanical failures, compared to other failure databases, could be due to differences in the ages of pipelines, construction standards, environmental, and climatic factors.

As in other countries with increasing pipeline infrastructure, TPI is always a concern, and Russia is no exception, although, as shown in Table 3-13, the trend of incidents is reducing. The decline is insignificant, and one possible explanation for the observed trend is unavailability of widely published data. However, Det Norske Veritas's (2003) concludes therefore that, *"the prevalence of failures due to third-party activities further emphasizes the importance of establishing effective regulatory and monitoring mechanisms in the countries for pipeline operations"*.

Table 3-13: Trend analysis of the Russian pipeline database byJSC Gazprom/Rostechnadzor.

Year	*No. of Incidents*	*% Change*	*Length (Km '000)*	*Rate*
1998	31		211	0.147
1999	23	-25.8%	211	0.109
2000	32	39.1%	213	0.150
2001	55	71.9%	214	0.257
2002	44	-20.0%	216	0.204
2003	45	2.3%	219	0.205
2004	51	13.3%	221	0.231
2005	45	-11.8%	223	0.202
2006	32	-28.9%	224	0.143
2007	27	-15.6%	226	0.119

3.9 Nigeria National Petroleum Corporation (NNPC)

Nigeria is Africa's leading oil and gas producer, and one of the world's top oil and gas producers. However, the severity of pipeline TPI in Nigeria (Figure 3-10) is higher than in the rest of the world combined. Many analysts have argued that poor governance, poverty, sabotage, and theft are the reasons. Critics have also argued that the problem is more complex and that technical and poor detection procedures contribute to this problem and are influenced by the fact that most pipelines in Nigeria were commissioned in the 1970s and thus due for decommissioning. There is, however, evidence from Guijt (2004a) and CONCAWE that an aged pipeline does not necessarily mean failure with time, rather, that the pipeline failure rate should drop. Perhaps the most serious reason for the record-breaking numbers of TPI in Nigeria is that until recently, the regulatory and monitoring systems in Nigeria were considered ineffective in preventing pipeline TPI.

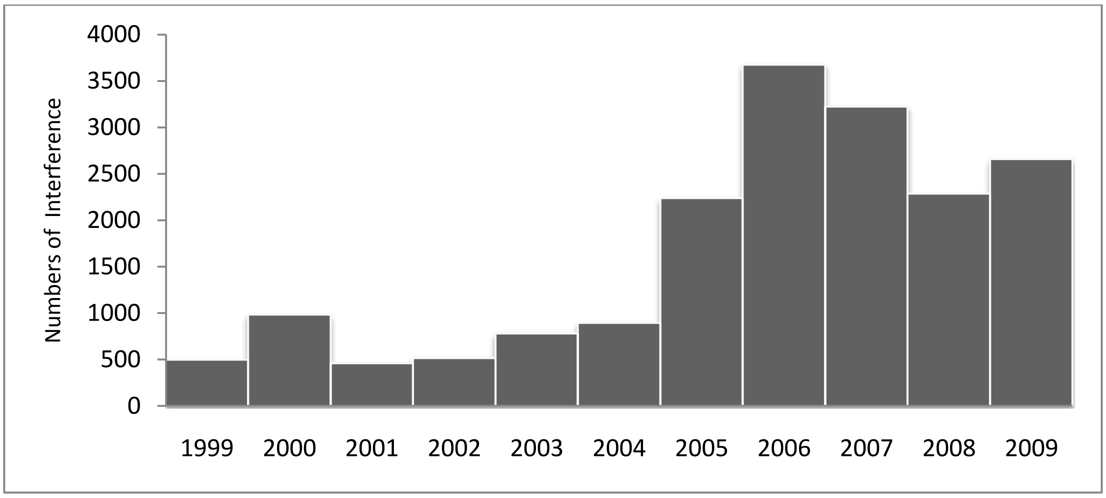


Figure 3-10: Pipeline third-party vandalism occurrence between 1999 and 2007 in Nigeria. The numbers of failures increased dramatically from 2003 to 2007 (NNPC, 2009).

Directly managing and collating the activities of the industry is the responsibility of the Nigerian National Petroleum Corporation (NNPC), established in 1977. NNPC is a public organisation tasked with managing all government interests in the Nigerian oil and gas industry, and itself supervised by the Department of Petroleum Resources (DPR), a department within the Ministry of Petroleum Resources. The DPR ensures that all activities of the pipeline industry comply with industry and environmental regulations (NNPC, 2005, NNPC, 2009). The management of Nigeria's total pipeline length of about 10,858km comprising of 126km condensate, 2,812 km of gas; 125 km of liquid petroleum gas; 4,278 km of oil; and 3,517 km of refined products is the responsibility of DPR.

Table 3-14: Trend analysis of pipeline incidence in Nigeria based on data extracted from Nigeria National Petroleum Corporation (NNPC, 2007).

Year	*No. of Incidents*	*% Change*	*Length (Km '000)*	*Rate*
1998	515		4.674	110.184
1999	497	-3.5%	5.542	89.679
2000	984	98.0%	5.542	177.553
2001	461	-53.2%	5.542	83.183
2002	516	11.9%	5.542	93.107
2003	779	51.0%	5.399	144.286
2004	895	14.9%	5.399	165.771
2005	2237	149.9%	9.265	241.446
2006	3683	64.6%	9.265	397.518
2007	3,244	-11.9%	10.858	298.766

In Nigeria, most of the terrorist and rebel attacks perpetrated against pipelines and personnel include incidents involving sabotage, arson and armed aggression. In 2007, Nigeria recorded an incredible 3,224 number of cases of pipeline vandalism and deliberate line breaks compared with only twenty (20) cases of pipeline rupture due to *wear-and-tear*. Petroleum product losses in the same year were about 242 metric tonnes translating into about £57 million pounds sterling. Figure 3-10 shows that over of 12,000 incidences of vandalism occurred between 1999 and 2007 resulting in over 3,000,000 barrels of oil having been spilled into the environment as a result. In 2006, for example, Shell Nigeria recorded 241 oil spill incidents, of which sabotage accounted for 165 (69 %,) (NNPC, 2007). Table 3-14 presents the trend of Nigeria's pipeline incidents from 1998 to 2007.

3.10 Summary and Conclusions

The review of literature identified the many causes of oil and gas pipeline failures, and can be considered to fall into one of five groups of basic causes, namely: corrosion, mechanical, external effects, natural events, and others (Table 3-15). The subclass in each group (as shown in Table 3-15) varies and each cause can be further characterised and classifiable by technical properties. The relevance of preventing pipeline TPI is clearly supported by the review of the pipeline incident databases, especially the recognition by most of the databases that it is one of the most dominant failure mechanisms. However, several limitations to this review need to be acknowledged. One significant shortcomings of the databases reviewed in this thesis is the inability to explicitly and uniformly define pipeline TPI across each database.

Table 3-15: Classification of incidence causes for pipeline database, third-party interference or external interference is present in most databases.

Corrosion			External Effects				Mechanical											Natural Events						Others		
Time dependent			Third-party Interference		Mechanical Damage		Manufacturing Defects			Installation Defects					Material Defects			Geotechnical			Weather			Miscellaneous		
Internal	External	Stress Corrosion Cracking	Intentional Third-party	Unintentional Third-party	Incorrect operation	Accidental Damage	Defective pipe	Seam failure	Defective pipe girth weld	Pipe-fitting weld	Wrinkle bend/buckling	Defective fabrication weld	Leaking clamps	Thread joint defect	Gaskets failures	Control malfunctioning	Pumps failure	Ground movement	Erosion	Soil stress	Heavy rain	Lightning	Cold environment	Internal cracking	Previously damaged pipe	Unknown

One of the issues with conducting such a comparison is that the definition and interpretation of the classification terms varies the across the databases. For example, the EGIG classifies external interference as being TPI leading to pipeline failure. The US Department of Transportation's PHMSA classifies external interference to include excavation, weather related, outside force, lightning, floods, and earth movements, which is a rather broad coverage. The NEB classifies unauthorized activities with potential to damage a pipeline or prevent maintenance access to a pipeline as third-party interference, with or without soil disturbance. All the databases reviewed have TPI in their database as one of the major cause of pipeline failures, and recognised it as being one of the single most serious causes of pipeline damage (Table 3-16), and one of the most significant current discussion topics in the industry.

Table 3-16: Existing classification of pipeline failures causes, by various organisation and regions. Third-party interference (external interference) is common to all the databases.

CONCAWE	EGIG	NEB	APIA
Corrosion	Corrosion	Corrosion	Corrosion
Third-party	External Interference	Third Party damage	Third Party Damage
Mechanical	Material /Const. defect	Material defects	Storm/Erosion
Natural	Ground movement	Geotechnical	Ground Movement
Operation	Hot-tap made by error	Others	Construction defects
	Other and Unknown		Others/Unknown
UKOPA	**OPS**	**GAZPROM**	**NNPC**
Internal Corrosion	Internal Corrosion	Corrosion	Corrosion
External Corrosion	External Corrosion	Third-party Activities	Third Party damage
External Interference	Stress Corrosion Cracking	Mechanical failure	Material /Const. defect
Girth Weld Defect	Third Party damage	Natural	Geotechnical
Pipe Defect	Defective pipe seam	Operational error	Others
Seam Weld Defect	Defective girth weld	Natural hazards	
Ground Movement	Degective pipe	Unkown	

However, in this thesis, these contradictions and shortcoming escape criticism considering the overall objectives and issues addressed, which include: to document trends and differences in TPI over time between various countries and regions; to examine possible correlation between TPI, failure frequencies and related length of pipeline; and to document best practices from individual database relatively to TPI.

In conclusion, the review of the pipeline failure databases in this thesis has thrown up many questions in need of further investigation, for example, singular recognition, as a security concerns, of intentional pipeline TPI as part of all future classifications. In addition, the inability of a uniform nomenclature for a universal classification of pipeline incidents database is perceived to show the need for the industry to share experience and practices. The review also shows that a unified classification procedure is more effective than conventional classification of pipeline failures by various organisations. An international standard for the recording occurrences of pipeline failure will enhance fruitful exchange of useable statistics.

4 PREVENTION OF THIRD-PARTY INTERFERENCE

4.1 Introduction

In theory, the protection of pipelines is the most effective method of reducing the risk of third-party interference (TPI). If engineering design of a pipeline has been carried out in line with international best practices, the protection depends primarily on utilising the range of opportunities created at various stages of a typical pipeline project: planning, design, installation, and maintenance (Williamson and Daniels, 2008). The inspection and monitoring of a pipeline against damage presumes that the pipeline, as designed and installed, is structurally safe and fit for its designed lifespan. However, although several methods for preventing and detecting TPI exist, there are still various limitations in the application of these tools under certain conditions. These limitations are evident as, despite wide industry utilisation of the various prevention and detection methods, pipelines have continually experience TPI (Miesner and Leffler, 2006, Berman et al., 1994).

Table 4-1: Various methods of detecting and preventing the potential for third-party interference: Pre-installation, During installation and Post-installation

	Prevention Methods
Pre-installation	☐ Land Use/Land Cover Mapping ☐ Stakeholders Participation ☐ Optimal Pipeline Route Selection ☐ Increased Pipeline Wall Thickness ☐ Increased Depth of Cover
During installation	☐ Slabs, Tiles and Plates over Pipelines ☐ Encasement Sleeves ☐ High Tensile Netting ☐ Maker Tapes ☐ Pipeline Maker Post
Post-installation	☐ Aerial Surveillance ☐ Vantage Point Survey ☐ Full Walking Survey ☐ Satellite Surveillance ☐ Global Positioning System (GPS) ☐ Electromagnetic Detection ☐ Fibre Optic Sensors (FOS) ☐ Site access Security ☐ In-Line Geometry Inspection(ILGL)

This chapter provides an extensive description of the various third-party interference detection and prevention methods that are available, and discusses their corresponding advantages, disadvantages and limitations. Based on a review of literature, the methods are classified into three broad categories: pre-installation, during installation and post-installation (Table 4-1). These categories are described in the following sections.

4.2 Pre-installation

The significant purpose of a pre-installation prevention method is to eliminate or reduce the potential for negative third-party impacts on pipelines before installation, a proactive first-step approach to preventing TPI. Pre-installation is the acquisition of all existing basic documents such as topographical and geological maps, aerial photographs, and technical documents relevant to the potential proposed routes. Prior to installation, at the planning stage, all relevant information is reappraised, synthesised and evaluated. Information is also required from various government agencies, academic and research institutions, and consulting firms. Where practicable, pipeline operators confer with local residents and professionals in order to validate information and identify gaps that could influence potential future pipeline TPI (Muhlbauer, 2004). The following methods of pre-installation prevention have been used, and found to be relatively effective: population density control, stakeholders' participation, optimal pipeline route selection, increased pipeline wall thickness, and increased depth of cover. These methods are discussed in more detail in the following sections.

4.2.1 Internal and External Stakeholders Participation

The purpose of this preventive method is to ensure continuity of pipeline security through to post-installation, and to establish future potential TPI monitoring strategies. Internal stakeholders are primary owners of businesses, customers, and employees; while external stakeholders share an interest in a business without owning the business (e.g. pressure groups, the press and media, governments and communities). Therefore, pipeline operators must solicit stakeholder participation at individual and group levels. At the individual level, questionnaires can be developed and used for a survey of local residents and officials. At the group level, public meetings are organised with representatives of the national and local government stakeholders, and non-governmental organisations. Public meetings are also held to provide feedback concerning the scope and impact of a pipeline project, and where the findings and recommendations from the process will be incorporated into the engineering design (Hopkins et al., 1999, Day et al., 1998).

This preventive method also helps to identifies and evaluates the positive and negative recommended impacts from stakeholders that are likely to result from a proposed pipeline project and to enable assigning technical values to curb or minimise the impacts. Stakeholders can sometimes recommend practical and cost-effective measures to prevent or reduce significant negative impacts from third-party interference to an acceptable level within their locality (Muhlbauer, 2004). Lastly, education about the risk and consequences of pipeline damage and a review of a sequence of events that can precede pipeline failure in an accommodating way to stakeholders, youth and communities can help to prevent third-party interference.

Table 4-2: Advantages and disadvantages of stakeholders' participation

Advantages	Opportunity to meet firsthand with potential third-party culprits Reduces total cost investments in preventing failures long term Increases public awareness and opportunity to educate them This method is a front-end prevention approach
Disadvantages	The benefits are unforeseeable and unpredictable It is dependent on public acceptance and willingness to cooperate Long term strategy that might not be beneficial

Sljivic (1995) recognised third-party interference as the most single probable cause of pipeline failure caused by landowners, utility companies, contractors, and local authorities. He studied the relationship between third-party activities and their influence on pipeline damage, and recommended that increased contact between the pipeline operator and potential third parties be encouraged through quality dissemination of information; a view that was also taken by Lu and Li (2005). In addition, work by Hovey and Framer (1993) confirms that the potential for a spill along a pipeline is the primary responsibility of the pipeline managers and not the influence of potential socio-economic factors. He further encourages collaborative communication between all the stakeholders, especially, the operators and the landowners. The advantages and disadvantages of stakeholder participation are presented in Table 4-2.

4.2.2 Land Use/Land Cover Mapping

The knowledge of Land use/land cover (LULC) is an important factor in the planning, installation and management of pipeline networks. This is difficult to quantify considering the rapid urbanisation in almost every country and the need to meet energy demands. The interrelationships between land use and land cover, both the observed and expected are an important component in the planning phase of a pipeline project, and play a key role in future potential third-party interference. The evidence of this can be clearly seen in pipeline codes, for example ASME B31.8: 2003 (Gas Transmission and Distribution Piping Systems). These design codes recommend some degree of caution to limit the potential for pipeline interference by ensuring some control of pipeline alignment to avoid regions with high population density (Hopkins et al., 1999). According to Day (1998), the method also provides some baseline information to evaluate potential third-party interference, since it identifies both formal and informal patterns of population growth operating within a pipeline's right-of-way and their potential influence. There are a number of important limitations of the method, and Table 4-3 presents the advantages and disadvantages of land use/land cover.

Table 4-3: Advantages and disadvantages of Land Use/Land Cover Dynamics

Advantages	Highly feasible for unintentional third-party interference Reduces total cost of equipment investments Increases public awareness
Disadvantages	Relies on accurate mapping and data No consensus system for the classification of land use data Not relatively effective against intentional TPI Not internationally recognized in prevention of TPI Requires complex computational spatial restrictions

4.2.3 Optimal Pipeline Route Selection

The efficient prevention of pipelines against TPI is also dependent on how the most optimal route selection is determined. In this method, it is assumed that the presence of towns, villages, and communities in close proximity to a pipeline alignment influence the occurrence of TPI (Watts and Kashi, 2008). In addition to reducing project capital expenditure and minimising effects on the environment, it is desirable that reconnaissance surveys along a proposed pipeline alignment are conducted in order to integrate environmental and physical components into the planning phase of a pipeline project (CEPA, 1997, TRB, 2004). One might argue that such an assessment may not be objective, but the strategy of avoiding pre-identified vulnerable areas has worked for preventing third-party pipeline interference (Muhlbauer, 2004).

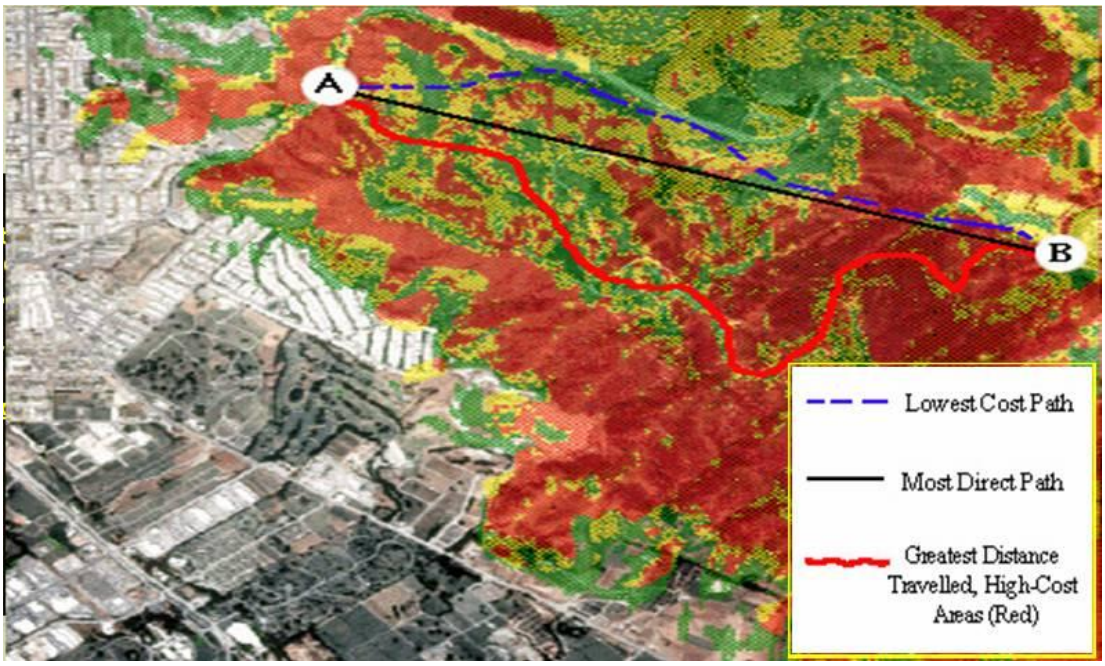


Figure 4-1: Three alternative pipeline corridors are evaluated based on cost, distance, and ground slope. The blue line shows the lowest possible cost, the red line shows the optimal route, but the greatest distance travel, and could possible affect installation cost.

In general, the objective of this prevention method is to find the best pipeline route considering basic constraints such as: no pipeline shall pass through a densely populated zone and to find the best secured route by avoiding physical constraints which might influence or facilitate possible future interference. In addition, the method enables evaluation of alternative corridors and pipeline accessibility design and allows a pipeline route to be chosen that is likely to be the least vulnerable to TPI, considering both political and human factors. This is because where a local population region favours a pipeline route along their backyard; they often indigenously protect the pipeline against TPI (Jager et al., 2002, Muhlbauer, 2004). However, these assumptions are based upon past occurrence, prior to the advent of full-blown terrorism and it is unclear if these differences persist with local population in support of pipeline along their jurisdiction or not, as no single study exists which adequately covers the issue directly.

By way of illustration, Figure 4-1 shows how three alternative pipeline routes have been evaluated in order to select the optimal route to prevent third-party interference. However, the final route selection will always be a compromise between cost and security. One major advantage of this approach is that vulnerable segments along the proposed alignment are identified. In addition, this type of assessment study along a projected route is designed so that inhabitants and the environment are not favourably opportune to the chance to interfere with the pipeline. This could be by limiting accessibility to pipeline alignments and avoiding local population as much as possible. The advantages and disadvantages of this method are presented in Table 4-4.

Table 4-4: Advantages and disadvantages of Optimal Pipeline Route Selection

Advantages	Moderate capital investment Availability of technical expertise in pipeline route planning and design Less field work and involve mostly desktop study
Disadvantages	Method is not accurate Optimal route might be the most expensive alternative route Difficult to implement practically to curb third-party damage

4.2.4 Increased Pipeline Wall Thickness

Traditionally, pipeline designers have subscribed to the belief that the minimum allowable pipe wall thickness is based upon the consideration for internal pressure, diameter, and pipe material. However, such explanations tend to overlook the one major advantage of this approach, to prevent third-party damage, heavier pipe wall thickness may be installed at vulnerable segments of a pipeline network that are likely to be prone to TPI e.g. road and rail crossings. The thicker the pipe wall, the lower the probability of pipeline damage from TPI (Menon, 2005).

Table 4-5: Advantages and disadvantages of Increased Pipeline Wall Thickness

Advantages	Easily implemented at the design stage of the pipeline project Provides increased and additional protection of pipeline Prevents major hazard in the case of accidental impact by excavation equipments
Disadvantages	Does not deter intentional pipeline damage(e.g. saboteurs and vandalism) Higher and additional budgetary cost of extra wall thickness Cannot be used for long distance pipelines, because thicker pipelines are expensive and requires additional cost per mile for installation

Hopkins et al. (1999) also affirmed that: *"Increased pipe wall thickness offers protection against damage. For example very few (about 5%) of excavating machines used in suburban areas will be able to penetrate 11.9 mm wall"*. Although increased pipe wall thickness may be beneficial in preventing unintentional third-party interference, it is considered that increased thickness of pipeline does not secure pipelines from vandalism and sabotage as the intent is to puncture the pipe wall, whatever the thickness. Table 4-5 presents the advantages and disadvantages of increasing pipe wall thickness as a method for preventing third-party interference.

4.2.5 Increased Depth of Cover

Increasing the depth of pipeline decreases damages cause by excavator, and discourages intentionally excavated cover of pipelines for pilfering products. This in addition to pipeline terrorism, have made the pipeline industry to identify the need to increase the depth of cover material on the top of pipeline during installation as an effective prevention method for potential TPI. Increasing the cover minimises the impact on a pipeline of third-party activities. This method is favoured by many previous findings, that contributed additional evidence that suggests that the depth of pipeline (or pipeline cover) as one of the major dominant factors in reducing TPI (Muhlbauer, 2004, TRB, 2004, Jager et al., 2002, Taylor et al., 1984, Andersen and Misund, 1983a).

Table 4-6: Advantages and disadvantages of Increased Depth of Cover for preventing possible pipeline third-party interference.

Advantages	Higher prevention rate and better protection against third-party activities Unnecessary alarm and effective if concealed from public knowledge Relatively effective if combined with other methods of protection
Disadvantages	Higher cost per mile if implemented over extensive pipeline network Increased maintenance cost because of need for increased excavation

For example, researchers have shown that the probability of damage to a pipeline is reduced by 90 per cent if the pipeline depth is doubled (Hopkins et al., 1999, Hopkins, 1993, Potter, 1985, Taylor et al., 1984). Exposed or shallow pipelines are easier to vandalise or to create illegal valves on for stealing the pipeline contents. Brantingham and Brantingham (1981) term the above scenario a crime generator, as they provide places where crimes are likely to happen. However, there are limits to how far the concept can be taken, and Table 4-6 presents the advantages and disadvantages of increased depth of cover as a method for preventing third-party interference.

4.3 During Installation

The prevention of third-party interference at the installation stage ensures protection of pipelines both during and post-installation. Susceptible segments of a pipeline network identified as being potential sites for TPI in accordance with pre-determined prevention specifications are actively protected from possible TPI. The methods include slabs and plates over pipelines; encasement sleeves: high tensile netting: marker tapes: and pipeline maker post. The following sections discuss these methods in detail.

4.3.1 Slabs, Tiles and Plates

This is the installation of precast or in-situ formed reinforced concrete planks, tiles or plates on top of the pipeline to intercept attempted disturbance to the pipeline beneath (Figure 4-2). This method of preventing TPI receives the first contact damage in any effort to excavate or physically interfere with the pipeline. The advantages and disadvantages of slabs, tiles and plates are presented in Table 4-7 (Muhlbauer, 2004, Mather et al., 2001).

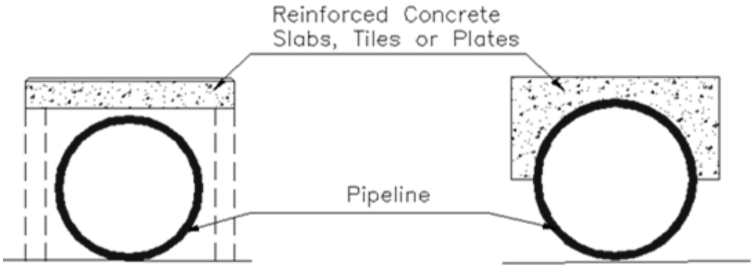


Figure 4-2: Illustration of precast slab tiles buried over pipeline, the slab material could be concrete, metal or other protective material capable to withstand interference.

Table 4-7: Advantages and disadvantages of slabs, tiles and plates.

Advantages	Good for preventing interference when combined with other methods A very good form of physical protection of the pipeline Effective for very shallow depth of cover
Disadvantages	Can be penetrated by very large mechanical equipment Expensive if to be used for long distance pipelines

4.3.2 Sleeves

This protection method is achieved by encasing pipelines with ring-like casts, or casing, of either concrete or steel, as illustrated in Figure 4-3. The gap between the sleeve and the pipeline is filled with either concrete or other solid material (Heier and Mellem, 2007, Bruce, 2005). The advantage of this method is to offer an extra layer of protection to the pipeline. According to Mather et al. (2001), third parties however sometimes do not easily recognise the contents of the pipeline, until they penetrate the pipeline by the continuity of their activities. The key importance and limitations of this method are listed in Table 4-8.

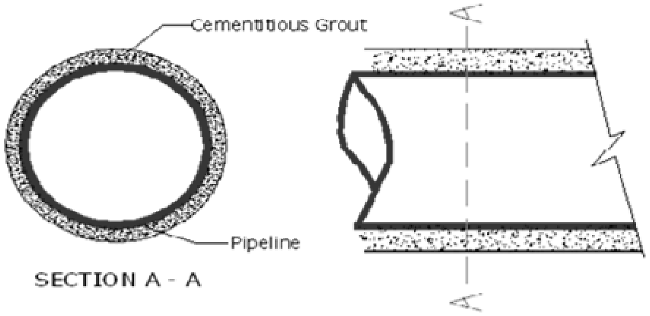


Figure 4-3: Installation of sleeves around pipeline. This acts as additional protection, making direct contact with the pipeline difficult.

Table 4-8: Advantages and disadvantages of Sleeves.

Advantages	Provides additional layer of protection against damage Effectively discourage intentional third-party interference Additional protection against other forms of defects, e.g. corrosion
Disadvantages	High capital investment to cover long distance pipeline The sleeve does not identify the content of the pipeline

4.3.3 High Tensile Protection Mesh

High Tensile (HT) nettings are relatively high ultimate strength mild steel grids or extruded plastic mesh materials installed to hold up excavation above a pipeline, and simultaneously serve as a warning symbol. Typically, mesh mattresses are buried above the pipeline (Zhuravlev et al., 2003, Crowhurst, 1983). The meshes are similar to those used in engineering for erosion control, slope protection and soil reinforcement (Figure 4-4(A)).

Figure 4-4: Pipeline installation activities: (A) A typical fabric protective mesh being laid along with a pipeline during installation; and (B) Maker tape being installed on a pipeline (Telemark, 2000).

However, it is only suitable for traversing short spans of pipeline or pipeline segments with difficult and unusual ground conditions. Another problem with this method of prevention is that of the associated high cost investment if used for long distance pipeline. Table 4-9 presents the advantages and disadvantages of using HT nettings during installation.

Table 4-9: Advantages and disadvantages of High Tensile Protection Mesh

Advantages	Additional protection, if combined with other methods Allows other forms of inspection for the pipeline Simple to install compared to concrete slabs and sleeves
Disadvantages	High cost investment if used for long distance pipeline Legitimate third-party equipment can get entangled with the net The method is labour intensive

4.3.4 Marker Tape

This method of preventing TPI is generally used in combination with other methods during pipeline installation (Figure 4-4(B)). The purpose of the installation of marker tapes, laid above pipelines is to serve as a warning mechanism during attempted excavation (Mather et al., 2001). Marker tapes with signs or symbols are cost effective enough that they can be used over the entire length of a pipeline. In addition, they can promptly identify the contents of a pipeline, however, they only warn of pipeline proximity during digging, and will not deter intentional pipeline damage. The advantages and disadvantages of this method of protection during installation are presented in Table 4-10.

Table 4-10: Advantages and disadvantages of Marker Tape

Advantages	Additional protection, if combined with other methods Simple to install compared to concrete slabs and sleeves Can support, as platform for other from of protection
Disadvantages	High cost investment if used for long distance pipeline Legitimate third-party equipment can get entangled with the net Deteriorate with age of the pipeline

4.3.5 Marker Posts (Signs and Notices)

Marker posts are protruding poles, approximately 1.5m in height erected above the pipeline, and along its length. Marker posts are clearly marked and inscribed with warning signs. They are durable and designed to be weather resistant (Fig 4-5). They are cheap to install and could cover the entire length of a pipeline. However, possible physical damage by fire or water is a disadvantage, and they do not deter intentional pipeline damage.

Table 4-11: Advantages and disadvantages of Marker Post.

Advantages	Lower cost of installation compared to other *during installation* methods Can cover an entire long distance cross-country pipeline Quick identification by third-party activities Could conceal some forms of detection equipment, e.g. spy camera, CCTV
Disadvantages	Moderate prevention against intentional damage, might be an attraction Highly predisposed to direct damage from vandalism Difficulty in identification of pipeline if too widely spaced apart

In addition, marker posts must be maintained in a legible condition throughout the life span of the pipeline (Miesner and Leffler, 2006, Mather et al., 2001). Table 4-11 presents the advantages and disadvantages of using Marker Posts.

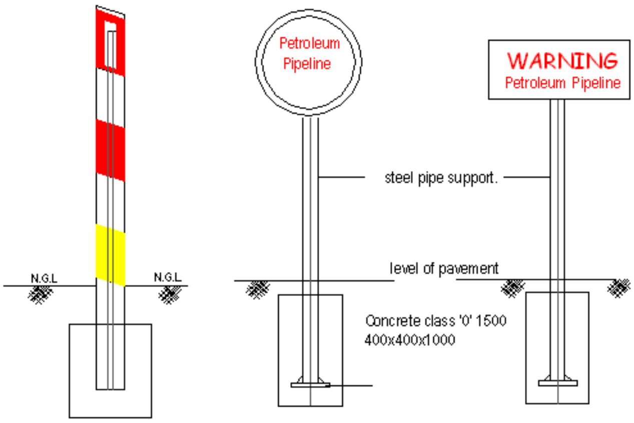


Figure 4-5: Typical variations of marker post used in pipeline right-of-way.

4.4 Post-Installation

Post-installation methods of protecting pipeline against third-party interference are aimed at detecting TPI prior to or during third-party activities. These methods include aerial surveillance, vantage point survey, full walking survey, satellite surveillance, Global Positioning System (GPS), electromagnetic detection, and Fibre Optic Sensors (FOS).

4.4.1 Aerial Surveillance

Aerial surveillance assists in the identification of illegal activities and changes in the land-use pattern within a pipeline's right-of-way and is usually undertaken using a helicopter, fixed wing aircraft or an unattended remote controlled flying vehicle. This prevention method, if done periodically, can help security analysts to assess any unusual area or disturbance trend that could be detrimental to the pipeline (Gregga et al., 2008, Riquetti et al., 1996, Gallacher, 1996). Palmer and Associates (2002) conclude that an additional benefit of aerial surveillance is that it serves as a reminder to the local population that there is a pipeline on their land and this could sometimes serve as a deterrent. In addition, aerial surveillance detects and confirms more targets and identifiable locations than satellite surveillance can achieve. The major disadvantage in helicopter surveillance methods remains the high costs associated with capital, operation, and maintenance.

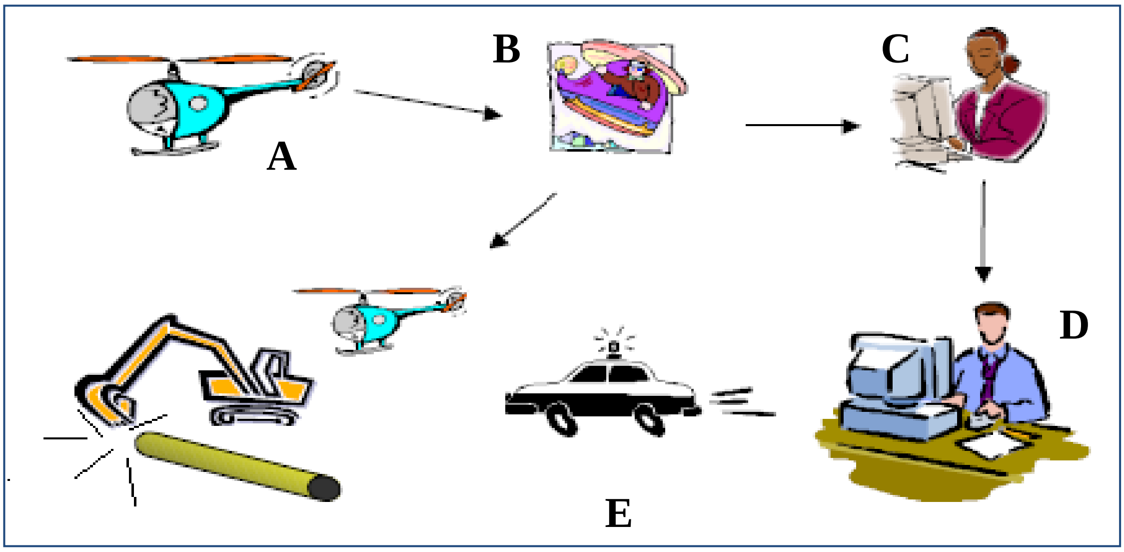


Figure 4-6: The sequence of typical helicopter surveillance (Palmer and Associates, 2002).

In the above illustration of aerial surveillance procedures (Figure 4-6): (A) a helicopter observer is shown patrolling over a pipeline's right-of-way; (B) an on-board observer makes a preliminary classification of any infringement and suspicious activity; (C) an observer takes notes and photography, and collates a survey report after flight; (D) a pipeline engineer reviews, evaluates and analyses the survey report; (E) the pipeline operator schedules immediate site response, inspection and investigation if necessary.

Table 4-12: Advantages and Disadvantages of Aerial Surveillance

Advantages	This method covers large pipeline network in a short time The presence of a helicopter could serve as a deterrent against intentional TPI Identifies other threats against a pipeline alongside third-party interference
Disadvantages	Can be automated if mounted with GPS/ camera for additional data capture High capital investment for equipment and machinery This method could be stalled by bad weather It requires frequent patrol frequency cycle to be effective

This method is still being used for the prevention of pipeline TPI, and may be applied to other forms of pipeline inspection (e.g. vegetation growth and encroachments into the right-of-way of pipelines). Table 4-12 shows the advantages and disadvantages of using this method.

4.4.2 Vantage Point Survey

According to Mather *et al.* (2001), this method of preventing TPI utilises the highest geographical features along a pipeline's right-of-way having 360° area coverage. Unusual activities along the pipeline's right-of-way can be observed from these vantage points. This method is beneficial for selective segments of a pipeline. It is cheaper and simpler to operate and implement. However, its use depends on the presence of a high point for a good line of sight. In extreme risk circumstances, snipers could be located in these vantage points with camouflage and concealment to combat extremists (e.g. militants and saboteurs). Digital Terrain Models (DTM), a representation of ground topography in digital format, can be utilised for undertaking visibility analysis. The DTM terrain study can then be use to determine the locations of the vantage point from where the best visibility is obtainable. Finally, although extensive research has been carried out on the advantage of this method, it can be concluded that the method is relatively inexpensive, especially if it is self-administered by the pipeline operator.

Table 4-13: Advantages and Disadvantages of Vantage Point Survey

Advantages	Directly covers particular segments of large pipelines in a short time Cost effective if used in selected segments of pipeline Could be used in conjunction with video monitoring to increase effectiveness
Disadvantages	Potential source of third-party damage are not always visible Requires extra manpower twenty four hours a day and seven days a week Unavailability of a suitable vintage point would be a disadvantage of the method

4.4.3 Full Walking Survey

This method of preventing TPI involves a periodic manual detailed condition survey of the pipeline route, highlighting all the susceptible areas that require immediate attention. Traditionally, many oil and gas companies have subscribed to the belief that this is an effective method to prevent potential pipeline damage (Chen et al., 2007, Badolato, 2004, O'Donnell, 1973). The walking survey method is a comprehensive route evaluation procedure that examines and re-examines any existing and possible threat to the pipeline alignment. Since a critical and thorough observation of the entire pipeline route is possible (Figure 4-7), this logically allows for visual observation of other forms of pipeline threat. For example, ground movement, oil spill, erosion and changes in pipeline intrinsic geometric characteristics.

Figure 4-7: Example of Pipeline inspection using a full walking survey method; line measurement, records, and notes are all collated.

However, time is frequently of the essence, and this method is time consuming (Mather et al., 2001), after all, 'time is money'. It could also be suggested this method distinctively requires frequent and several number of patrols for an effective results (Hopkins et al., 1999). Table 4-14 presents the advantages and disadvantages of using a full walking survey.

Table 4-14: Advantages and disadvantages of Pipeline inspection using a Full Walking Survey

Advantages	Moderate capital investment for equipment and machinery Effective against intentional third-party interference This method also identifies other threats, for example ground movement
Disadvantages	More intensive labor work is needed It is very time consuming Very dangerous in volatile oil and gas producing regions, e.g. the study area

4.4.4 Satellite Surveillance

Satellite surveillance as a preventive tool for TPI uses Remote Sensing (RS) technology. This is the observation from satellite produced images for interpretation of a pipeline route (Smith, 2002). Generally, satellite remote sensing technology provides an extensive variety of information about any location or target (e.g. pipeline) without physical contact (Lillesand et al., 2004). This assists in visual inspection and investigation of vulnerable pipeline alignments susceptible to TPI (Palmer-Jones et al., 2004a, Palmer and Associates., 2002, Gallacher, 1996). For example, Quiñones-Rozo et al. (2008) recently proposed the use of an RS image algorithm that can track excavation activities which is applicable to pipeline third-party interference. In a study for the Health and Safety Executive (HSE), Palmer-Jones et al (2004b) and Lothon and Akel (1996) evaluated pipeline surveillance by the use of a high resolution satellite for preventing TPI. Figure 4-7 shows a typical sequence in satellite monitoring of a pipeline (Palmer and Associates., 2002).

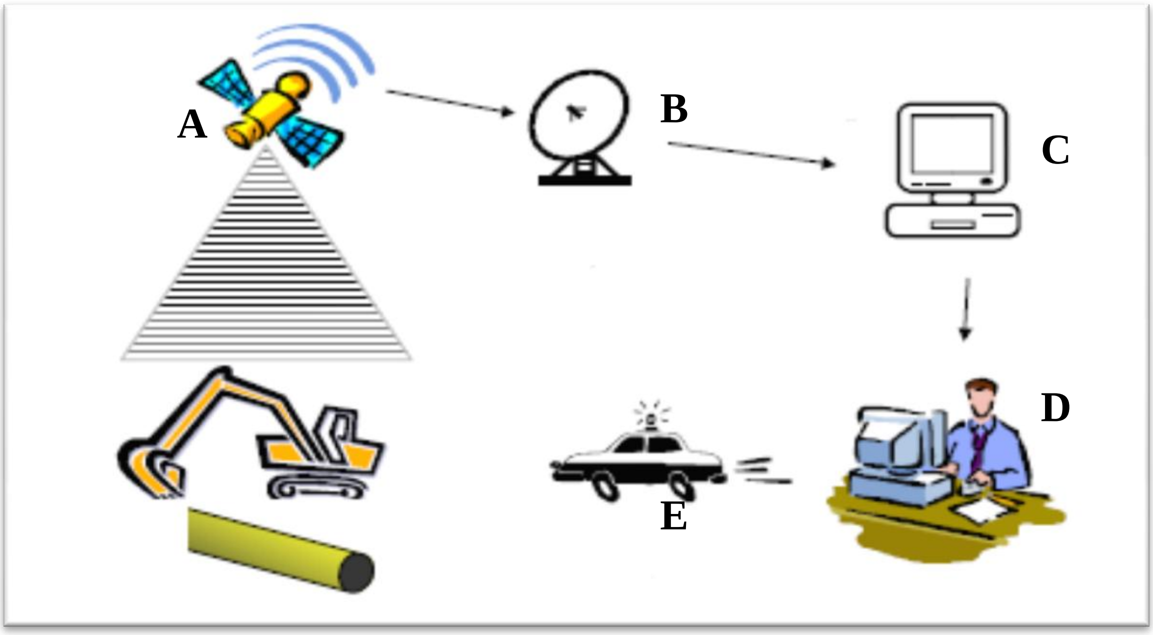


Figure 4-8: (A) Satellite collects image data, (B) Space Imaging receives data and checks quality, (C) 3. Service provider screens data for 'high risk' points; (D) Local pipeline engineer reviews satellite images of 'high risk' points, (E) Site investigation if necessary (Palmer and Associates., 2002).

The advantage of RS is that analysing data is relatively inexpensive, when compared to sending teams of surveyors out into the field and *"the average location accuracy of 29m (with a standard deviation of 16m) estimated for the satellite method is superior to that achieved with helicopter surveillance"* (Palmer and Associates., 2002). This rapid collection and evaluation of data is thus much more efficient than undertaking a ground survey. RS has the further advantage of making otherwise inaccessible areas visually accessible to surveyors. In addition, the rapid production of maps and quick and easy manipulation by computers of satellite imagery makes RS an innovative technology aid in preventing pipeline TPI. Fig 4-8 illustrates a typical scenario in satellite surveillance, and shows the mapping of a vehicle (circled in the pictures) progressing towards a pipeline's right-of-way.

Figure 4-9: Satellite Multi-spectral (colour) imagery with a resolution of 1m showing (clockwise, an excavator circled red) a typical fictitious scenario of an excavator advancing towards pipeline ROW.

Table 4-15: Advantages and Disadvantages of Satellite surveillance

Advantages	This method covers large area of a pipeline in a short time Rapid and quick production of analysis and result This method also facilitates the exchange of images and data between the various agencies concerned with pipeline security Identifies other threats against a pipeline, for example, oil spill Provides additional data for other and future analysis
Disadvantages	High capital investment for equipment and machinery Except the use of radar system, this method is affected by bad weather, It requires frequent and high spatial and temporal resolution images to be effective, e.g. Figure 4-9 could not be produced in minutes.

Nonetheless, the cost of high-resolution satellite imagery make RS technology unattractive for surveillance and until prices reduce to the minimum cost per km, according to Palmer-Jones (2004b), cost might be a major negative factor to the full utilisation of this technique. However, advancements in satellite technology have overcome most of the shortcoming of satellite surveillance, including cost. It now competes as the best alternative to other forms of third-party surveillance because of the following reasons: time for delivery of images, fast data handling, and the reduction in cost of producing images. Satellite data can now be acquired quickly processed and analysed with fast super-computers. The emergence of more third-party vendors and carriers has all contributed to the appreciable reduction in the cost price of satellite images (Roper, 2003).

4.4.5 Global Positioning System (GPS)

The Global Positioning System (GPS) technology has various uses apart from data collection. It is now in use as a tracking system in land, sea and air applications, and as a navigational aid. The GPS, if aided with a satellite communication system, facilitates quick delivery and exchange of data by enhancing good real time monitoring services (Qi et al., 2008, Roper, 2003). In helping in preventing TPI in the pipeline industry, this method requires mechanical equipment (excavators, bulldozers, drillers etc.) to be fitted with a GPS, or inbuilt as is now common with most heavy industrial earth moving equipment. The position of the equipment is geo-located and rapidly deployed over communication network systems to a supervisory control and data acquisition centre. If the operation of third-party activities (equipments and machinery) in close proximity to a pipeline goes beyond a certain *"comfort level",* a warning or caution alarm is consequently relayed back to the equipment to intersect and warn against a possible interference (Mather et al., 2001).

Technology is moving very fast, with GPS equipment presently finding wide application in our daily use. If parents and guardians can track children and dogs, then tracking third-party activities with GPS is much more important in order to prevent pipeline failures. Consequently, many GPS based communication satellites now provided additional services using their on-board systems to help monitor infrastructure. For example, Nigeria's recent NIGCOMSAT-1 (a hybrid geostationary satellite) comprises 2-L-band transponders (antenna) for global coverage and is useful for navigation purposes and serves as a space based augmentation system for global navigation satellite system such as GPS (NASRDA, 2005). Table 4-16 shows the advantages and disadvantages of the Global Positioning System (GPS) methodology.

Table 4-16: Advantages and disadvantages Global Positioning System (GPS) technology

Advantages	The method can work independently of the pipeline Operators know in real-time, activities within a pipeline's right-of-way Effective if used in conjunction with other forms of protection methods Adaptable with many daily navigational gadgets and machinery
Disadvantages	Requires pre-processing of pipeline networks on a pre-digitized base map Expensive in terms of capital, implementation, and operating costs Impractical for third-party activities that are not directly related or commissioned by the pipeline operators

4.4.6 Fibre Optic Sensors (FOS)

Pipeline Fibre Optical Sensors are intrusion detection systems that use signal recognition to detect and alert the operator to unauthorized TPI. The continuous optical fibres are encased in a thin core of suitable material with an outer cladding of transparent or other optical quality material. The fibres thereafter are laid alongside the pipelines during or post installation. The system relies on the basic principle of electromagnetic laws of transmission and reflection, detection being based on periodic light pulses travelling through the optical fibre. The vibration or fracture generated by any intrusion changes the light reflected and transmitted in the fibre, and with the known velocity of light, an intruder's location is easily determined by measuring the time difference of the reflected light pulse (Martins-Filho et al., 2008, Tennyson et al., 2007, Voet et al., 2005, Li et al., 2003).

The flexibility and ability of the fibre optics to detect various physical parameters, for example, acoustics, temperature, pressure, and magnetic field means that it is now gaining acceptance in the pipeline industry, although there is still scepticism regarding its reliability (Possetti et al., 2008, Nikles et al., 2005, Voet et al., 2005, Re and Colombo, 2004). Although field measurements have validated the technique to some extent, further validation is required in order for confidence to be gained in their use. Moreover, besides industry standardisation and acceptance, the influence of installation cost is another disadvantage since wiring the entire length of the pipeline is required. However, this current thesis is aimed at developing predictive models that can be used to identify vulnerable segments of pipeline and that could be beneficial to the selective installation of the above method, thereby reducing overall cost and increase optimal security. Table 4-17 summarises the advantages and disadvantages of the fibre optic method.

Table 4-17: Advantages and disadvantages optical fibres sensors

Advantages	Very efficient detection of intrusion over long pipeline distances The method can continuously monitor pipeline in real-time Wide and growing acceptability because of the telecommunication market and decreasing price of faster data transmission rates
Disadvantages	Adsorption efficiency is highest with high tensile fibers, else booster transmitters are required over long distances Instrumentation and signal processing are complicated and require additional experts and operating cost. False alarms from inability to practically filter out environmental noise, e.g. above traffic, and nearby authorized construction activities

4.4.7 Target Motion and Smart Camera System

This prevention method uses "change detection" and "automatic object recognition" technology to detect encroachment into a pipeline's right-of-way. Closed-Circuit Television (CCTV) and Closed Circuit Video Recording (CCVR) transmit activity signals to a control centre (room) where operators analyse and compare pictures presented to the system (Cumming, 1994, Dezham et al., 2007). Cumming (1994) have reported the use of this method to cover a distance range of over 2 km, where both transmitted and received data have been successfully analysed.

Table 4-18: Advantages and disadvantages CCTV and CCVR

Advantages	Less manpower is required The method could operate independently and continuously Availability of many producers and vendors means good price and quality competition Excellent for night monitoring in real-time if used with infrared camera
Disadvantages	Moderate prevention rate Lower qualities due to frequent presence of false alarms Requires good lighting condition if used at daylight Requires additional software for advanced image processing If video quality is poor the method could be subjective in detection

The advantage of the method is the capability for continuous operation and the ability to operate in environments that are uninhabitable or dangerous for any reason to operators or patrol teams. For a successful prevention of TPI, this method depends on a good CCTV specification. The advantages and disadvantages of the "target motion" and "smart camera" systems are shown in Table 4-18.

4.4.8 Acoustic monitoring devices

Acoustic monitoring devices uses Acoustic Emission (AE), whereby ultrasonic elastic waves of up to 1MHz are converted from a mechanical wave into an electrical signal. Acoustic monitoring in the prevention of TPI employs the transmitted ultrasonic signal along the pipeline itself to generate the approximate source of interference. For example, TPI produces noise vibrations whose frequencies are ultrasonic and these are detectable by the pipeline operator via transducers that pick the signal (Koduru et al., 2008, Papadopoulou et al., 2008, Nam et al., 2006, Wang et al., 2006, Leis et al., 1998, Hou et al., 1999). British Gas, for example, has developed the method into a standard monitoring tool (Hopkins, 1993). The disadvantage of AE is the production of only qualitative estimates, therefore other complementary methods are required to undertake thorough examinations and furnish quantitative results of the location and extent of pipeline TPI.

Table 4-19: Advantages and disadvantages of Acoustic monitoring device

Advantages	Higher capture rate and better quality of information about a location Independent method that does not require equipment attached to the pipeline Can detect other forms of threat such as leaks and product theft Covers long distances of pipeline and very effective against intentional damage
Disadvantages	Requires transmitter if required to cover long cross country pipelines Requires complicated signal and noise filtering to avoid false alarms Difficulties in differentiating acoustics from routine maintenance operations sources, for example, valve closures and traffic activities above pipelines

Wang et al. (2006) and Leis et al. (1998) demonstrated the use of AE techniques in the prevention of pipeline third-party interference. They tested for drilling, excavation, and hammering near pipelines. However, the method fails to significantly identify and filter out false alarms and environmental noises common with signal detection (Papadopoulou et al., 2008, Cao et al., 2005). In addition, this method will incur high investment cost with expensive transmitters and receivers, in addition to lacking industry standardisation (at least for now) and limited acceptance in pipeline project procurements. Table 4-19 shows the advantages and disadvantages of acoustic monitoring devices.

4.4.9 Telephone calls prior to digging

Summed up, this method can be simply termed as *Call-Before-You-Dig*. The US government, pipeline operators and underground utilities companies introduced this free telephone campaign (Watts and Kashi, 2008, Meadows and Sage, 1985, Miller, 1975). It requires that people with the intention of carrying out activities associated with digging, farming, construction, and excavation within a pipeline's right-of-way call a free telephone number to get information about pipeline facilities within their workspace. This method is now a legal requirement in the Netherlands, and a similar scheme now operates in the U.K (Hopkins et al., 1999). According to Sljvic (1995), the method also educates the public on locating pipelines markings and safe digging practices. In summary, no digging can occur until the "*One Call*" is made and a satisfactory response to proceed obtained (Jeong et al., 2003). The proper management of this method however depends largely on good administration and organisation as well as on active participation by trained and informed staff (Williamson and Daniels, 2008, Lu and Li, 2005, Jeong et al., 2003, Caldwell, 1997).

Table 4-20: Advantages and disadvantages of telephone calls prior to digging.

Advantages	Opportunity to simultaneously educate the public on pipeline safety Simple to operate and easily prevent unintentional third-party damage Give immediate notification to pipeline operators of activities near pipeline
Disadvantages	Time constraint due to pre-processing procedures and bureaucracy Public observation and obedience of the method is not guaranteed Accuracy is based on the existence of a pipeline already in the database Difficult to implement if no markers exists to prompt calling the operator

4.4.10 Intelligence Information

Intelligence information is another method of preventing pipeline TPI. Pipeline companies, in association with government and security agencies, employ secret intelligence gathering in volatile regions having propensity for pipeline TPI. Based on the information provided, pipeline operators can supply security agencies with the necessary information to plan patrol locations, determine sites to mobilise security forces and to plan the security instruments and tools for managing susceptible areas. According to Krizan (1999), *"Intelligence is more than information. It is knowledge that has been specially prepared for a customer's unique circumstances"*. The intelligence control in this method could take the form of usage of satellite spy equipments, listening devices, and other espionage techniques (Muhlbauer, 2004). Consequently, intelligence information will provide the law enforcement agencies and pipeline operators with the following capabilities: (i) visualize incident patterns; (ii) identify trouble spots by mapping repeat information; (iii) improve police officers safety; (vi) identify TPI prone areas; and (vi) maximise limited resources in combating TPI.

Table 4-21: Advantages and disadvantages of intelligence information

Advantages	Highly feasible for saboteurs, vandalism and terrorists Usage of existing local security agencies, e.g. police, security outfits, individuals Relatively cheap and effective for intentional third-party damage
Disadvantages	Depends on peoples' willingness to cooperate and help Some of the security/ intelligence agencies may themselves be corrupt Difficult to quantify, depends on the quality of the information source

4.4.11 Site access security

This is an expensive but effective preventive method for countering third-party interference. The surrounding critical areas and vulnerable segments of a pipeline are secured with chain-link security fences. These could be galvanized iron core, meshed and coated with PVC, and mechanically strained and supported with wires placed horizontally and fixed to posts. These intermediate posts must be spaced at intervals and cast into a concrete base. In addition, the installation of adequate wide lockable access gates at the valves, pump access points, suitably locked and secured are used to prevent unauthorised access. This method is an excellent method for preventing intentional TPI, although it does come with a high capital investment. Table 4-22 presents the advantages and disadvantages of site access security.

Table 4-22: Advantages and disadvantages of Site access security

Advantages	Does not allow unauthorised direct access to the pipeline route Effective against intentional third-party damages, e.g. saboteurs/ vandals This method discourages casual intrusions
Disadvantages	High capital investment for equipment installation and maintenance Does not allow for immediate response, hence needs additional tools

4.4.12 In-Line Geometry Inspection

This method of preventing and detecting TPI uses In-Line Inspection (ILI) techniques, and as the name implies-they are inspection tools. The method utilises ‘intelligent pigs’ or geometry pigs to transit through the pipeline and inspect and provide information about the geometric position of TPI that has modified the dimensions, properties and the profile of a pipeline (Huwener et al., 2007, Wilkowski et al., 2007, Bellamy, 2002). The most common is the use of caliper tools. They measure dents, wrinkles, ovality, and bend radius changes of the pipeline from interior measurements. These measurements reveal physical damage, deformations or any anomalies present in a pipeline, sometimes because of third-party activities. Caliper tools now use new improved technologies to increase accuracy and provide relatively rapid profile information of pipelines, using electronic based and computerised state-of-the-art software and hardware.

In mitigating TPI, once the geometry pig detects and indicates a problem, a response team could immediately be dispatched to locate the exact position. Sadly, not all pipelines are piggable; this is the industry challenge of considering this method in preventing TPI.

Table 4-23: Advantages and disadvantages of In-Line Inspection (ILL) method.

Advantages	Detects other anomalies extensively, e.g. leak detection, bend and cracks Allows for immediate response, saving time and money Very effective to locating imminent third-party damage
Disadvantages	Not effective against some intentional third-party damages, e.g. saboteurs The time between two ILI inspections could be several years Requires high cost of investment in machinery Disruptions of normal pipeline activities, dropping output production

4.5 Summary

This chapter has provided an extensive description of the various tools that are available for detecting, measuring, monitoring and/or preventing TPI. Although not exhaustive, it has identified the well-established and standard methods in use in the industry. It also discusses various corresponding advantages, disadvantages and limitations of the three broad categories.

In a questionnaire survey, as part of this thesis, respondents were asked to complete a 15-item Likert scale to measure their perception about various methods of preventing third-party interference during and post-installation. The answers were recorded into a 5-point rating scale from excellent to poor. The results of this study indicate that increasing pipeline wall thickness is the most preferable methods to prevent unintentional pipeline third-party interference by respondents. This is perceived as representative of their various organisations. In addition, a Multidimensional scaling (MDS) analysis performed to transform respondents' judgments and preference into multidimensional spatial maps, shows that some groups of methods are expensive to implement (e.g. GPS, acoustics, RS, and fibres).

From the forgoing, it could thus be concluded that the dwindling resources available to pipeline operators have prompted the need for selective protection of vulnerable segments of a pipeline by installing security tools where most needed. The results of this thesis could be used to minimise the cost per mile of pipeline installations against TPI, and to develop an understanding of relationships between the various contributory factors. Therefore, it could complement other solutions as discussed above, and appreciably reduce the huge investment in the protection of pipelines.

5 FACTORS INFLUENCING THE OCCURRENCES OF PIPELINE THIRD-PARTY INTERFERENCE

5.1 Introduction

The improvement of protection and prevention technologies for pipeline failures to date has tended to focus less on the root influencing factors of TPI. Although, the needed improvement is detail understanding of these various factors influencing the occurrence. This is expected to be the most significant current discussions in pipeline security. This chapter describes and discusses currently available information on the several factors influencing the occurrence of pipeline TPI. A detail review is also given on the characteristic and justification for use of each of the factors in this chapter. The chapter subsequently examines various dependent and independent variables associated with these factors. In general, this chapter present several hypotheses regarding factors that potentially influence the occurrences of TPI.

As explained in Chapter 1, one of the objectives of this thesis is to determine, using hybrid multivariate statistical analysis models, identify and predict vulnerable and susceptible pipeline segments. This is be achieved by examining relationships between occurrence of pipeline TPI and various factors, using a combination of socioeconomic and socio-political factors and several pipeline variables (described in the following sections). The thesis hypothesised that these are the major contributory factors influencing the occurrence of TPI, and form the considerations for inclusion into the multivariate statistical and spatial models. The data under consideration consists of twenty-five independent variables, collected and collated from the years 1999 to 2003, as the majority of all information needed for the thesis are available for this period. The twenty-five variables fall into one of the seven categories or groups of factors: land use, socioeconomic, socio-political, population density, accessibility to pipeline; pipeline intrinsic properties (age, diameter, buried or aboveground pipelines); and topographical conditions. These factors are discussed in the following sections.

5.2 Land Use

The increasing land use, for example, population encroachment on pipeline rights-of-way has been potentially identified as a major contributing factor for the decline of pipeline safety. More recent arguments supporting the influence of land use have been summarised by Kash et al. (2004), that *"Land use decisions can affect the risks associated with increased human activity in the vicinity of transmission pipelines"*, and that *"Pipeline safety and environmental regulation have generally focused on (a) the design, operation, and maintenance of pipelines and (b) incident response. They have not directed significant attention to the manner in which land use decisions can affect public safety and the environment"*. Therefore, the relationship between land use and occurrence of pipeline TPI is an intriguing one that needs a more detailed understanding. Particularly, how land use affects the decision about the use of rights-of-way, pipeline design procedure, and depth of cover.

Figure 5-1: An abuse of land use in vicinity of a pipeline network in the study area, this typical scenario is very common throughout the study area where aboveground pipeline are encroached into and abused (Watts and Kashi, 2008).

This thesis particularly examines land use as a major primary factor, and the rationale for the inclusion is that the impacts, positive or negative, that rapid land use in most countries have on existing pipelines, are becoming dominant. For example, Figure 5-1 shows a typical scenario in the study area, an example of direct encroachments into right of way of pipeline alignments. This type of land use pattern has been shown to directly influence the occurrence of pipeline TPI, especially the risks to the local population in proximity to pipelines (Muhlbauer, 2004 and Kash et al., 2004).

One of the important factors defining the way in which pipeline safety are designed is land use planning, primarily to decrease damage risk to pipelines. This is achieved by keeping human activity away from pipelines, especially in the event of pipeline failure. The problem with full utilisation of this technique is that land use change decisions are not regional ones, about 95 per cent of land use decisions and policies are actually made locally (Kleppel et al., 2006). Therefore, a land use decision in one region differs relatively in another region. A questionnaire survey, undertaken as part of this research, did show significant results that land use is one of the major influencing factors promoting TPI, and as the most ranked factor for consideration in mitigating intentional TPI.

The above reasons justifying the importance of land use factor on pipeline TPI, has also made it of global concern in the pipeline industry. Land use has become a central issue, and a recent statutory directive in this area of land use planning, for example, is the Article-12 of the *Directive Seveso II* on dangerous substances. This requires that land use regulatory planning policies stipulate safe distances between a potentially dangerous facility and local urban infrastructural developments (Cozzani et al., 2006, Directive, 1996). Likewise, Kash et al. (2004) infer that regulatory agencies *"have not systematically considered risk to the public from transmission pipeline incidents in regulating land use"*.

Land use regulations promulgated by most regulatory agencies do not consider risk to the public from eventual pipeline failures, and while pipeline integrity procedures are comprehensive, they are not however being utilised in planning land use. These are typically left at the judgement of various land regulatory bodies that may be less knowledgeable about transmission pipeline mechanics. This relationship of transmission pipeline and land use also illustrates why Kash et al. (2004) concludes that many political and policy *"decision makers lack adequate tools and information to make effective land use decisions concerning transmission pipelines"*.

There is no consensus system for the classification of land globally, regionally or locally. The classification system for land use cover varies primarily because it's based on the objective of a particular LGA or council governments. Therefore, the classification and definition of land use and land cover types vary considerably in existing literature, mapping ambiguity and different interpretation of results are significant in the development of the concern (Mücher et al., 1993, Singh, 1986).

The knowledge of land use and land cover is an important factor for planning and the management of earth's activities (Muhlbauer, 2004). The Land use classification according to the FAO/UNEP Land Cover Classification System (LCCS) methodology is adopted considering its applicability to the requirement of the study area. In particular, the LCCS is a standard in used by various land use mapping projects, and the standard was chosen for this thesis as shown in Table 5-1.

Table 5-1: Land Cover Classification System (LCCS) adopted for the thesis, according to the FAO/UNEP classification system.

Value	*Label*
11	Post-flooding or irrigated croplands (or aquatic)
14	Rainfed croplands
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
50	Closed (>40%) broadleaved deciduous forest (>5m)
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
70	Closed (>40%) needleleaved evergreen forest (>5m)
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous)
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
150	Sparse (<15%) vegetation
160	Closed to open (>15%) broadleaved forest regularly flooded
170	Closed (>40%) broadleaved forest or shrubland permanently flooded
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded
190	Artificial surfaces and associated areas (Urban areas >50%)
200	Bare areas
210	Water bodies

5.3 Socioeconomic Factors

The socioeconomic status of a region reflects the economic type and position of its population relative to other neighbouring regions, and is based on the total average income, education level, and types of occupation. While various definitions of the term have been suggested, this thesis will use it as a measurement that provides a feedback on a community's standard of life, comprising historical background, cultural norms, demographic characteristics, morbidity rate, mortality rate, occupations, income distribution, health and overall social infrastructure. This agrees with Goodchild and Kemp (1990) who identified socioeconomic factors as relating to all human activities (e.g. farming, infrastructure developments). Their relative socioeconomic variable classes include the derivatives of the following (Goodchild and Kemp, 1990):

- Housing quality and cost
- Transportation infrastructure
- Retailing (customer locations, store sites, mailing lists).
- Demographics-age, sex, ethnic and marital status, education, and
- Economics- incomes, employment, occupations, industry, regional growth.

An implication of this is the possibility that the socioeconomic status of a region suggests or infers that people from poor and deprived areas are more likely to interfere (intentionally) with a pipeline than are those from an area that is better-off. For example, Bennett (1991) found that the theft rate was directly related to gross domestic product per capita of a region, this was supported by Blau and Blau (1982), who suggest that poverty and deprived economic empowerment in a region can result in frustration, thus leading to higher rates of crime (e.g. TPI) in that region. Many authors (e.g. Chainey and Ratcliffe (2005)) have also shown a relationship between risk of crime occurrence and the socioeconomic status of a region.

Specifically, in the current study area, Nigeria, unemployment and economic neglect are prevalent. The socioeconomic level of the population in the study area is essentially low; particularly health, education, social and community facilities are lower than the expected national standard (Siraj, 2002). The socioeconomic status of the study area supports the significance of this factor as one of the major factors influencing the occurrence of TPI. For example, a socioeconomic survey of selected areas by Siraj (2002) in the study area reveals very interesting picture of the local population. The average family sizes of households are 6 to 8 persons, and local trading is the major occupation. The average family income is less than a £100 per month, with majority of the households lacking drinking water, health and transportation, amongst other important basic amenities. This large gap is hypothesised to no doubt encourage TPI, especially intentional interference.

5.4 Human Development Indicators

In addition to land use factor, the human development index of a region is an important factor that could indicate how widespread the incidents of intentional and unintentional pipeline TPI in that region area. Recent evidence (e.g. Sagar and Najam (1998)) suggests that these indices could be used to explain the unease of the people, and of a region's political and administrative status, particularly the state of the local social infrastructure and services.

Therefore, various indices and data extracted from the Niger Delta Human Development Report, prepared by the United Nations Development Programme (UNDP), were used in this research as proxies for human factors. The key aspects of these indices are Life Expectancy Index (LEI); Gross Domestic Product (GDP); Human Development Index (HDI); Gender-related Development Index (GDI); and Gender Empowerment Measure (GEM); and Human Poverty Index for developing countries (HPI-1) (UNDP-Nigeria, 2006). The "human development index" (HDI) theory has been strongly challenged in recent years by a number of writers (e.g. McGillivray, 1993) However, the HDI, as used in this thesis is to assesses development levels via life expectancy, adult literacy and local purchasing power using per capita GDP. It is used as an index, reflecting the human development significance of the study area. In general, these factors are briefly described in the following paragraphs.

The term Life Expectancy Index (LEI) has come to be used as a measurement of mortality that indicates the average number of further years of life remaining for a person from his/her present age, using population demography and age-specific data. Similarly, GDP can be defined as the measurement of a region's cumulative human activities in terms of the economic production, distribution, and consumption of goods and services per calendar year.

According to UNDP (2006), the Human Development Index (HDI) *"is a summary measure of human development"*. This factor measures the average achievements in three basic dimensions of human development: (a) healthy life rate, using life expectancy at birth as a measurement; (b) education level, using the adult literacy rate; and (c) standard of living, derived from the GDP per capital of a region (UNDP-Nigeria, 2006). The term GDI is a relative socio-economic parameter, commonly referred to as the measurement of average achievement, reflecting the relative inequalities between men and women. This factor uses the following dimensions (UNDP-Nigeria, 2006): "(i) a long and healthy life, as measured by life expectancy at birth; (ii) knowledge, as measured by adult literacy rate and the combined primary, secondary and tertiary gross education enrolment ratio; and (iii) a decent standard of living, as measured by estimated earned income".

The UNDP (2006) apparently uses the term, GEM as the ratio measurement of political and economic participation and decision-making of female and male shares of parliamentary seats, and, in particular, gender control over available economic resources (measured as female and male estimated earned income). The term Human Poverty Index for developing countries (HPI-1) refers to a social factor characterised as a probability measurement of a long and healthy life at birth (but of not surviving to age 40) together with adult illiteracy rate (UNDP-Nigeria, 2006). In conclusion, and from the foregoing, the influence of human factors is significant in the occurrence of TPI, and this explains why it is normally included in safety management system. Therefore, the understanding of this factor can help in decision making of protecting the pipelines against TPI.

5.5 Socio-political Factors

Socio-political factors, a relative combination of social and political variables (e.g. ethnic group and cultural status) provide a measure of the understanding of a societal structure and how it affects human activities. An understanding of the socio-political aspects of a society is required in order to understand crime formation, for example, a crime like intentional TPI. Little research has been undertaken, which explores how socio-political factors influence the occurrence of oil and gas pipeline failures, and TPI in particular. In addition, the motivation and instigation of intentional pipeline damage (e.g. vandalism, saboteurs, thefts, cyber-attacks etc.) are sometimes politically motivated (Lorenz, 2007). Therefore, it could be hypothesised that minority and low-income communities are more negatively motivated and likely to cause damage to a pipeline compared to proportionate communities that are more politically and socially favoured.

Miethe and Meier (1990) have shown that criminal tendencies are dependent not only on socioeconomic factors but also on the social-political conditions as well. An excellent socio-political status can influence the rate of crime in a society; for example, good employment opportunities and unemployment benefits can psychologically reduce the tendency to vandalism and theft. The following variables from Mauro (1995) socio-political forecasting review are used in this thesis: (a) adult literacy rate; (b) government expenditure capital projects; and (c) socio-political indices from the Niger Delta Human Development Report prepared by the UNDP.

Information about the socio-political situation is readily available from public sources, largely because of extensive media coverage. However, gathering consistent data from the study area is difficult. Hence, ethnicity, percentage literacy, presence of pipe borne (domestic) water; presence of oil and gas facilities; and percentage of oilfield are used as proxies for socio-political variables in the multivariate analysis part of this thesis. This approach agrees with Ascher's (1979) socio-political forecasting review, in that the *"use of social indicators, usually of society-wide phenomena such as the distribution of wealth, levels of alienation, consumption patterns, and broad aspects of the political climate"* are alternative elements of socio-political factors. In addition, the average total sum of government's expenditure on each spatial unit (of the study area) for capital project was used in this thesis, as one of the proxies for the underlying dimensions of socio-political variables.

5.6 Population Density

The rapid population growth worldwide is pressuring urban infrastructures to breaking point; and one of the effects, in Nigeria, the study area, is the encroachment of right-of-way (ROW) of petroleum pipelines. Pipelines laid in previously sparsely populated areas, are now vulnerable because of rapid population growth, especially with people now living near to these pipelines. It is important, therefore, to understand the potential impacts of population growth (and patterns of migration) on future possible pipeline TPI and the effects on the management of pipeline networks.

In the history of risk estimation development, growth of population density has been thought of as a key factor that has serious implications for public safety and lifespan security of the pipelines (Kash et al., 2004, Bilo and Kinsman, 1998). However, Radevsky and Scott (2004) point out that *"having populations close to the pipeline is not entirely a negative factor. An operator may wish to involve the local population in pipeline monitoring and incident reporting"*. While this seems logical, this can critiqued, in the study area, because, the immediate populations around pipeline networks are indirectly responsible for TPI, especially in politically unstable oil and gas producing regions.

According to Siraj (2002), only 31 per cent of the total population in the study area is employed and the balance of 69 per cent is a combination of infants, children, aged persons and persons seeking employment. Pipeline alignment tends, where possible to avoid large population density, thus smaller settlements, with limited resources, facilities at their disposal, and a limited economy to support its development are more likely to have pipeline traversing their neighbourhood. Thus, because of unavailability of these facilities, the settlements are constraints, and often result in the likelihood of a pipeline to experience TPI. The underlying influence of population density on the occurrence of TPI is the fact that it is often governed by the socio-political and administrative importance of the settlement amongst all other factors. This is because the probability and area of opportunity for occurrence of TPI increased as human activity increases.

Muhlbauer (2004) points out that design provision from population density classification provide an inaccurate measurement of the consequences of pipeline failures. Such exposition is satisfactory and shows the degree of the significance of population density as an influencing factor to the occurrence of TPI. Therefore, the significance of population density as one of the dominant factor influencing TPI relies heavily on the argument that sufficient protections are need for the local population and the pipeline in close proximity.

5.7 Geographical Accessibility to Pipeline Network

The importance of geographical accessibility to the pipeline right-of-way when considering the security of energy infrastructure (e.g. pipeline) cannot be overemphasised. The susceptibility of a region to pipeline TPI is highly related, and can be explained by criminological theories. For example, these assumption agrees with Brunndon and Corcoran's (2006) and Cohen and Felson's (1980) evaluation of Routine Activity Theory (RAT), that the opportunity, a potential offender, and an appropriate target are all that is needed for potential occurrence of crime (e.g. intentional pipeline TPI).

The implication is that, the closer the proximity of roads, rivers, streams and railways to a pipeline, the higher the likelihood of TPI (Muhlbauer, 2004). Chainey and Ratcliffe (2005); Brantingham and Brantingham (1981); and Frisbie and Minnesota (1977) have argued that ready accessibility to a crime location (e.g. intentional TPI) is important in understanding crime incidents and how to prevent them. For example, illegal planning to attack pipeline is often by taking advantage of the easiest accessibility, and the typical access is only by roads, river, streams or railways. Therefore, using degree of accessibility as a model variable would help to establish a greater degree of accuracy in examining and anticipating TPI and develop an understanding of the influence of the "journey to crime".

From the foregoing, this thesis separately investigates the geographic accessibility by looking at how using the unrestricted travelable distance to a pipeline as a dependent variable could predict future pipeline TPI. Thus it was hypothesised that the determinants factors of accessibility, as independent variables, to a pipeline are related to the fastest and shortest accessibility distance of a 'third party' to a potential pipeline. These variables are: (i) shortest distance from villages to a pipeline incident; (ii) shortest distance from rivers to a potential pipeline incident; and (iii) shortest distance from roads to a potential pipeline incident.

5.8 Pipeline Intrinsic Properties

Pipeline intrinsic properties that influence the potential occurrence of TPI are age, location, diameter, length, burial depth, pipeline type, and pipeline facilities (Andersen and Misund, 1983b, Jeglic, 2005). For example, numerous studies have identified depth of pipeline (or pipeline cover) as one of the dominant factors observed in general pipeline failure (Muhlbauer, 2004, Kash et al., 2004, Jager et al., 2002, Andersen and Misund, 1983b). Critics have also argued that not only do aboveground pipelines provide a general security risk, but that they also provide a criminal with easy access opportunities, because it is simply easier to vandalise or create illegal valves for stealing products from an above ground pipeline compared with a buried pipeline. Brantingham and Brantingham (1981) termed this scenario a *crime generator*. Aboveground or surface pipelines simplify the maintenance routines of pipelines and save on installation time; however, it is a major concern with some pipelines in political and economic high-risk areas. Third-party interferences are generally more limited if pipelines are buried. Other unlikely but possible factors that could affect aboveground pipelines are fallen trees, or third party direct impact damage, e.g. vehicle contact (CONCAWE, 2006, Radevsky and Scott, 2004).

The length of a pipeline is another factor that could influence TPI. It has been suggested that longer pipelines over shorter alternative alignments increase exposure to TPI, in addition to increasing maintenance costs of the pipeline right-of-way (Day et al., 1998). The relationship between location and type of pipeline has also been widely investigated (Radevsky and Scott, 2004, Day et al., 1998). When possible, pipelines should traverse areas where they will be easy to patrol or be otherwise monitored. Lastly, ancillary pipeline facilities (pump stations, valves, pig receiving stations, and compressor stations) could also influence TPI. These facilities, if not strategically located, apart from meeting the required security specification, could be attacked or be an anchor point for TPI.

5.9 Topographical and Geological Factors

The topographical and geotechnical formation of the underlying soil structure, supporting and surrounding a pipeline affects ground stability, physical accessibility, and various types of possible man-made activities. For example, rugged topographic terrain make access for intentional damage to pipeline more difficult, and geotechnical conditions determine the probability rate of corrosion, landslides and earthquakes. In addition, steep terrain slopes could encourage potential soil erosion and land stability, particularly following rainfall. Therefore, topographical and geotechnical characteristics are important contributory driving factors for potential pipeline TPI (Sweeney, 2004, Day et al., 1998).

The topographical and geotechnical variables considered in this thesis, are hypothesised to influence the risk of TPI. For example, natural hazards (geohazards) are often referred to as a form of TPI, and are recognized as a contributor to pipeline failures. This thesis thus included these factors in the statistical model because numerous studies have attempted to explain the influence of this factor, (for example, Porter et al. (2004)) that: *"where geologically active terrain is encountered and not properly recognized during pipeline design, construction, and operation, natural hazards may have an overriding influence on pipeline risk and system reliability"*.

The geological characteristics of a pipeline alignment influences the consequences of geotechnical hazards, for example, soil heave, landslides, debris flows, ground settlement and subsidence, all of which are possible in the study area except for landslides. In addition, the original pipeline cover may be lost due to geological properties (e.g. erosion and undercutting from debris through rain and abrasion). This justifies the inclusion of geological variables of the study area in this thesis. The pipelines in the study area traverse six geological zones and comprise: (a) Abandoned beach ridges; (b) Alluvium; (c) Coastal plains sands; (d) Mangrove swamps; (e) Meander belt, back swamps fresh water swamps; and (f) Sombreiro Deltaic Plain. The inherent presences of these geological characteristics also justify their inclusion as one of the factors.

5.10 Summary

Current knowledge about TPI lacks a deep understanding of the interaction effects of the various factors influencing the occurrence. Therefore, this chapter has discussed several factors influencing the occurrence of TPI, and the theoretical properties of the failure mode. In conclusion, this thesis examines various hypotheses to determine whether any of the factors described in this chapter account for the observed occurrence of TPI in the study area. In addition, the thesis examines the unique relationship between each factor and a combination of factors for predicting occurrence of TPI. The next chapter will explain the methodology employed for the overall thesis in four part namely, the study area and data; spatial disaggregation of the study area; hotspot spatial modelling; and the development of the multivariate statistical models.

6 RESEARCH METHODOLOGY

6.1 Introduction

As stated in Chapter 3, the pipeline industry generally recognised that third-party interference (TPI) is the dominant cause of pipeline incidents, throwing up many questions in need of further investigation, for example, the recognition of influencing factors, as a security concern, to minimise pipeline TPI. The success of the review of TPI in Chapter 2 and review of various international pipeline incident database reported in Chapter 3 led to the adoption of the research methodology described in this chapter. One of the goal of this thesis is to determine and the explore relationship between the factors that influence the occurrence of pipeline TPI, using a hybrid spatial regression model based approach. The subsequent prediction models developed examines land use, environmental factors, socioeconomic and socio-political factors, population density, and pipeline characteristics, such as diameter and age. To assess the thesis hypotheses, as examined in Chapter 5, this chapter therefore examines the various theoretical characteristics of GIS based statistical models and of their suitability for modelling pipeline TPI. Three different applications of GIS statistical analysis for hot spot identification and vulnerability prediction were used in this thesis, and to define TPI prone locations and ranking of the main factors considered to be influencing the possible occurrence.

Apart from general descriptive statistics, the first application of the hybrid-GIS based statistical methods involved the use of Getis-Ord Gi* statistics and the Geographical Weight Regression (GWR) statistical methods for spatial hotspot determination. After the pipeline incidents hotspots were investigated, two GIS-based prediction methods of Generalised Linear Models (GLMs) were developed in order to examine all the factors considered to influence the TPI phenomenon and to predict possible occurrences in pipeline segments and in spatially divided units of the study area. The GLMs procedures used are the Logistic Regression (LR) analysis and the Poisson GLMs. In general, the LR model was used to model the probability of TPI, and the Poisson GLMs were used to model the association and the relationship between the factors under consideration. These procedures are summarised in Figure 6-1 showing the overall methodology flowchart used in the thesis.

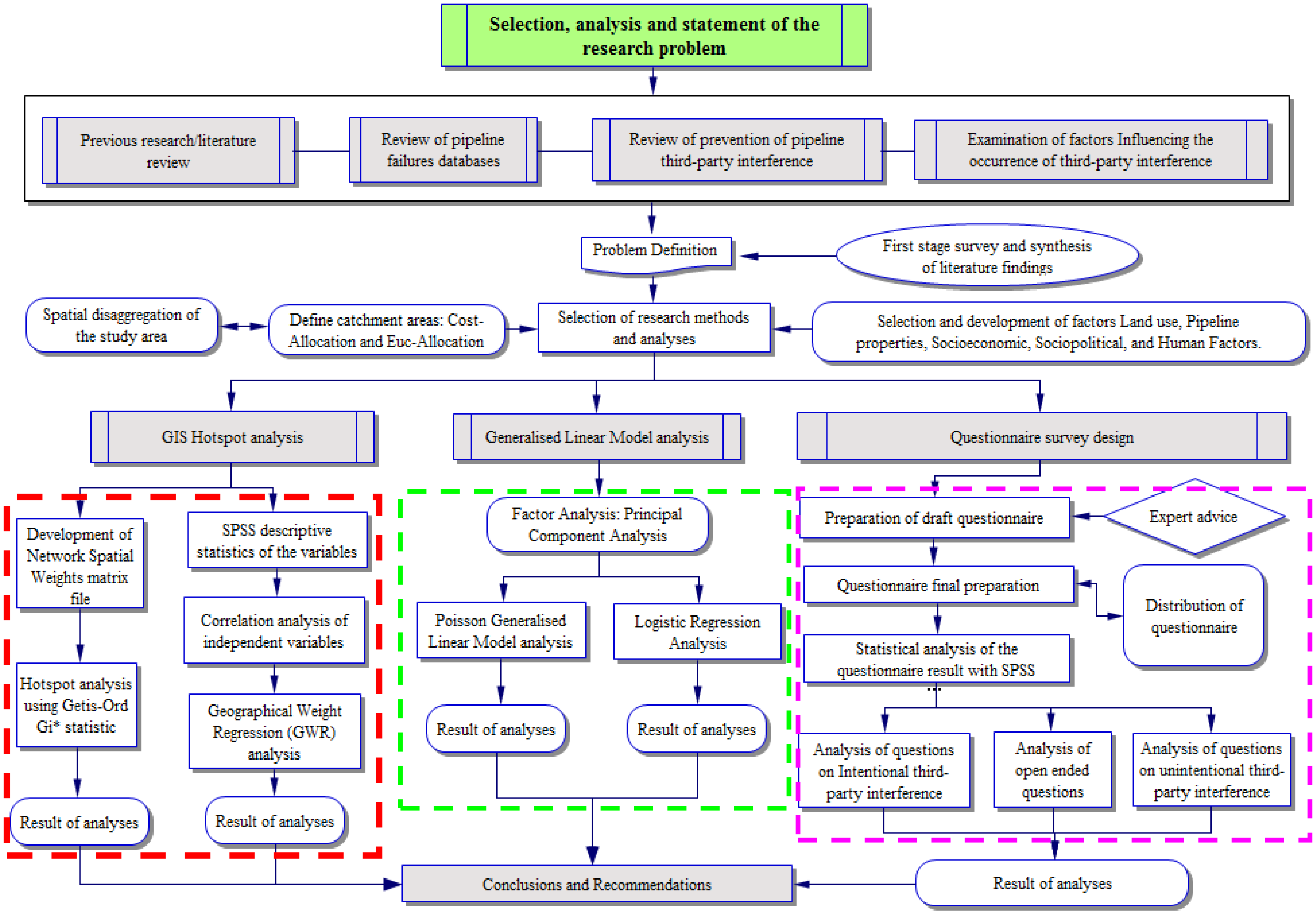


Figure 6-1: The overall methodology flowchart of the thesis

6.2 The Study Area and Research Data

The selected study area is the Delta State of Nigeria, and which is one of the major oil and gas producing regions of the country (Figure 6-2). The study area is approximately 8000 sq.kms, with a population of 0.96 million and having a population density of approximately 120 persons per sq. km, representing 1.1 per cent of the population of Nigeria (Siraj, 2002). There are six major ethnic groups: *Igbos, Ijaws, Isokos. Itsekiris, Ukwanis and Urhobos*, and over seventy per cent of the state's population live in rural areas. The study area is swampy and marshy, crisscrossed with many rivers and creeks, and the main rivers are the Benin, Escravos, Forcados, Warri and Ramos in the west and the Niger River in the east. The network of rivers and creeks serve as the only corridor for movement within the study area where transportation is only through boats and waterways, in the absence of a reasonable systems of roads and railways (Adewumi, 2006).

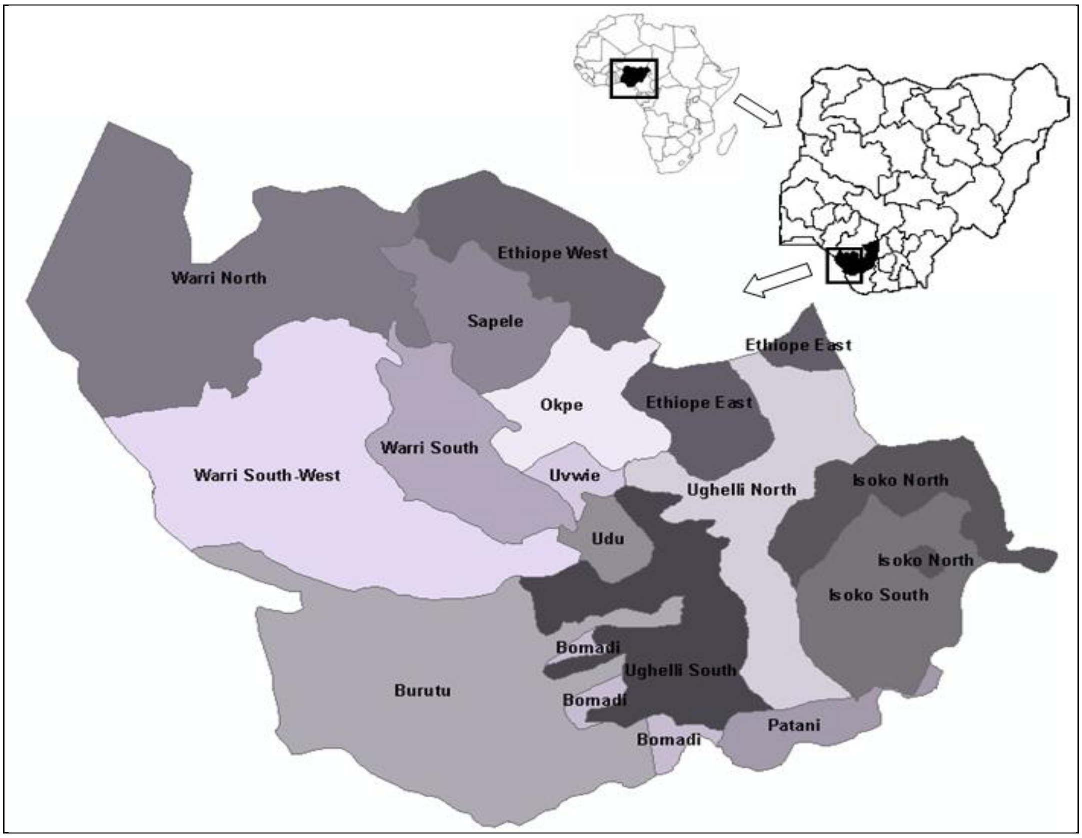


Figure 6-2: Map showing the selected study area in Nigeria for the thesis.

The primary raw data source used for the thesis was obtained from Siraj International and from the Department of Petroleum Resources (DPR), Nigeria, for the four years from 1999 to 2003. This duration, although considered relatively limited, was used because other available secondary data are accessible and available for this period. One additional reason for this period of time frame is because the occurrences of pipeline incidents are generally sporadic, with no reported incidents, sometimes, within a four-year period, combined with the inconsistent way that incidents data, in the study area are collated and recorded.

Table 6-1: The secondary raw data used in the thesis and their various sources.

Data	***Source***
Land Use	FAO-UN, Land cover of Nigeria (Source:www.fao.org/geonetwork/srv)
Ethnicity	www.waado.org/NigerDelta/Maps/delta_state/delta_state_ethnic.html
Average Daily Households Income	FAO(www.gisweb.ciat.cgiar.org/povertymapping/download/Nigeria.pdf)
Percentage Literacy	Siraj Int'l (Regional Development Plan for the Riverine Area of Delta State)
Capital expenditure (revenue allocation by government)	Delta State Capital Expenditure Report (Source: www.globalratings.net/attachment_view.php?pa_id=222)
Geological type	Zephyrgold Int'l, Extracted from the GIS based Geological Map of Nigeria
% of Households with Electricity	Siraj Int'l (Regional Development Plan for the Riverine Area of Delta State)
% of Households with water	Siraj Int'l (Regional Development Plan for the Riverine Area of Delta State)
Total Road length	Siraj Int'l (Regional Development Plan for the Riverine Area of Delta State)
Total river/stream lengths	Siraj Int'l (Regional Development Plan for the Riverine Area of Delta State)
Total length of Pipeline	Department of Petroleum Resources, Nigeria (with permission)
Pipeline status	Department of Petroleum Resources, Nigeria (with permission)
Average pipeline diameter	Department of Petroleum Resources, Nigeria (with permission)
Average age of pipeline	Department of Petroleum Resources, Nigeria (with permission)
Population density	Extracted from Gridded Population Density of Nigeria (GPWv3): By Center for International Earth Science Information Network (CIESIN). Available at www.sedac.ciesin.columbia.edu/gpw
Presence of oil/gas facilities	Siraj Int'l (Regional Development Plan for the Riverine Area of Delta State)
Percentage of oilfield/wells	From 'Regional Development Plan for the Riverine Area of Delta State'
Nos. of third-party incidents	Siraj Int'l (Regional Development Plan for the Riverine Area of Delta State
Life Expectancy Index	Niger Delta Human Development Report by UNDP Nigeria. Available at: www.hdr.undp.org/en/reports/nationalreports/africa/nigeria/name,3368
Gross Domestic Product (GDP)	Niger Delta Human Development Report by UNDP Nigeria: www.hdr.undp.org/en/reports
Human Development Index (HDI)	Niger Delta Human Development Report by UNDP Nigeria: www.hdr.undp.org/en/reports
Gender-related Development Index (GDI)	Niger Delta Human Development Report by UNDP Nigeria: www.hdr.undp.org/en/reports
Gender Empowerment Measure (GEM)	Niger Delta Human Development Report by UNDP Nigeria: www.hdr.undp.org/en/reports
Human Poverty Index (for developing countries)(HPI)	Niger Delta Human Development Report by UNDP Nigeria: www.hdr.undp.org/en/reports
Geopolitical locations	www.waado.org/NigerDelta/Maps/delta_state/delta_state_ethnic.html
Digital Elevation Model (DEM)	www.gdem.aster.ersdac.or.jp

The other data considered for the thesis consists of twenty-five independent variables, covering the period between 1999 and 2003, as the majority of all the information required for the thesis is available for this particular period. The thesis also used data obtained from references and from offices and organisations in Nigeria (e.g. Federal Ministry of Environment (FME)). In addition, data was gathered from other multiple sources, as shown in Table 6-1. Additional data was collated manually, for example, village locations, date, and distances from roads, rivers and villages. These data were all digitised on screen, using ArcGIS, and entered into an ArcGIS geodatabase, so that different analyses could be performed on the various variables. Table 6-1 shows the list of variables and indicates their various sources, they fall into one of the seven categories or groups of factors: land use, socioeconomic, socio-political, population density, pipeline accessibility, pipeline intrinsic properties (age, diameter, buried or aboveground pipelines), and topographical conditions.

6.3 Spatial Disaggregation of the Study Area

All spatial based modelling and analyses requires appropriate geographical units in order to better represent data in a model and to avoid the Modified Areal Unit Problem (MAUP) (Wong and Lee, 2005). For example, the United Kingdom is composed of four countries, namely Northern Ireland, Wales, Scotland and England; England can be further subdivided into nine regions, which can be further subdivided into smaller regional levels of ninety counties, and a further refinement into the smaller districts level at an areal unit, thus forming a hierarchical partitioning system. If data from different zones and scale levels are simply combined for analysis purposes, they produce results that are often inconsistent, and are known as *zonal* and *scale* effects respectively. The combination of these two effects is known as the MAUP. These two phenomena affect statistical analysis, especially correlation analysis (Wong and Lee, 2005).

The selected study area suffers from the above defined MAUP problem. It does not have an established distribution of appropriate geographical units to meet the required level of data available, hence the need for disaggregation of the study area in order to meet the required level for data analysis. The disaggregation was made by using village hierarchy procedures, and the main objective was to reorganise the existing structure of villages, growth spurs, and facility nodes, to provide a more balanced and even distribution of development in the region. In the procedure that was adopted, villages in the study area are grouped together, to form clusters of villages, according to the demographic function that they perform. These hierarchical patterns (Figure 6-3) show the dependencies of villages on a lower order hierarchy on the villages at a higher order.

This procedure of hierarchy planning is an adoption of the United Nations Environment Programme (UNEP). This method have been applied by Siraj (2002) to a study in Nigeria, using the population analytical report of Nigeria's National Population Commission (NPC) and the Delta State statistical year book, published by the Delta State in collaboration with UNEP. In general, Nigeria does not have further district or ward level spatial areal units, hence the consideration of this method to depict the actual socio-economic context of this selected study area. The method will also ensure accurate spatial analysis for the thesis.

6.3.1 The Village Hierarchy Planning

It was considered that quantitative measures would usefully supplement the required level for spatial analysis, especially to eliminate the MAUP discussed earlier. Therefore, the village hierarchy procedures were adopted for the study area, and the "Central Place Theory" was employed to accomplish this. This is a location patterns analysis method that attempts to explain the spatial order of distribution patterns, and the size and number of villages. The theory, originally introduced by Christaller (1933) affirmed this procedure as:*"examining and defining the functions of the village structure and the size of the hinterland with which he found it possible to model the pattern of village locations. In the present case the Central Place Theory is used for evolving a central place pattern to serve a given population for the provision of community facilities".*

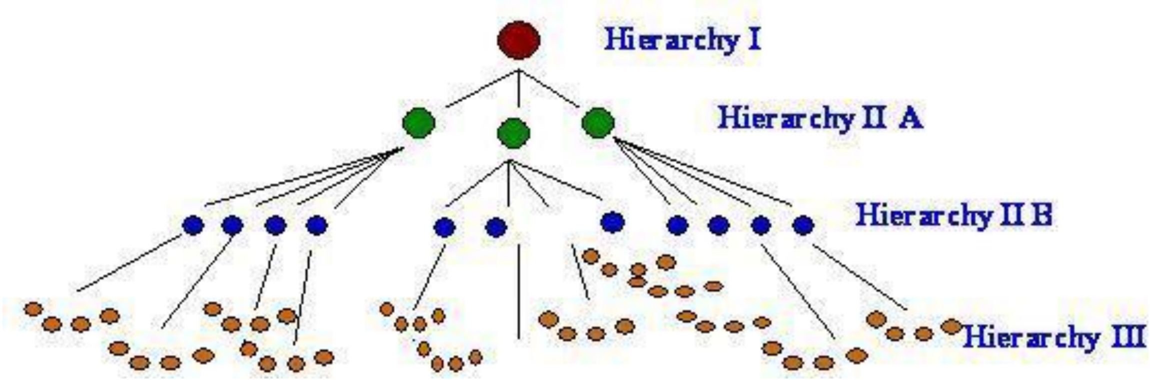


Figure 6-3: The hierarchy identified for the distribution of facilities of the region. Hierarchy I includes regional growth centre, which includes all the villages included in the Warri Effurun master plan, the figure shows how lower order villages depend upon higher order villages for facilities and how thus a dependency network is formed (Adapted from Siraj (2002)).

The overall study area is a developing region, hence, preferred method would be to apply Christaller's model. However, because of the incomplete and inadequate spatial data in the study area, the Christaller's model could not be satisfactorily applied. This is in addition to other limiting factors, for example, the domination of the terrain by water bodies and the socio-economic context, shaped to an extent, by various ethnicities composing the regional population. For all the above reasons, additional parameters were used in establishing the village hierarchy for the Siraj (2002) study; for example, population density and the numbers of available educational facilities within the study area.

6.3.2 The Application of Central Place Theory

The Christaller's procedures selected as the measurement tool provided a scoring table built on planning parameters specific to the study area. In Siraj's (2002) study, the classification of a village into a hierarchy is conducted by obtaining a sub-facilities score for the village, which was then arithmetically divided by the total number of the same sub-facilities available in an area. The total score for each village is the result of the summation of all sub-facilities available in the specific village under consideration, derived from the percentage conversion of the individual score for the given sub-facility. For example, if Warri (in the study area) has 50 primary schools and the total number of primary schools in the overall study area is 300. Hence, the score for the sub-facility of primary schools in Warri will be (50/300*100)*100= 1667. Similarly, if Warri town, for example, has 20 secondary schools and the total number of secondary schools in the study area is 110. Hence, the score for the sub-facility of secondary schools in Warri will be (20/110*100)*100=1818 (Siraj, 2002).

Table 6-2: Results of classification: The proposed hierarchy (Siraj, 2002).

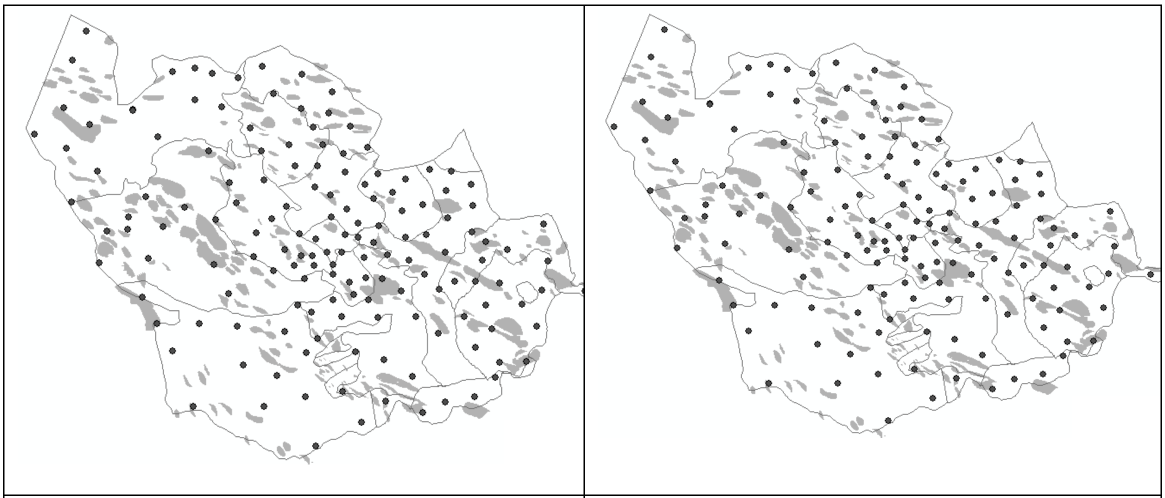
Units	*Types of Growth Centres*
Hierarchy I	Regional Growth Centre
Hierarchy IIA	Growth Centre serving a population of around 300,000
Hierarchy II B	Sub Growth Centre serving a population of 60,000-75,000
Hierarchy III	Service Centre serving a population of about 5,000 – 30,000

The same type of calculation is applied to all of the remaining facilities available in Warri, and the total score obtained for Warri are added up for that facility. Similarly, the total score for each village then shows the relative importance of that village in the study area. The Central Place Theory, as described above, relates to the catchment area of each village, considering the relative economic and social importance of operations within the boundaries of each village's territorial perimeter. The villages thus selected will operate within that general clusters, with specific roles assigned to each one according to its relative importance, and subsequently assigned to one of the hierarchy levels shown in

Figure 6-3. The growth centres are then organised based on a regional planning approach as shown in Table 6-2, this approach follows Siraj's (2002) procedure.

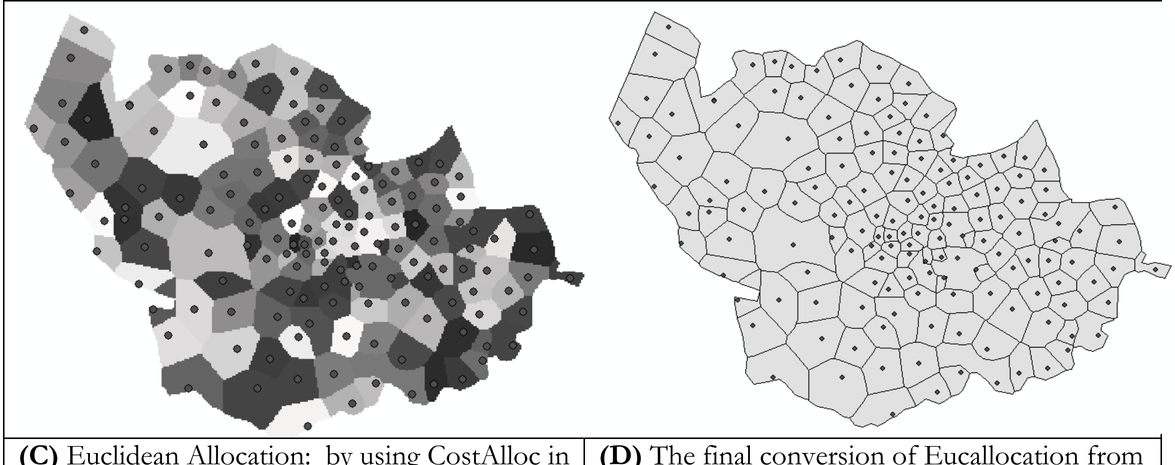
6.4 Defining the Study's Catchment Areas

The basic spatial units used for the thesis were prepared by first delineating the study area using the population distribution, and the distribution of oilfields in the same area as the basis. It was decided that this was the best approach, because pipelines usually traverse oilfields, and it was thus considered more important to use the oilfield distribution as the measurement for creating the spatial units.



(A) Oilfields and villages vector layer were converted to raster layer in arcGIS. These were the original data from the above procedures

(B) CostAllo: this is ArcGIS Costallocation of oilfield raster and village raster, and serve as the primary input features into ArcGIS



(C) Euclidean Allocation: by using CostAlloc in ArcGIS, with raster output (the shade of gray is for simple graphic display purposes).

(D) The final conversion of Eucallocation from the raster format to vector layer for further analysis in ArcGIS.

Figure 6-4: The actual ArcGIS procedure used in the Cost-Allocation analysis, figures from (A) to (D) shows the output result how the study area was disaggregated into 151 spatial units.

The data management and analysis was performed using ArcGIS 9.3; specifically, the image analysis functions of the Cost-Allocation and Euc-Allocation tools in ArcGIS were used to subdivide the entire study area into units, this was considered more precise than employing Thiessen polygons, according to Chou (1997). The ArcGIS image analysis function of Cost-Allocation derives spatial unit from the input features (Figure 6-4 (A)), using their spatial location and using the oilfield raster feature as weights. The costs (not a monetary value) are distance calculations from the input feature, the villages, and multiplied by the cost raster weight, the oilfields. Thereafter, the EucAllocation Spatial Analyst function allocates each village (from the disaggregated hierarchy) by association with the nearest oilfield (Figure 6-4).

Figure 6-5: The final map of the study area showing the final disaggregated 151 different spatial units subsequently used in the various analyses for the thesis.

After the study area was disaggregated into 151 different individual spatial units, the total road length, river length, and pipeline length was calculated within each spatial unit. The same procedure was also applied to the population density and number of incidents per spatial unit. The *Identity-Overlay* in ArcGIS analysis tools were used for the analysis; some typical parameters were Input Features (e.g. roads dataset) and Identity Features (the study area). This procedure splits the lengths of roads, rivers and pipelines at the borders between spatial units, creating a new layer that contains a joint attributes listing. The ArcGIS summary statistics tool was then used to create a spreadsheet formatted database that was joined to the original spatial unit's dataset thereafter.

6.5 Hotspot Spatial Approach and Modelling Methodology

A hotspot (black spot, black zone, or cold spot) is generally referred to as being an area having a noticeably higher than average cluster density of incidents (e.g. pipeline TPI), and could identify concentrations of events due to spatial interaction between neighbouring locations (Flahaut et al., 2003). This thesis analyses the spatial distribution of pipeline TPI incidents by detecting concentrations of hot segments in a network. A 'segment' is defined, in this thesis, as a subdivided section of a pipeline alignment in a network, and is represented as a feature. It is considered to be a hotspot if it experiences more than an expected number of occurrences of TPI, compared with otherwise normal random occurrences. There are different geographical and statistical methods that have been developed to model and analyse point patterns for hotspots, and their distributions and clustering. The red box in Figure 6-1 shows the overall methodology flowchart used in the hotspot analysis and spatial variation of the variables using the GWR.

Wong and Lee (2005) provided several reasons why considering the spatial local autocorrelation technique, which is a linear clustering technique, are useful, for example for the investigation of problem such as pipeline hot-segments (hotspots) and potentially vulnerable regions. They further emphasised how this technique gives a consistence and actual representation of a linear network (e.g. pipelines), unlike other methods (e.g. the Kernel Estimation Method) that analyses only the location of points. The local autocorrelation technique includes the attributes of the points in the analysis, and this allows for measurement of location proximity and differences in the characteristics of each of the points (Wong and Lee, 2005). This method is adopted as one of the most practical ways of examining the direct influence of factors that affect the occurrence of TPI, and makes it possible to investigate further the significant relationships between two or more factors.

The spatial local autocorrelation corresponds to Tobler's (1970) First Law of geography, in that all things are related, but closer things are more strongly related. The spatial local autocorrelation effect is a phenomenon that is always present to a certain degree in every spatial data whose patterns are clustered, dispersed or random. The measurement of these patterns of similarity or dissimilarity through space is known as spatial autocorrelation. Positive spatial autocorrelation occurs if neighbouring spatial units are more alike, and negative autocorrelation describes patterns where neighbouring spatial units are unrelated. The study of spatial autocorrelation starts with the introduction of Morans' I (Li et al., 2007, Shiode, 2008), for determining and measuring the level of spatial autocorrelation between spatial units. Morans' I is used for both polygon or points data with continuous variables and it compares a specified value at any one location with all other neighbouring values (Li et al., 2007, Wong and Lee, 2005).

6.5.1 Spatial Neighbourhood and Weights

The specific characteristics of the linear distribution of network utilities (e.g. pipelines) that is to be used in identifying hotspots needs utmost consideration in order to avoid a biased interpretation of the results. The use of Euclidean distances (direct distance between two points), appropriate connectivity and movement restrictions are examples of issues that make the analysis of patterns and clusters difficult. To increase the reliability of the measurements, it was decided that the best method to adopt in order to avoid biased interpretation of the results was the development of *network spatial weights*. This is done in order to improve the performance of spatial relationships among the pipeline network dataset, for example, pipeline TPI incidents. Many applications (e.g. accessibility to services, emergency response, and pipeline incidents) are found in real world travel networks and simple Euclidean distance measurements do not properly define actual spatial relationships.

Spatial weight matrices, used to determine the *network spatial weights,* are ways in which relationships between a geographic defined feature (e.g. a point incident) and its immediate neighbours (other point incidents) are spatially represented as part of a model. This is typically an *n* x *n* matrix, where *n* is the number of geographical units (points or polygon), and each unit is represented by both a row and a column. The value of *0* or *1* could represent whether a unit is considered spatial related to an adjacent unit. Apart from using the adjacency distance, the centroid distances between two areal units (e.g. polygon features) can be used to define their spatial relationship (Wong and Lee, 2005). The following sections describe a typical procedure for the creation of the *spatial neighbourhood weight*.

In Figure 6-6, two spatial units (1 and 3) of the study area, as labelled, illustrate how spatial weights matrix file was generated. A sample extract from a binary spatial weights matrix file from ArcGIS output is shown in Table 6-3, using the 'Queen's move adjacency' analogy (De Smith et al., 2006).

Table 6-3: A ArcGIS software procedure for determining spatial weights matrix file

1 3
$p_1, p_2, \ldots, p_3$ (IDs of the three neighbors)
3 4
$q_1, q_2, \ldots, q_4$(IDs of the four neighbors)

Here, the first line indicates that spatial unit 1 (*Agoro*, in the study area) has 3 spatial neighbors, followed by the IDs of the three neighbors (p_1, p_2, p_3); while spatial unit 3 (*Torugbene*, in the study area) has 4 spatial neighbors ($q_1, q_2, \ldots, q_4$). Therefore, based on this proximity, a set of spatial weights matrix was computed using the Euclidean distance ($d_1, d_2, \ldots, d_n$) from the centroids of each spatial units (figure 6-6).

1	p_1	d_1
1	p_2	d_2
1	p_3	d_3
3	q_1	d_4
3	q_2	d_5
3	q_3	d_6
3	q_4	d_7

Figure 6-6: Spatial weights computation, using a segment of the study area as an example.

This relationship weight given for two feature of interest, often denoted by *w* (a spatial weights matrix) captures the spatial aspects of the problem of expressing the relative proximity of pairs of features or places. The above procedure can be similarly applied to entire spatial units in the study area, to determine the *spatial neighbourhood weights*.

6.5.2 Hotspot Analysis Using Getis-Ord Gi* Statistics

Several studies have used the Moran's I measurement of spatial autocorrelation discussed above for hotspot determination in a linear network. While these models indicate a relatively high (positive or negative) autocorrelation, they generally lack accuracy. This is because they do not explain local differences between areas with high concentrations (hotspots) and those having low concentrations (cold spots) and thus one cannot distinguish between areas (called hotspots and cold spots) with different spatial autocorrelation. This thesis considered it to be an important factor in choosing an appropriate method to identify clusters of high or low value, by using local G-statistics (Mitchell, 2005, Wong and Lee, 2005). This statistic computes a comparison between neighbouring features within a given distance to show the extent of how features are surrounded by similar high or low values.

There are two alternative methods for determining the G-statistic. The first is the Gi-statistic method, where the value of a specific feature of interest is not included in the computations. The second method, Gi* statistic includes the value of the specific feature of interest in the computations. Since the value of a target feature is considered to contribute to the occurrence of a cluster, the Gi* statistic method is most suitable for finding hotspots and cold spots. The Gi* statistic is neighbourhood based and uses adjacent features or a specified distance, the distance not necessarily Euclidean, and could be related to travel time, between occurrence of two successive events. The Gi* statistic is calculated using GIS, and this is done by summing the values within a feature's neighbourhood and dividing by the sum of all values in the overall study area. The computation formula for the Gi* statistic is given in equation 6.1, and is to test hypotheses about the spatial concentration of the TPI incidents within *d* of the of another TPI incident (Mitchell, 2005) :

$$G_i *(d) = \frac{\sum w_{ij}(d)x_j}{\sum_j x_j} \qquad \text{(Equation 6.1)}$$

The $G_i *(d)$ in equation 6.1 is the Getis & Ord measurement of clustering and is for a feature (*i*) at distance (*d*), where $\sum w_{ij}(d)x_j$ is the summed result of each value of a neighbour's feature (*x*) multiplied by the weight of the feature of interest pair w_{ij}. The strength of the spatial relationship, $\sum_j x_j$ is the sum of the values of all neighbours (x_j) of all the features in the dataset of the study area. A group of features, for example pipeline incident points, with a high value of $G_i *$ indicates a cluster of a particular feature with high attribute values and is thus defined as a hotspot, while the group of a feature (e.g. pipeline incident points) with low $G_i *$ value reveals a cold spot. The $G_i *$ statistic is also a measure of standard deviation or the *Z*-score, a test of statistical significance that determines whether the null hypothesis should be rejected. In G_i* statistic, the Z-scores are calculated by subtracting the expected G_i* from the calculated G_i* value given a random distribution, and dividing by the square root of the variance of all the features (Mitchell, 2005). The expected Z-score is thus calculated as:

$$Z(G_i*) = \frac{G_i* - E(G_i*)}{\sqrt{Var(G_i*)}} \qquad \text{(Equation 6.2)}$$

The $Z(G_i*)$ in equation 6.2 is the expected Z-score for G_i*; and $G_i* - E(G_i*)$ is the expected G_i* subtracted from the observed G_i*; while $\sqrt{Var(G_i*)}$ is the square root of the variance (Equation 6.2). The computation for the expected G_i* is the sum of the weights at distance (*d*), divided by the number of features, minus one. The formula is:

$$E(G_i*) = \frac{\sum_j w_{ij}(d)}{n-1} \qquad \text{(Equation 6.3)}$$

The GIS-based statistical analysis calculates the *Z*-score for each feature at distance (d), a high value indicates high similar attributes among neighbours, and a low value indicates low similar attributes. The aim of identifying clusters of similar high or low values is to determine the statistical significance of the Z-score. At a confidence level of 95%, for example, a *Z*-score would have to be less than -1.96 or more than 1.96 to be accepted as being statistically significant. Therefore, the individual values of G_i* that have been derived can be mapped in ArcGIS, to show clusters of high or low *Z*-scores (Mitchell, 2005, Wong and Lee, 2005).

Finally, an attractive feature of this method is in the computationally efficient combination of the original G_i* statistic and the *Z*-score for use as a single measurement. The Getis-Ord G_i* statistic has same interpretation as the *Z*-score, if the local sum is much different from the expected local sum, the difference is too large to be the result of random chance, and thus a statistically significant Z-score results. The Getis-Ord G_i* statistic is a derivative of equations 6.1 to 6.3 (Ord and Getis, 1995).

6.5.2.1 The Application of the Getis-Ord Gi* Statistic

One of the most significant objectives of this thesis is to define the locations of segments of a pipeline alignment with unexpectedly high occurrences of TPI in relation to the distance from nearby roads, rivers, and villages as variables. The ArcGIS 9.3 Getis-Ord Gi* (d) statistic approach (equation 6.1) ,described in section 6.5.2, is one of the more practical ways of identifying statistically significant high or low attribute values as clusters using data points of TPI incidents. Since pipeline TPI data shows geographic patterns based on occurrence location, spatial statistical techniques were considered as being an effective tool for analysing such patterns.

The ArcGIS Network Analyst extension tool was used to generate and model *the network spatial weights* matrix (described in Section 6.5.1) in order to represent the spatial structure of the pipeline network in the study area. This tool uses, as point feature class, the geographical location of pipeline incidents and the linear pipeline network dataset in order to generate the spatial weights quantifying distances and the degree of proximity between each and every other pipeline incident (Getis and Aldstadt, 2004, Haining, 2003). The spatial relationships, based on the spatial weights matrix calculations are thereafter used in further statistical analyses, for example, the spatial autocorrelation (Moran's I) and hotspot analysis (Getis-Ord Gi*). This procedure is necessary in order to remove the uncertainty regarding spatial interactions between each incident along a linear pipeline network.

Subsequently, the Getis-Ord Gi* (d) statistic method was used to statistically show significantly high and low relative hot-segments in pipeline alignment. This was performed with the analytical spatial statistical tool in ArcGIS, using the Getis-Ord Gi* algorithm. This tool required various input fields, these include: input feature class (pipeline incidents); input field (weights: distances from villages, roads and rivers); and conceptualization of spatial relationships from the *network spatial weight* matrix file described in Section 6.5.1. The network spatial weight matrix defines the spatial relationships and improves the statistical computation performance. In addition, different applications of the GIS, such as the map calculator, buffer and network analysis were applied to the datasets. The hotspot analysis (Getis-Ord Gi*), like other local spatial autocorrelation statistics (e.g. cluster and outlier analysis, and Morans I), does not use individual incidents but rather uses weighted points. Therefore, the distances from roads, rivers, and villages were employed as the relevant weights for the analyses.

6.5.3 Geographically Weighted Regression (GWR)

In this thesis, the geographically weighted regression (GWR) method was used to examine the significance of geographical accessibility to pipelines, especially vulnerable pipeline segments. This approach also shows spatial variations of the exploratory independent variables, especially since accessibility to pipelines is a function of distance. In this thesis, geographic access to the pipeline was evaluated by using the travelable distance (i.e. the relative ease of access distance) to the pipeline as a dependent variable; to explore the connection, the distances from rivers, roads, and villages to the pipeline were used to measure accessibility. The assumption is that the when pipeline networks are less accessible, interference becomes difficult, and might discourage intentional interference. This means pipeline segments with limited and physically difficult access are relatively safe and less exposed to interference opportunities, especially intentional interference (Brantingham and Brantingham, 1984). Brunsdon and Corcoran (2006) also discusses how criminal tendency is a product of motivated offenders and suitable targets, hence, if adequately studied and examined, can facilitate and promote appropriate preventative measures.

In addition to proximity and geographical accessibility, the intrinsic properties of the pipeline itself are important factors for consideration in evaluating TPI. For example, numerous studies have describe the influence of pipeline age and diameter on failures of pipelines (Section 5.8), therefore there is a potential for reducing TPI by altering these variables, albeit at the design and installation stages. Therefore, based on the availability and nature of data for analysis (point data), the age and diameter of pipelines were used as additional independent variables for inclusion into the model. The inclusion of these two additional variables is based on the assumption that its knowledge determines the attack strategies of saboteurs (intentional interference). Most intentional interference reflects the character of easy of accessibility, first because they are not a random attack, and second because they are always reasonably well planned, that does indicate some prior knowledge of the intrinsic properties of the pipeline.

The ArcGIS hotspot analysis using the Getis-Ord Gi* (d) statistic, described in section 6.5.2 and so far, examines the spatial patterns of the pipeline incidents to determine pipeline segments that persistently experience TPI as shown by the clustering of a higher than expected proportion of incidents in the study area. However, the most important question involves asking why these particular segments of pipelines TPI. What might be causing this? What other factors contribute to a higher than expected TPI? How can mitigating actions that will reduce interference be identified and implemented? To answer these questions a potential approach is to use the Geographically Weighted Regression (GWR) technique, which is a *local* version of the popular Ordinary Least Squares (OLS) regression technique that models, examines, and explores spatially varying relationships among sets of variables. For example, it could enable a pipeline operator to understand the major characteristics of these contributory factors to assist in designing legislation and mitigation measures aimed at protecting pipeline facilities.

6.5.3.1 The Basics of the Geographically Weighted Regression (GWR)

The Geographically Weighted Regression (GWR) technique is an extension of the Ordinary Least Squares (OLS) regression model where parameters vary by location. It is a modelling technique that is used for analysing spatial data, where the measurements of local relationships are mapped spatially. The GWR is not limited to global models, as is the OLS, and allows it to be rewritten as (Fotheringham, Brunsdon and Charlton, 2002):

$$y_i = \beta_0 + \sum_k \beta_k x_{ik} + \varepsilon_i \qquad \text{(Equation 6.4)}$$

In equation 6.4, x_{ik} are observations for $i = 1,..,n$ cases and $k = 1,..,m$ independent variables, y_i is the dependent variable, β's are the estimates of the coefficients, and ε's are the normally distributed error terms. In this thesis, n equals 266, the total number of pipeline TPI incidents in the overall study area, the independent variables x_{ik} are distance variables (proximity distances to pipeline); shortest distance from villages to a pipeline incident; shortest distance from rivers to a pipeline incident; diameter of pipeline; shortest distance from roads to a pipeline incident and age of pipeline at time of incident. The dependent variable, y_i, is the geographical shortest accessibility distance of a ‘third party’ to a pipeline (MinDist).

In order to identify the geographical coordinates, the standard x and y coordinates of a point, Fotheringham, Brunsdon and Charlton (2002) showed that:

$$y_i = \beta_0(u_i,v_i) + \sum_k \beta_k(u_i,v_i)x_{ik} + \varepsilon_i \qquad \text{(Equation 6.5)}$$

In equation 6.5, (u_i,v_i) are the x and y coordinates of the ith point in space, and $\beta_k(u_i,v_i)$ are spatially varying, continuous functions at point i. In this thesis, the coordinates of the ith point correspond to the particular geographic location of a pipeline TPI incident. Furthermore, Fotheringham, Brunsdon and Charlton (2002) showed that $\beta_k(u_i,v_i)$ is:

$$\hat{\beta}(u_i,v_i) = (\mathbf{X}^T\mathbf{W}(u_i,v_i)\mathbf{X})^{-1}\mathbf{X}^T\mathbf{W}(u_i,v_i)\mathbf{y} \qquad \text{(Equation 6.6)}$$

Where $\mathbf{W}(u_i,v_i)$ is an $n \times n$ matrix in which the off-diagonal elements are zero and the diagonal elements denote the geographical value of each n observed data for a given regression point i. Using the standard regression equation in matrix form, $\mathbf{Y} = \mathbf{X}\beta + \varepsilon$ and $\hat{\beta} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{Y}$. Hence, the GWR equivalent is as given in equation 6.7 below:

$$\mathbf{Y} = (\mathbf{b} \otimes \mathbf{X})\mathbf{1} + \varepsilon \qquad \text{(Equation 6.7)}$$

Where the *tensor operator* $'\otimes'$ means that each element of matrix **b** is multiplied by the corresponding element of **X.** Therefore, for n data points and k independent variables, dim(x) = $n \times (k+1)$ and $\mathbf{1}$ is a $(k+1)\times 1$ vector of 1's. Therefore, **B** is given as:

$$\begin{bmatrix} \beta_0(u_1,v_1) & \beta_1(u_1,v_1) & \ldots & \beta_k(u_1,v_1) \\ \beta_0(u_2,v_2) & \beta_1(u_2,v_2) & \ldots & \beta_k(u_2,v_2) \\ . & & & \\ . & & & \\ . & & & \\ \beta_0(u_n,v_n) & \beta_1(u_n,v_n) & \ldots & \beta_k(u_n,v_n) \end{bmatrix}$$

Thus, the estimated parameters in each row are obtained with equation 6.8:

$$\hat{\beta}(i) = (\mathbf{X}^T\mathbf{W}(i)\mathbf{X})^{-1}\mathbf{X}^T\mathbf{W}(i)\mathbf{y} \qquad \text{(Equation 6.8)}$$

In equation 6.8, $\boldsymbol{y}$ is a location-based weighted least squares estimator, and i is a matrix row, while the $\mathbf{W}(i)$ is an $n \times n$ spatial weighting matrix: $\mathbf{W}(i)$, and is given as:

$$\begin{bmatrix} w_{i1} & 0 & \cdots & 0 \\ 0 & w_{i2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & w_{in} \end{bmatrix}$$

Where w_{ij} is the weight given to a data point *j* in the calibration model for location *i.*

6.5.3.2 The Application of Geographically Weighted Regression

According to Brunsdon and Corcoran (2006), *"people travel along known activity pathways to nodes around which the offender searches for potential targets".* Therefore, the dependent variable in modelling the determinants of accessibility to a pipeline, in this thesis, is the shortest possible accessibility distance for a 'third party' to travel to the pipeline **(MinDist).** The independent variables are: (i) shortest distance from villages to a pipeline incident site (DistVlg); (ii) shortest distance from rivers to a pipeline incident site (DistRiver); (iii) diameter of pipeline (DiaPipe); (iv) shortest distance from roads to a pipeline incident site (DistRoad); and (v) the age of pipeline at incident (AgePipe). This thesis hypothesised that the occurrence of TPI is a function of geographic accessibility to pipeline, and is is directly proportional to the age and diameter of a pipeline; and inversely proportional to the distances from roads, rivers, and villages. The relationship between the age and diameter of a pipeline and the occurrence of TPI has been widely investigated (Section 5.8).

The first set of analyses conducted before the application of the GWR technique was to examine the statistical and spatial relationships between the variables. Accordingly, descriptive statistics and a Pearson's product moment correlation were used to determine initial characteristics and relationships between all the above variables. The data for the model were transformed to meet the assumptions of statistical analysis, using SPSS 17 procedures. The distances from rivers, roads and villages do not conform to a normal distribution, and the distributions are generally positively skewed and display various degrees of *kutosis*, leaving no option but to transform the data. The most appropriate transformation method is the natural logarithmic method. Therefore, the correlation analysis between the variables was to determine their suitability as reasonable predictors of geographic accessibility to a pipeline network, especially to detect the absence or presence of multicollinearity.

On completion of the preliminary descriptive analysis and the Pearson's correlation analysis, the variables were fitted into the GRW procedure using the ArcGIS 9.3 facility. It was decided, following Charlton and Fotheringham's (2005) study, that the best method to adopt for this model was to use the spatial kernel as a geographic weighting tool, and with a coefficient that also controls the size of the kernel. The density of the data in the study area was considered to be clustered by visual observation of the TPI occurrence in the data; hence ADAPTIVE kernel method of the GWR-ArcGIS tool is appropriate. The ArcGIS tool provides various choices for selecting the bandwidth (the width of the range of point data that can be used for a given set of analysis); however, the automatic method for finding the bandwidth was the preferred choice after Charlton and Fotheringham's (2005) rationale that it gives the best more meaningful predictions.

6.6 The Development of Multivariate Statistics Model

Multivariate statistics are a collection of procedures for use in analysing, exploring, examining or manipulating two or more independent variables at a time. The multivariate statistics approach was chosen because pipeline third-party interference is characterized by many correlated variables interacting with the pipeline's intrinsic properties. Therefore, the methodology employed here consists of the application of three techniques, namely, the Principal Component Analysis (PCA), the Generalised Linear Model (GLMs) and the Logistic Regression (LR) analyses, in order to develop a statistical base from which to predict and estimate the likelihood of third-party interference at vulnerable pipeline segments.

6.6.1 Factor Analysis: Principal Component Analysis

The Factor Analysis (FA) method is a statistical approach that analyses the structure and correlations among a given set of variables to identify various dimensions of the structure of the body of data and to determine how each variable is explained by each dimension. The objective of FA in this thesis is to reduce the number of independent continuous variables by summarizing the important information contained in a set of variables by a smaller number of factors. This technique allows for the grouping of the variables into a smaller set of underlying factors. The overall aim is to identify the significant information in the data: (i) to find out the statistical variance of each variable, which is the measure of the variability of the variables across dataset; and (ii) to identify if these variables can be grouped and decreased into a smaller number.

The dataset considered for the thesis, for each of the 151 spatial units described in Section 6.4, consists of twenty-five independent variables collected between 1999 and 2004. However, the use of large numbers of variables make examining the patterns of relationships among these variables difficult; this is in addition to the fact that some variables are likely to repeat essentially the same information indirectly. The FA method of Principal Components Analysis (PCA) was used to solve these problems by simplifying and reducing the dimensionality of the set of multivariate data, and to produce a smaller number of significant variables. This procedure ensures that the selected *principal components* (factors) accounted for the larger percentage of the total variance. However, all of the variables that are pipeline related and are intrinsic were excluded from the PCA analysis. These variables are:

- Total length of pipeline
- Average pipeline external status (buried or aboveground)
- Average pipeline diameter
- Average age of pipeline
- Presence of local oil and gas facilities
- Percentage of oilfield and wells

The ten types of derived land use characteristics of the study area, based on the classification system of ILLC model, were also excluded from the PCA because they were considered integral part of the objective of the study, and especially because relevant research conducted for TPI have always acknowledged their influence. The thesis primarily concerns pipeline TPI, and based on a review of the literature, the following variables were also omitted from the reduction and simplifying process. This is because they are considered important and a major significant variable to the occurrence of TPI, especially as they pertain to accessibility: (a) total road length per each areal unit; (b) total river/stream lengths; and (c) population density. The geological types, ethnicity, and geopolitical locations of the study area were also excluded due to effect of spatial autocorrelation, namely: geological type; ethnicity; and geopolitical location.

The general characteristics of the excluded variable are perceived significant to the occurrence of TPI and because they do not exhibit similar associations or measure similar theme. However, the following remaining eleven continuous variables were subjected to the PCA analysis, mainly because they are assumed be correlated using the SPSS PCA procedure:

- Average daily household income
- Percentage literacy
- Capital expenditure (revenue allocation by government)
- Percentage of household with electricity
- Percentage of household with pipe borne water
- Life Expectancy Index (LEI)
- Gross Domestic Product (GDP)
- Human Development Index (HDI)
- Gender-related Development Index (GDI)
- Gender Empowerment Measure (GEM)
- Human Poverty Index (HPI), for developing countries.

6.6.2 Theoretical Considerations of Generalised Linear Model

The general and conventional linear regression model is not adequate to model or describe discrete and non-negative variables that are typical of sporadic events such as pipeline failures, particularly TPI. This is because such records generate count data, and failure frequency inventories that are always either zero or a positive integer. Zeros populate the distribution of such data because one cannot count or even recognise a negative number of failures. In addition, when the number of failure events counted is low, the frequency distribution of failures is likely to be a highly non-normal distribution, and statistically right-skewed, with a majority of observations near zero or otherwise. This type of distribution follows a Poisson distribution.

A Poisson distribution is the foundation of most statistical regression models. One of the objectives of this thesis is to use Poisson GLMs distributions to establish an explicit relationship between the various factors influencing TPI (land use type, socioeconomic, socio-political parameters, etc). The general framework for the Poisson distribution and GLMs are the underlying assumptions presented in the following sections.

The GLMs procedure is an extension of the linear regression model, where a dependent variable Y is linearly associated with a series of independent variables X (Agresti, 1990). The dependent variable can be non-normal, continuous or categorical. The GLMs is specified as:

$$Y= \beta_0 + \beta_1 x_1 + \ldots + \beta_p x + \varepsilon \qquad \text{(Equation 6.9)}$$

Equation 6.9 shows the estimated regression coefficients as β_1, β_2 ... β_p and the first part of the right-hand side of the equation ($\beta_0 + \beta_1 x_1 + \ldots + \beta_p x$) specifies the expected value of y given $x_1 \ldots x_j$. This is called the 'mean' part of the equation and contains a linear combination of x variables. The ε in equation 6.9 is the error variability that cannot be accounted for by the dependent variables. Therefore:

$$Y = \beta_0 + \sum_{j=1}^{P} \beta_j X_j + \varepsilon \qquad \text{(Equation 6.10)}$$

Where Y is the dependent variable, an occurrence of TPI; and X are independent variables, for example, pipeline segment, population density, land use type, etc. In equation 6.10, the β is the unknown parameters; and ε is the error term, and the expected value of Y can be calculated by using equation 6-11:

$$E[Y] = \mu = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \qquad \text{(Equation 6.11)}$$

Therefore, μ, in equation 6.11, is the expected value of Y. For example, it is possible to estimate and model (i.e. predict) an occurrence of pipeline TPI as a function of a combination of land use types, pipeline geometry, failures count data, socio-economic, socio-political and pipeline variables. However, in the *GLMs*, the relationship between $E(Y)$ and μ is defined by a non-linear link function called g(μ), which could be alternatively defined as either *Poisson, Normal, Gamma, Inverse Normal, Binomial, or multinomial* distributions. Thus, we introduce the non-linear link function into equation 6.11, and we have the expected value of Y as:

$$E[Y] = g(\mu) = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \qquad \text{(Equation 6.12)}$$

The link function for *Generalised Linear Poisson Regression* as specified from equation 6.12 could be written as:

$$Ln(\mu) = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \qquad \text{(Equation 6.13)}$$

The values of the parameters, from β_0 to β_j are obtained using Maximum Likelihood Estimation (MLE) procedures. The MLE determine maximize the probability the parameters of the sample data, and usefull for estimating good statistical properties and considered more to different types of data (Agresti, 1990). The *Generalised Linear Poisson Regression* (*Poisson GLMs*) requires that the ratio of the deviance to degrees of freedom be approximately 1 to avoid biased coefficient estimates. If the model's variance is greater than the mean, the model is considered overdispersed, and if the variance is less than the mean, the model is underdispersed. In an overdispersed model, *Negative Binomial Regression* models can be used (Agresti, 1990).

6.6.3 Application of the GLMs to the pipeline data

The selected study area consists of 16 political wards that were disaggregated, divided into 151 units (Figure 6-3). Section 6.4 addressed the issue of dividing the study area into useable spatial units for the analyses. In order to evaluate and test the variables that are considered to influence the occurrence of pipeline TPI and if and how they contribute as prediction parameters, the GLMs model (using the log link function), was developed using the SPPS GENLIN procedure. The exponential distributions family, the Poisson GLMs distribution was then used as a first step to fit the model.

The Poisson distribution describes the number of events that will occur over a certain time interval, and will approximate a binomial distribution when the binomial parameter *p* is small. If an event occurs randomly and within a unit time interval, on the average, there will be λ occurrences. Hence, the number of occurrences *m* in time *t* will be given as:

$$m = \lambda t \qquad \text{(Equation 6.14)}$$

Assuming that the numbers of occurrences in different time intervals is independent, we could use the assumption that the probability of observing ***r*** events in time ***t*** will be given as P(r,t). In a considerable time interval Δt, of such duration that it may contain one random event but the probability of it containing more than one event is negligible. Thus the probability of one event in this interval is $P(1, \Delta t) = \lambda \Delta t$ and conversely, the probability of no events in this interval is $P(0, \Delta t) = 1 - \lambda \Delta t$. Assuming independence of occurrences, the formula for the Poisson distribution could be given as:

$$P(n,t) = e^{-\lambda t} \frac{(\lambda t)^n}{n!} \qquad \text{(Equation 6.15)}$$

The application of the Poisson GLMs to the available data results in the value of the deviance's ratio to its degrees of freedom was greater than *1*, and this suggests some overdispersion in the model. Thus, the overdispersed Poisson model was fitted and redefined using a Negative Binomial distribution for the dependable variable. Table 6-4 shows the twenty-three variables used for the development of the GLMs model.

6.6.4 Logistic Regression Analysis

The methodology for employing the Generalised Linear Poisson Regression (Poisson GLMs) for predicting the numbers of occurrences of TPI has been described previously. However, the problem is that pipeline operators are more specifically interested in the risk and the likelihood of TPI in segments of their pipelines, or in a local region, than the numeric numbers of TPI. The knowledge that a segment will experience or not experience TPI is invaluable. Therefore, a model for the prediction, in addition to predicting the numbers of occurrence, to determine this potential of risk should be robust, and without any misspecification. This robustness can be achieved with the aid of LR.

Table 6-4: The list of variables used in the multivariate statistical analysis.

Short Name	***Description***
Numb	Numbers of Pipeline Third-party Interference
PcBW	Percentage of Household with Pipe Borne Water
PcLt	Percentage Literacy
HDI	Log of Human Poverty Index for developing countries (HPI-1)
OilF	Area of Oilfields/Wells
PiLe	Total Length of Pipelines
RvLe	Total Length of Rivers and Major Streams
RdLe	Total Road Length
PopD	Population Density
Age	Average Pipeline Age
PDia	Pipe Diameter
PiSt	Pipeline Status(aboveground or buried)
Geol	Geology Classification
wb	% LandUse: Water Bodies
esd	% LandUse:Evergreen semidecidous forest
mvc	% LandUse:Mosaic vegetation / cropland
tsg	% LandUse:Thicket, Secondary Growth
mbw	% LandUse:Marsh brakish water
cgl	% LandUse:Closed grassland
glf	% LandUse:Mosaic grassland/forest or shrubland
blf	% LandUse:Broadleavedforest
sbl	% LandUse:Shrubland/grassland
mfc	% LandUse:Mosaic forest / cropland

In statistics, LR is a predictive analysis method, involving the prediction of a dichotomous dependent variable (independent variables can also be continuous or dichotomous). Logistic regression is similar to Ordinary Least Squares (OLS) regression, except that OLS is unsuitable for use with a dichotomous variable as the dependent variable. Logistic Regression, however, can predict a discrete outcome, for example, a pipeline failure or the possibility of pipeline failure for a given series of regions within a pipeline network, from a dataset that may be continuous, discrete, or dichotomous. Although, similar to discriminant analysis and ordinary regression analysis methods, LR is more flexible. It does not fulfil the assumption of normality of the independent variables and it does not have a problem in predicting negative probabilities.

Logistic Regression predicts probabilities between 0 and 1, using the *odds-ratio* (α) that indicates the number of times the probability of one region (with pipeline failures) is larger than the probability of the other region (with no pipeline failures). Thus, we could have:

$$\alpha = \frac{\mathrm{Y_i}}{1-\mathrm{Y_i}} \qquad \text{(Equation 6.16)}$$

In equation 6.16, $\mathrm{Y_i}$ = *P*(*pipeline TPI*), and is the probability that a region *i* will experience a pipeline third-party interference, and 1-$\mathrm{Y_i}$ = *P*(*no pipeline TPI*), and indicates the probability that a region *i* is unlikely to experience a pipeline third-party interference over a given period of time. For example, suppose region *i* has experienced pipeline TPI, such that *P*(*pipeline TPI*) = 0.8 and *P*(*no pipeline TPI*) = 0.2. Therefore, the calculations are that, it is four times more likely for region *i* to experience TPI than not to experience one. The *odds ratio,* α lies between 0 and infinity. This result from equation 6.16 is generally restricted, and therefore a *logit* $\mathrm{L_i}$, a natural logarithm of the odds ratios is used to scale the dependent variable with an unlimited range. Thus:

$$L_i = \ln(\alpha) = \ln\left(\frac{Y_i}{1-Y_i}\right) \qquad \text{(Equation 6.17)}$$

In LR, based on equation 6.17, the logarithm function converts the parameters results of equation 6.16 into intervals of real numbers by a linear combination of the independent variables, and is given as:

$$L_i = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p$$ (Equation 6.18)

The *ln* symbol in equation 6.17 refers to a natural logarithm and $\beta_0 + \beta_1 x_1$ in equation 6.18 is the general equation of the regression line. Therefore, *P* can be theoretically calculated, by the expected probability that *Y* = 1 for a given value of *X*. Thus:

$$\hat{Y}_i = \frac{e^{L_i}}{1 + e^{L_i}} = \frac{\exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p)}{1 + \exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p)}$$ (Equation 6.19)

The LR approach, described so far, was chosen because it does not fulfill any assumptions of normality, linearity, and homogeneity of variance for the independent variables. Therefore, with the available data, the thesis evaluated the probability that a region (spatial unit) will experience pipeline TPI or will not. TPI was used as a binary outcome variable, and the odds ratio of TPI was estimated. The SPSS version 17.0 was used to conduct the LR analysis, in order to produce a mathematical combination of the variables that best predicts the probable occurrence of TPI. The SPSS direct logistic regression method was used to construct the model, and the *forward stepwise* procedure was used to check for agreement. This evaluates the quality and accuracy of our model. The SPSS estimates coefficients using the MLE method. The model reports coefficients that express the effect of changing one of the factors on the probability of the outcome, analogous to a linear regression model (*y* = *a* + *bx*) where changing *b* influences *y*.

The model's initial logistic regression output were in logodds, but in order to model the actual probability of a region experiencing TPI, they were converted into odds, by exponentiating (e^{logodds} = odds). Thus, determining the probability of occurrence is given as probability = odds/ (1+odds). Finally, the probability of occurrence was subtracted from 1 in order to obtain the probability of TPI occurrence (probability of TPI occurrence = 1 – probability of occurrence). The resulting model from the logistic regression analysis was redefined as data and was then exported into ArcGIS raster calculator to develop a vulnerability and probability graphic map.

6.7 Summary

This chapter have discussed the various methodologies and applications adopted for this thesis. The chapter explored and discussed the methods considered the most appropriate, as well as the reliability. The chapter describe three applications of GIS statistical analysis for hot spot identification; two GIS-based GLMs, the LR analysis and the Poisson GLMs. Another important aspect of the thesis was also presented in this chapter, which is the appropriate disaggregation of the study area into several geographical units in order to meet the required level of data. The next chapter, Chapter 7 utilised the methodologies presented in this chapter for the subsequent analysis of the in the thesis.

7 GETIS-ORD GI*AND GEOGRAPHICALLY WEIGHTED REGRESSION (GWR) STATISTICS

7.1 Introduction

In order to be able to manage the threat of pipeline third-party interference (TPI) and mitigate against it, a detailed knowledge of the occurrence patterns (particularly of intentional interference) is essential. This thesis, therefore, seeks to address these questions, and this chapter, in particular, presents and discusses the results of the analysis of the hotspot and pattern variations for the study area selected. The analyses were examined using the Getis-Ord Gi* (d) statistic and geographically weighted regression (GWR) described in section 6.5.2 and 6.5.3 respectively.

7.2 Result of the Spatial Neighbourhood Weights Statistics

This thesis used the *network spatial weights* matrix in order to limit the edge problem commonly associated with linear clustering (Section 6.5.1), particularly to determine appropriate and realistic spatial relationship among incidents, taking into consideration the linear nature of the pipeline (Steenberghen et al., 2004). The procedure that was employed created a binary *spatial weights matrix* file (swm) that defines the relationships among pipeline incidents, and the pipeline network itself. This procedure, according to Wong and Lee (2005), improves performance, optimizes the data processing, and reduces unnecessary calculations. Table 7-1 shows the summarised output of the spatial weights matrix file, following the example procedure described in Section 6.5.1; and Section 6.5.1.

Table 7-1: Summary output of spatial weights matrix from ArgGIS spatial modelling module.

- *Number of Features: 266*
- *Percentage of Spatial Connectivity: 3.01*
- *Average Number of Neighbours: 8.*
- *Minimum Number of Neighbours: 8*
- *Maximum Number of Neighbours: 9*

It was found that there was no significant change or difference between the results of the analyses carried out with or without the network *spatial weights matrix*. The results of hot segment analysis using the Getis-Ord Gi* and GWR statistics are not significantly different from the one using the binary spatial weights matrix file created. This result is surprising as it does not support the considered importance of the spatial attributes in the analysis of the pipeline incidents. This is because the understanding of the relationships and connectivity between pipeline segments is important in planning and in network spatial analysis. Wong and Lee (2005) concluded that the *"connectivity of links is the most fundamental attributes of a network",* because good spatial analysis relies on this phenomenon.

Figure 7-1: Map showing the pipeline network and the pipeline incidents in the study area.

The importance of network *spatial weights matrix* for analysis cannot be overemphasised, for example, in Figure 7-1, the pipeline segment '3' connects to the overall network, the clusters of pipeline segments in the west, and in the north; while pipeline segment '4', connects to the overall network, the clusters of pipeline segments in the east and in the north (Wong and Lee, 2005). If any of these segments is removed, the network will be divided into two or three separate systems; this analysis can determine the vulnerability of the entire network, and how the overall network will be protected. The aim of network spatial weights matrix analysis is to assess objectively the connectivity in a network.

It was, therefore, although not convenient, considered fundamental to use the created *spatial weights matrix* file in order to define the relationships among pipeline incidents, and fulfil the normal requirement for spatial pipeline network analysis. One of the most significant findings to emerge from the development of the network *spatial weights matrix* is that fewer links in a pipeline network make accessibility to a pipeline segment an easier task (Wong and Lee, 2005). An implication of this finding is that both the number of links and the degree of robust connectivity should be taken into account when planning a pipeline network in a region. In addition, prior to the spatial analysis of network data, the accurate visual and spatial connection of nodes and links (e.g. accurate snapping of vertices and nodes) is crucial to a successful implementation. However, the spatial data in this thesis were rather difficult to use, because they lack robust connectivity, therefore, the entire pipeline network was re-examined and carefully redrawn.

7.3 The Getis-Ord Gi* (d) Statistic

The Getis-Ord Gi* (d) statistic determines hotspots by relatively calculating the statistical significance of each feature in a dataset, by identifying whether a feature is of a high or a low value, relative to the value of neighbouring features. For example, a pipeline segment with high numbers of TPI is only recognised as a hotspot if it has high numbers of incidents and is surrounded by other incidents with high values. The results of this thesis, as discussed in this chapter, show that Getis-Ord Gi* (d) statistic successfully answers such questions as, *"where is the most vulnerable segment of a pipeline?"* using various proximity distances as factors.

7.3.1 Villages as the variable for hot/cold spot analysis

Figure 7-2 shows the output map of the Getis-Ord Gi* (d) ArcGIS analysis results for hotspot and cold spot occurrences of TPI using the *shortest distance to the nearest village* from an incident as the variable. The red segments shown in Figure 7-2 indicate statistically significant hotspots while the dark blue segments shows statistically significant cold-spots, both at 95 per cent confidence level. The measurement determining the statistically significance at the confidence level is the Gi*Z-score, measured in standard deviations, it indicates the direction of deviation from a distribution's mean. In other words, the large negative value of the Gi*Z-score (Section 6.5.2, equation 6.2) indicates that a pipeline incident (represented as a point feature), is surrounded by neighbours with dissimilar values. A large positive value indicates that surrounding values are similar. The larger value of the Getis-Ord Gi* (d) statistic means that the *shorter distances* from villages to pipeline incidents are found together (hot spots), and a small value of the Getis-Ord Gi* (d) statistic means *longer distances* away from pipeline incidents are found together (cold spots).

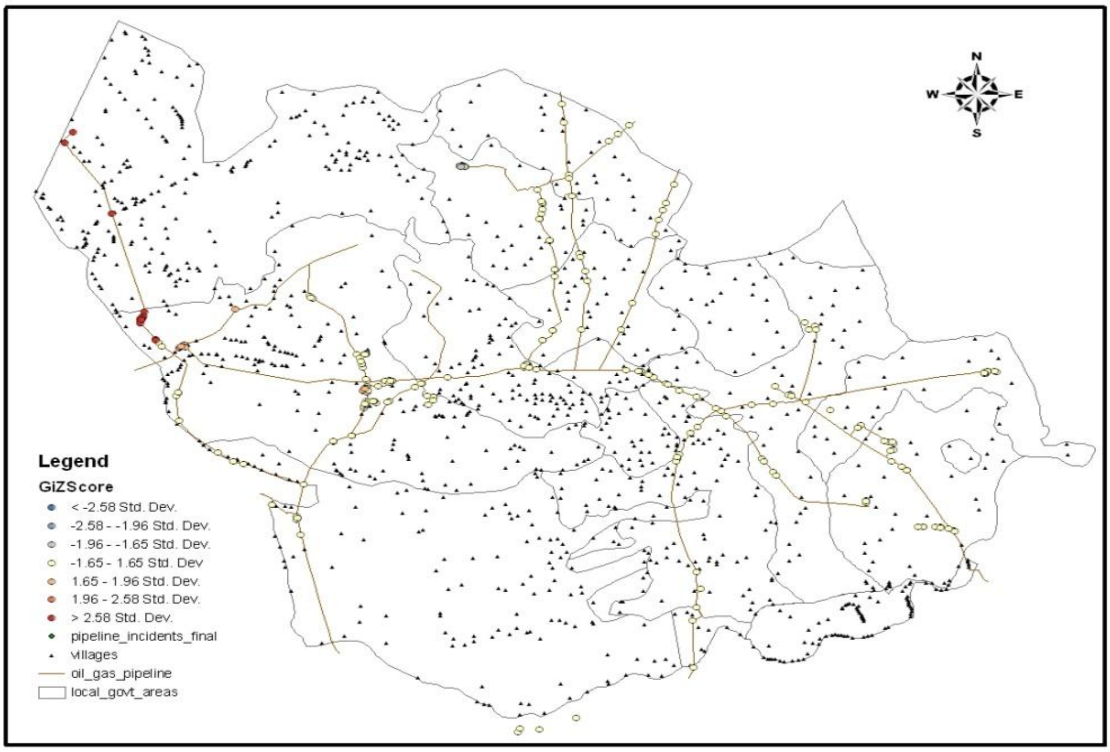


Figure 7-2: Getis-Ord Gi* (d) statistic output from ArcGIS using the shortest distance to the nearest village from an incident as the variable

After the data processing for the Getis-Ord Gi* (d) generated output of the Gi*Z-score map, an Inverse Distance Weighted (IDW) surface map was created. According to ESRI (2009), *"IDW is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell"*. The objective is to provide a visual understanding of the influence of the selected variable. The ArcGIS output map in Figure 7-3 shows the surface map that was created. The map indicates that pipelines in the western region of the study area (Warri North and Warri South-West) are at highest risk from TPI. The results from the Getis-Ord Gi* (d) statistic analysis is similar to variety of ways that hotspot have been measured, for example, the Kernel Density Estimators (KDE) method, a non-parametric density estimators (Silverman, 1998). However, the Getis-Ord Gi* (d) statistic is a more practical way and specific in identifying the underlying characteristic of the variable that drives the occurrence of events.

This result is quite revealing, the hot segments produced is perceived to be because the pipelines that lie in close proximity to shoreline villages are more vulnerable, possibly due to the additional effect of fishing boat and ship anchors interfering with the pipelines. It is apparent from the results that TPI at shorelines are hotspots, and this is especially so at *Madagho* in Warri Southwest local government of the study area (Figure 7-3).

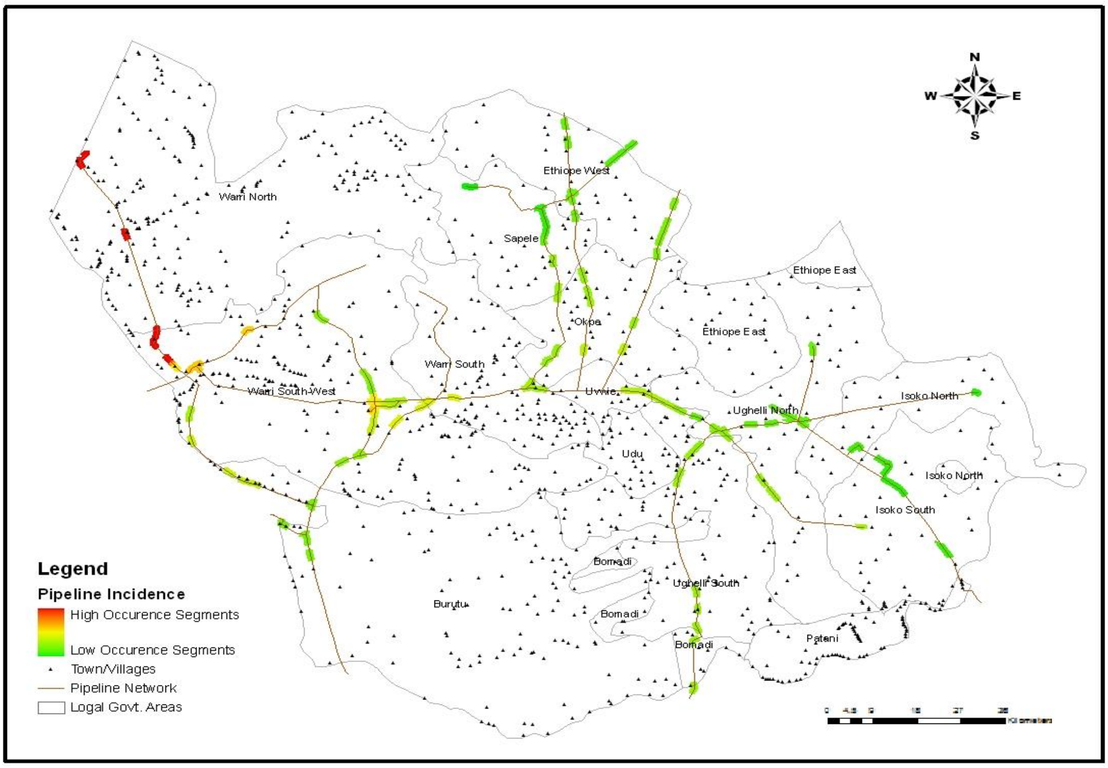


Figure 7-3: IDW surface output for hot and spot analysis using Getis-Ord Gi* (d) statistic GiZscore using the shortest distance to the nearest village from an incident as a variable.

These findings further support the view that local population density plays a significant role in determining and understanding the level occurrence of pipeline TPI. This is evident in Table 7-3, where, Warri North and Warri South-West account for the lowest share of the study area's population density, but with highest occurrence of TPI, compared to LGAs with high population density (e.g. Uvwie) with very low hotspots in the study area. Therefore, these findings do not support the assumption that high population density regions tend to have higher hotspots experience of pipeline TPI, as reported in most studies (e.g. Kash et al.(2004), Bilo and Kinsman (1998), and Sljivic (1995)).

Table 7-2: Population density of the study area, from the 1991 population census of Nigeria.

LGA	***Area (Sq. km)***	***Population***	***Density (Persons/Sq. km)***
Warri North	2187.98	49,635	22.68531
Warri South-West	1683.32	41,098	24.41485
Warri South	543.84	239,553	440.4843
Uvwie	97.69	141,669	1450.189
Udu	166.22	72,583	436.6683
Burutu	1907.99	169,077	88.61524
Ughelli South	783.85	139,349	177.7751
Bomadi	168.65	74,114	439.4545
Patani	277.86	34,213	123.1304

Another most striking observation to emerge from the analysis for hotspots using villages as a variable is that the hotspots are prevalent amongst the Itsekiri ethnic group, one of the major linguistic and ethnic groups of the Niger Delta. This ethnic group has been struggling for regional democratic and development reforms, especially with reference to the absence of educational facilities, health facilities, and infrastructure developments in the region. Therefore, this could be a major factor, in the motivation of these peoples to sabotage local pipelines (Ikelegbe, 2001, Ifeka, 2000). These findings suggest that, in general, accessibility to pipelines should be reduced correspondingly, possibly outside normal design standards and specifications. This will avoid the consequences of risk (e.g. pipeline explosion and fire) caused by the activities of peoples in the villages, especially those that are located at shorelines, and in close proximity to pipelines. Therefore, this risk, in a social approach, should to be communicated to both the local communities and the pipeline industries.

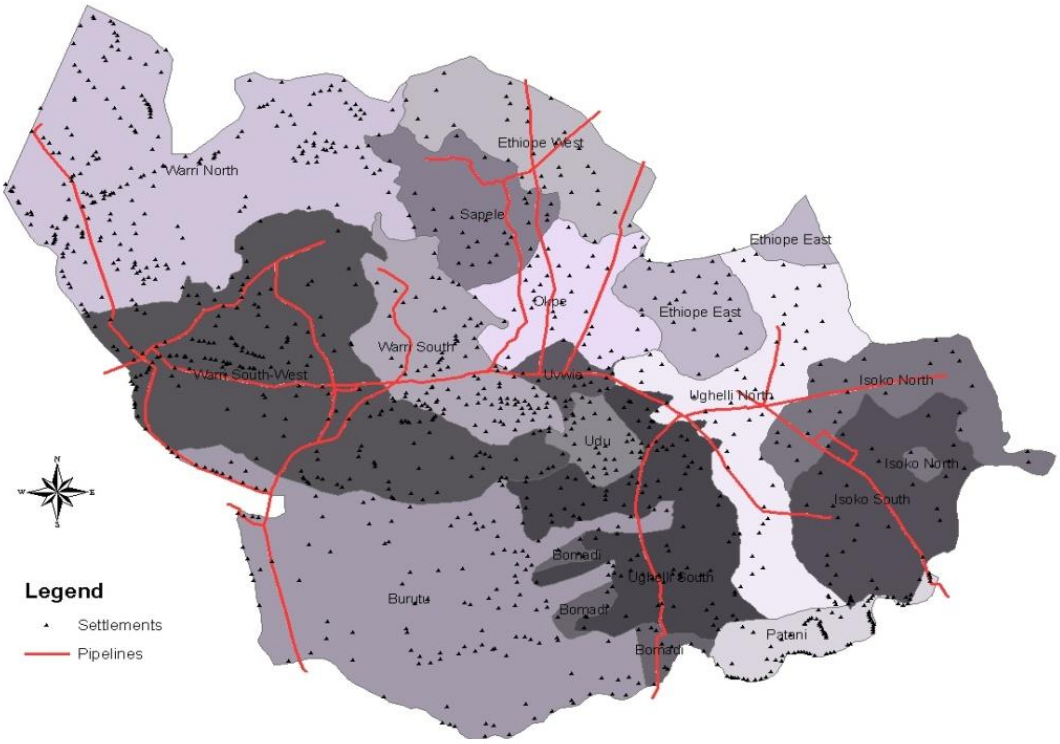


Figure 7-4: The distribution of villages in the study area, where the results of the hotspot analysis shows that hotspots are prevalent amongst the Itsekiri ethic group.

7.3.2 Distance to the Nearest River as the Variable for the Hotspot

The results of Getis-Ord Gi* (d) statistical analysis using the shortest distance to the nearest stream/river from an incident (pipeline TPI) as the variable is shown in Figure 7-5, along with the IDW surface output for both hot and cold spots being given in Figure 7-6. These maps present the spatial clustering of both high and low attribute values in the

Warri South-West and Ughelli North regions of the study area. There is a clear trend of the consistent occurrence of TPI in Warri South-West. As mentioned in the literature review, this area is criss-crossed largely by various rivers and streams, which can support people carrying vessels.

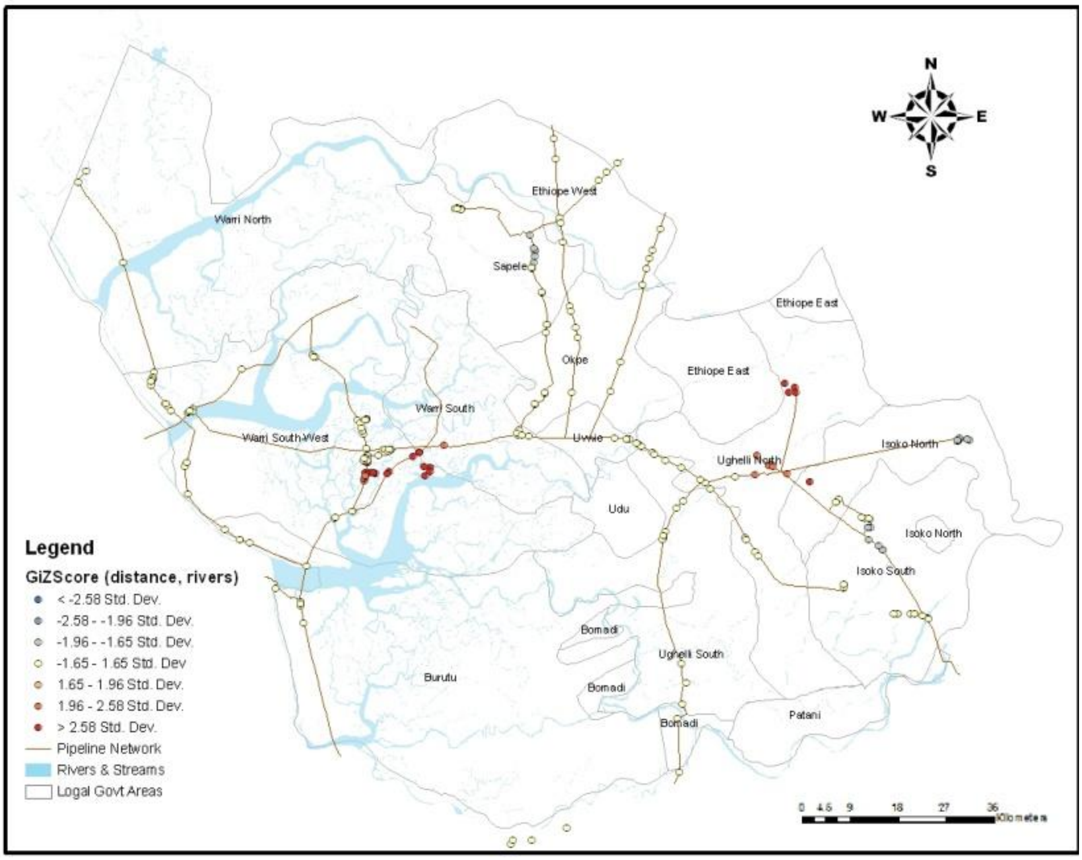


Figure 7-5: Getis-Ord Gi* (d) statistic output from ArcGIS using the shortest distance to the nearest stream/river from an incident as variable

In general, within the study area, there are approximately, 244 km of navigation channels for ocean-going ships (International Channels), 750 km of federal waterways and several hundred km of major and minor rivers and creeks that could provide various degrees of access to oil and gas facilities. Generally, physical obstacles such as shallow depths, sharp bends and shifting sandbanks, especially during the dry season, limit navigation, thereby preventing effective patrolling of the pipelines and facilities by law enforcement agencies.

It is apparent from the results that very few of the region's water bodies appear to exhibit a relationship between distances with the occurrence of TPI. Therefore, it is likely that any connection that exists between TPI and the hotspots are because significant proportions of these hotspots are in local regions without safe water. For instance, in Warri South-

West and Ughelli North only 33 per cent of the local population have access to pipe-borne water (Siraj, 2002). In some cases, some of the rivers that are the only source of drinking water in the region are polluted by hydrocarbons released from oil companies' facilities. This underdevelopment has led to growing vandalism in response to perceived injustice from both the government and the oil companies in the region.

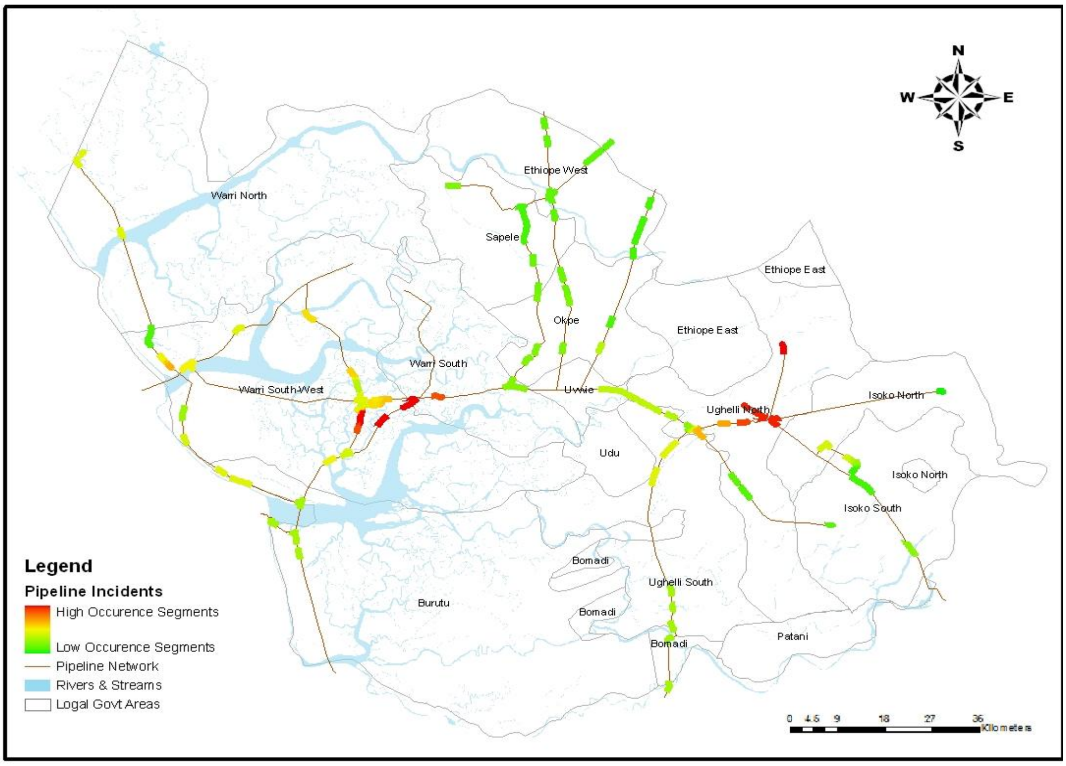


Figure 7-6: IDW surface output for hot and cold spots analysis using Getis-Ord Gi* (d) statistic GiZscore using the shortest distance to the nearest village from an incident as a variable.

There are, however, other possible explanations, especially for the inconsistent ratio of river density and the occurrence of TPI in the hotspot segments in Ughelli North, compared to other regions. This may be due to the unchecked proliferation of illegal structures sited in close proximity to pipelines and waterways, including local trader's activities along drainage channels in Ughelli North. The relationship between the occurrence of TPI and the river network in Ughelli North was unexpected, especially considering the fact that the LGA is one of the farthest from the coast and hence the least affected by the swampy conditions that are associated with the coast.

7.3.3 Roads as a Variable for the Hot/Cold Spot Analysis

The results of Getis-Ord Gi* (d) statistical analysis using the shortest distance to the nearest road from a pipeline incident as the variable can be seen in Figure 7-7, and the

IDW surface output for both hot and cold spots is shown in Figure 7-8. The Getis-Ord Gi* (d) statistic-generated map shows a very distinct and bias spatial pattern of clustering of third-party interference in regions with high road density. This shows that pipeline incidents in the study area are clustered in patterns that appear to signify that they are affected by road proximity to the pipelines. These spatial patterns of road proximity are predominant in the eastern part of the study area, as shown in Figure 7-7; and visual inspection of the map indicates that roads are almost non-existent in the most western part of the study area where the spatial patterns are clearly considerably lower.

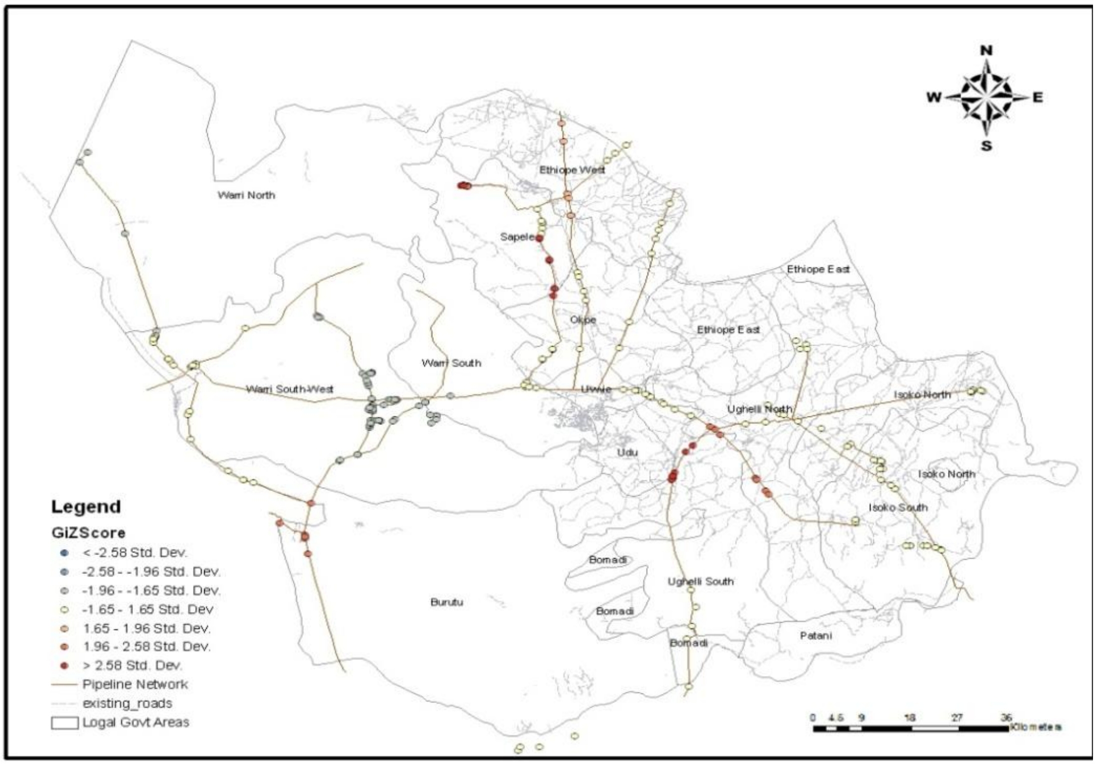


Figure 7-7: Getis-Ord Gi* (d) statistic output from ArcGIS using the shortest distance to the nearest road from a pipeline incident as a variable.

Sapele LGA (Table 7-7 and 7-8) shows significant presence of TPI hotspots. The major problem in Sapele LGA is, again, sabotage of pipelines as a form of protest (Agyeman et al., 2003), especially against the inadequate and inefficient economic movement of goods and services within, to, from and through the region. The existing road network is perceived as being inadequate to provide accessibility and connectivity to villages and towns in the LGA. However, this perception, as a justified reason (albeit immoral and illegal) to vandalise and sabotage pipelines has a number of limitations.

Table 7-3: Descriptive statistics summary by LGAs for roads, pipeline length, numbers of pipeline accidents, population 2002(estimates).

LGAs	**Populations**	**Road length**	**Road Density**	**%Literacy**	**pipeline length (m)**	**Electricity %**	**Nos. incidents**
Bomadi	98141.77	20533.74	4.78	78.32	18,798	99.00	3
Burutu	199795.82	94558.90	2.11	62.17	122,081	94.10	15
Ethiope East	178704.88	207235.90	0.86	76.89	0.00	41.30	0
Ethiope West	181196.88	371421.70	0.49	76.89	42,169.00	41.30	12
Isoko North	128297.95	336997.20	0.38	74.84	35,531.00	67.60	18
Isoko South	202663.68	382970.40	0.53	74.81	35,070.00	67.60	22
Okpe	115725.81	29461.70	3.93	87.19	85,210.67	30.30	12
Patani	46218.89	104206.95	0.44	67.00	6,898	43.85	0
Sapele	152980.32	20261.00	7.55	88.22	47,123.89	9.40	33
Udu	126832.81	213966.45	0.59	0.00	7,548.13	43.84	0
Ughelli North	168559.34	340010.03	0.50	80.37	88,592	52.00	21
Ughelli South	190082.64	28275.00	6.72	80.37	36,076.00	51.60	14
Uvwie	170410.08	171287.17	0.99	0.00	20,783	65.12	5
Warri North	122197.00	71770.00	1.70	88.54	35,902.18	12.60	4
Warri South	270041.13	201623.14	1.34	88.54	39577.54	13.40	12
Warri South-West	53203.80	49120.76	1.08	44.34	99,598.88	12.45	95

According to Siraj (2002), the creation of new roads in the study area cannot be justified only by the conventional reasoning of economic benefit, because the swampy terrain, that is the geo-physiographical and hydrological status of the study area, makes road construction difficult and relatively expensive. This is in addition to the fact that there are low levels of traffic in the study area. For example, the average road density in the study area, in terms of km/million population is 14, and the second largest road density by LGAs is observed in Ughelli South (Table 7-3), an area that has experienced high clusters of incidence as determined from the results of Getis-Ord Gi* (d) statistical analysis.

All of the studies reviewed so far, however, suffer from the fact that the absence of roads has considerably constrained economic activities in the region, and made access practically impossible for the effective socioeconomic development of the region. However, the objective should really be to assist the LGAs socially, so that they can improve their conditions and thus can contribute to the total regional development, and as a result possibly interfere less with the pipelines.

There are many reasons that emerge from the preliminary analysis of the road transportation network in the region, and that possibly could explain the occurrence of sabotage to pipelines as a form of protest. The road network in the study area is almost non-existent in most parts of the study area, according to Siraj (2002) the entire region *"lacks consistent pattern in the overall road network, for example, the total road length in Ughelli South is 428 km whereas in Warri South West it is only 8 km"*. Field assessments (site visit to the study area) also indicated that the general road conditions, especially in the hotspots of this analysis, are poor, with typically several potholes and damaged surfaces commonly found along any given length of road.

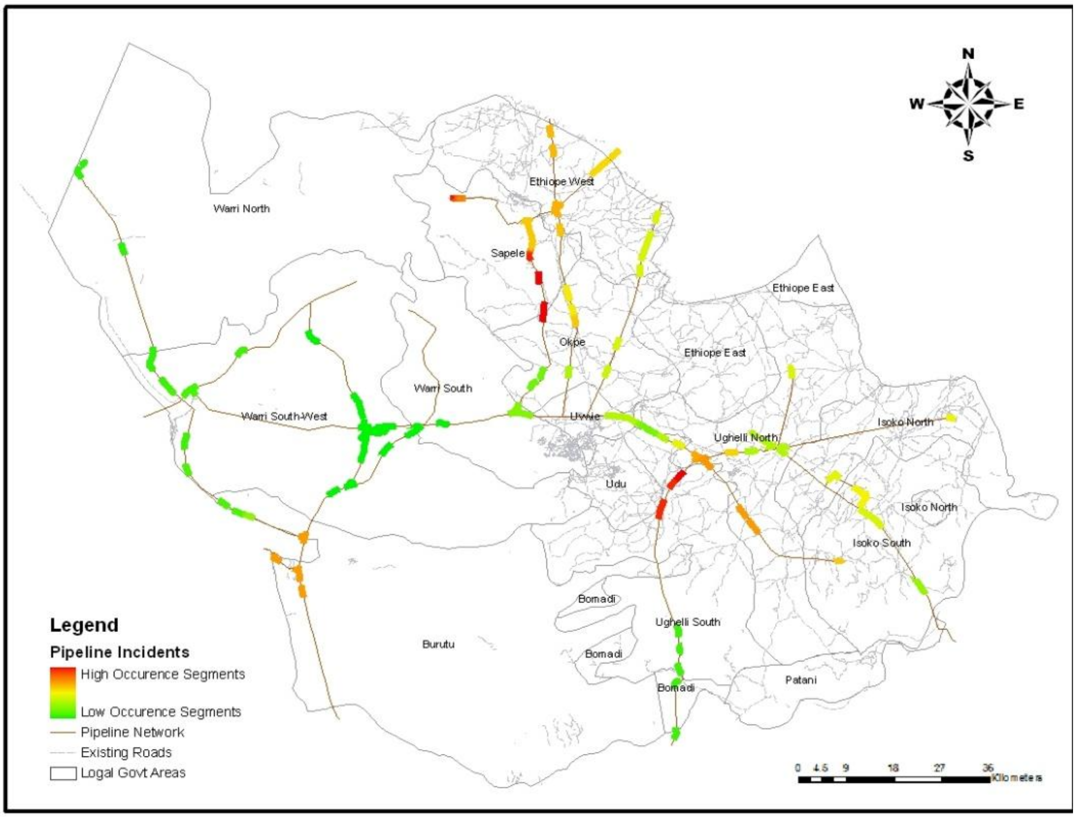


Figure 7-8: IDW surface output for hot and cold spots analysis using Getis-Ord Gi* (d) statistic GiZscore using the shortest distance to the nearest road from a pipeline incident as a variable

In conclusion, the result the Getis-Ord Gi* (d) statistic has gone some way towards enhancing the understanding of how the proximity of settlements and villages, roads and rivers influence the occurrence of pipeline third-party interference, and in how the Getis-Ord Gi* (d) statistic can be use to determine hotspot (hot-segments) for use in network surveillance activities. In addition, the Getis-Ord Gi* (d) statistic is showed to be suitable for investigating the minimum distance at which the proximity of pipelines should be positioned away from roads, villages, and rivers.

7.4 Results and Discussion from Geographically Weighted Regression (GWR) Model Analyses

Fotheringham et al. (2002) and the literature review in Section 6.5.3 discussed in detail the use of Geographically Weighted Regression (GWR) as a technique for determining exploratory spatial varying relationships between variables, based on the primary principle of the Ordinary Least Squares (OLS) regression. It was decided that it was the best method to adopt for this thesis, for investigating the spatial varying relationships between variables. In crime analysis, this technique is being widely used, for example, Cahill and Mulligan (2007) and Brunsdon and Corcoran (2006) have used the technique to explore local crime patterns, by exploring spatial patterns of crime using various independent variables. However, while geographical accessibility, using distances from villages, roads, and rivers was the only focus addressed by the Getis-Ord Gi* (d) statistic method, the GWR incorporates pipeline intrinsic properties (average pipeline age and diameters) as additional variables. This approach is to focus, in addition to the hotspots determination by the Getis-Ord Gi* (d) method, the local influence and relationships of the pipeline intrinsic properties as variables most directly related to TPI. The aim is to broaden the scope of important variables beyond only accessibility to pipelines, and to connect the targets (pipelines) and the means (various accessibilities) by exploring the relationships.

7.4.1 Descriptive Statistics of the Variables for GWR Statistics

This section examines the quantitative descriptions of the variables for inclusion in the analysis with the GWR statistics. This is the general first step in quantitative data analysis, and where the basic characteristics and statistical summaries about the variables are examined. The measurement for the descriptive statistics was performed using SPSS 17.0. The statistical summary for the variables are presented in the Figure 7-9. Skewness and *kurtosis* describe the shape of the distributions of the variables, and are zero if the distribution are perfectly normal; positive value for skewness indicate positive skewness, while negative value of *kurtosis* indicates a distribution that is flatter (Coakes, 2005).

Table 7-4: Summary descriptive statistics of each variable (shortest distances from village, rivers, and road combined to a pipeline) used in the subsequent analyses for determining hotspot of pipeline TPI incidents.

Variable Name	*DistVlg*	*DistRiver*	*DistRoad*	*MinDist**	*DiaPipe*	*AgePipe*
Mean	1598	1885	4336	408	13.8	7.86
Median	1354	974	940	301	12	8
Mode	3203	1194	57	57	8	1
Std. Deviation	995.73	2312.35	5767.68	367.05	5.83	4.69
Skewness	0.672	2.159	0.998	1.895	0.496	0.076
Kurtosis	0.249	4.455	-0.815	4.363	-1.053	-0.72
Minimum distance	69	45	23	23	4	1
Maximum distance	5923	10765	16902	1990	26	22

**MinDist= average shortest distances from village, rivers, and road combined to a pipeline, in metres (m)*

Table 7-4 illustrates the characteristics and descriptive statistics of the variables used in the GWR model, it is apparent that the average age of the pipeline in the study area is eight years and that the minimum combined distance from rivers, villages, and roads (MinDist) is relatively short compared to the average distances of each of these variables. It is interesting to note that the skewed nature of the data in the datasets as shown in Figure 7-9. However, GWR analysis requires that variables have multivariate normal distributions; hence the data were screened and transformed for normality prior to analysis with GWR.

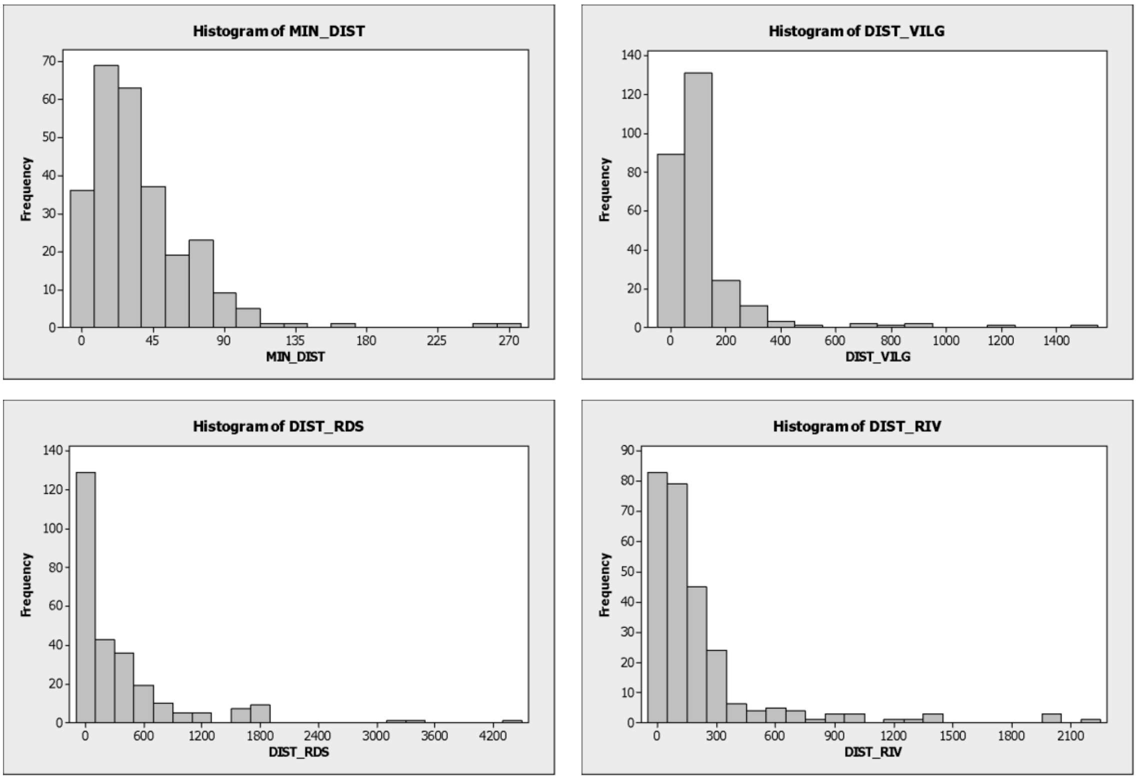


Figure 7-9 The graphs showing the histogram quantitative descriptions of the variables (min distance, distance from villages, distance from roads, and distance from rivers) for analysis with the GWR. It shows that the variables are highly skewed.

7.4.2 Correlation Analysis of Variables for the GWR

Correlation analysis between the independent variables, using the Pearson correlation technique, suggests there are initial relationships and associations in the variables that make them suitable as predictors of geographic accessibility to pipelines. In addition, the absence of *multicollinearity* (a situation of high degree of correlation in which two or more variables are highly correlated, r >0.9 and above) indicates that the factors are independent and hence suitable in the GWR model. The diameter and age of a pipeline are included because they are primary intrinsic properties of a pipeline and potential major contributing factors for the occurrence of TPI. The result in Table 7-5 shows the expected associations of the independent variables with the selected dependent variable. The application of GWR analysis does not like *multicollinearity*, hence the collinearity diagnostics analysis to show that the variables correlate substantially, not to high and not too low. The result in Table 7-5 shows no violation of the assumption of *multicollinearity*.

Table 7-5: Correlation coefficients between variables.

	DistVlg	***DistRiver***	***DistRoad***	***MinDist***	***DiaPipe***	***AgePipe***
DistVlg	1	.369**	-.432**	0.04	.241**	0.114
DistRiver	.369**	1	-.513**	-0.106	0.071	0.119
DistRoad	-.432**	-.513**	1	.577**	-.154*	0.093
MinDist	0.04	-0.106	.577**	1	.199**	.302**
DiaPipe	.241**	0.071	-.154*	.199**	1	-.310**
AgePipe	0.114	0.119	0.093	.302**	-.310**	1

***Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).*

7.4.3 Geographically Weighted Regression Model

The dependent and independent variables of the spatial dataset were fitted to the GWR procedures using the ArcGIS 9.3 software. The model uses the spatial kernel as a geographic weighting tool in models, and a coefficient that controls the size of the kernel. The density of the data in the study is clustered, and hence the ADAPTIVE kernel method, of the GWR-ArcGIS tool is considered to be appropriate. The ArcGIS tool provides various choices for selecting the bandwidth for the spatial data for analysis; however, the automatic method for finding the bandwidth was the preferred choice after ESRI (2010), as it gives the most accurate predictions.

Table 7-6 outlines the results of the analysis from the GWR-ArcGIS, the results contain general diagnostic statistics and a list of coefficient values. The 266 in Table 7-6 is the neighbours' value (numbers of pipeline TPI as spatial points) used in the estimation of each set of coefficients, and it indicates that each kernel used 100% of the dataset. In statistical terms, the *ResidualSquares* value is the sum of the squared residuals; the *EffectiveNumber* is a measure of the complexity of the model; and *Sigma* is the square root of the normalised residual sum of squares. Accordingly, the *AICc* is the corrected Akaike Information Criterion; and *R2* and *R2Adjusted* are indications of the goodness of fit of the model. A further definition of these terms, with example, is described by Fotheringham et al. (2002).

Table 7-6: Summary of the GWR analysis output.

Neighbours	266

ResidualSquares	61.76666
EffectiveNumber	11.50265
Sigma	0.492645
AICc	388.2947
R2	0.721837
R2Adjusted	0.710358

The results of the model diagnostics given in Table 7-6, indicate the multiple *goodness-of-fit* measurements for the model, for example, the *R2* and *R2Adjusted* values are 0.72 and 0.71 respectively. The *R2* value is a measurement of the proportion of the variation explained in the dependent variable, where values closer to *1* indicate a good predictive performance of the model. The *R2Adjusted*, as the name implies, is simply an adjustment of the *R2* value based on the numbers of variables. A value of 0.71 in the model indicates that it accounts for 71% of the variation in the dependent variable. This is satisfactory and shows the model has a strong predictive value. Using the ArcGIS tool, the output of the GWR analysis was visualised by mapping the StdResid (the standardised residual) coefficient estimates from the GIS attribute table of the output data. The objective is to spatially display pipeline segments with unusually high or low residuals and to see if they are spatially autocorrelated (Figure 7-10).

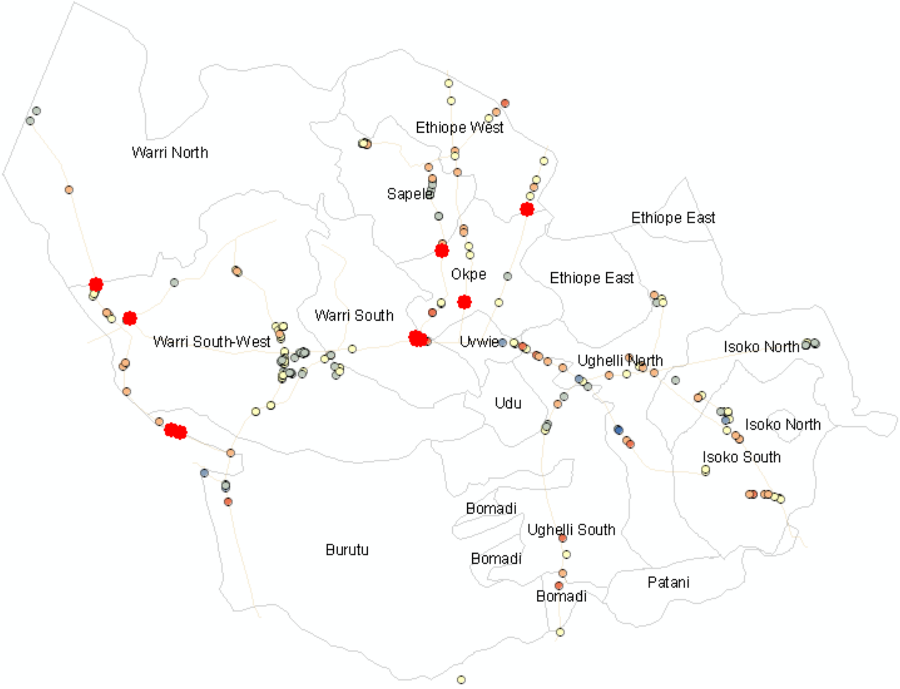


Figure 7-10: Map showing the visualisation of the standardised residual (StdResid) coefficients that identifies pipeline segments with high or low residuals in the study area, indicating possible misspecification.

Figure 7-10 provides the plot of the *StdResid* values obtained from the GWR analysis, and there are clear indications of hotspots of pipeline TPI. The red spots are the segments of the pipeline network with very large positive residuals (*StdResid* > 2) in the study area; they occur in Warri South, Warri South West, and Okpe. This would be expected as the pipelines that pass through these regions are relatively close to clusters of rivers, roads and villages. These segments of pipelines having locations with high positive residual values have diameters from 8inches to 12inches and their average age prior to interference is approximately seven years.

These independent results corroborate the findings of the previous analysis that was undertaken using the Getis-Ord Gi* (d) statistic to determine hotspots, as both analyses showed Warri South West as being the most vulnerable. However, the Okpe LGA, in this later analysis showed more hotspots than the two Warri locations combined. The findings of the current analysis are consistent with those of Onoiribholo (2005) who noted that the Okpe LGA experienced daily incidents of pipeline vandalism. For example, a pipeline explosion in 2000 resulted in the death of 250 people in this LGA. A further possible explanation for some of these results may be a lack of adequate maintenance and replacement of old aboveground pipelines in Okpe LGA.

7.5 GWR Local Coefficient Estimates of Variables

While the previous section presented a general collective overview of hotspots within the study area with a single combined consideration for all variables, in this section, the GWR local coefficient estimates associated with each of the independent variables considered in the model are extracted and mapped. The mapping of the GWR local coefficient estimates is a graduated surface colour rendering of the feature, which will help to understand the visual variation in the variables. Figure 7-11 to 7.15 inclusive shows the map patterns for the local coefficients from the GWR model analysis.

7.5.1 Spatial Variation of Distance from Villages to Incidents

The map for the local coefficients of *distance from village* variable reveals considerably varying influence, with a strong central-north direction orientation. The Inverse-distance weighted (IDW) contour plots of the GWR output for the local coefficient estimates shows a strong influence of villages in the northern part of the study area. The variation tends towards Ethiope West LGA from Sapele LGA. An implication of this is the possibility, that in the north, distances from villages to pipelines have a positive (statistically) relationship with TPI. There are similarities between the results expressed in Figure 7-11 in this thesis and those described by Chokor (2004), that growing restiveness in Ethiope West and Sapele has led to various conflicts between local communities and the oil companies. This has forced local people to vandalise pipelines, for example, in 1998, an oil pipeline explosion in the region killed over 1000 people who were scavenging petroleum products. However, more research, particularly a socio-economic investigation on the northward trend (towards Ethiope West) of the influence of this variable, needs to be undertaken in order to provide critical explanations of the results and to clearly understand the phenomenon.

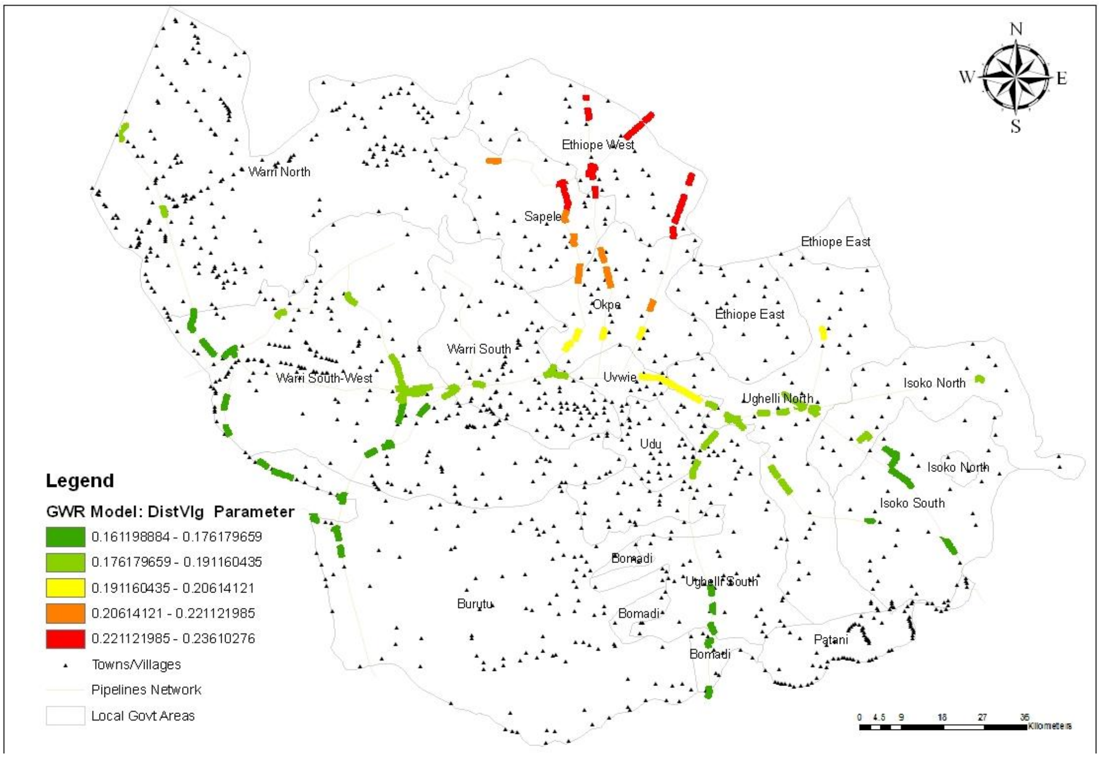


Figure 7-11: Inverse-distance weighted (IDW) contour plots of the GWR model for spatial variation of distance from villages to a pipeline incident (DistVlg).

7.5.2 Spatial Variation of Distance from Rivers to Pipeline Incidents

The IDW map of the GWR model for local coefficients of distances from rivers and streams to locations of pipeline incidents reveals the significant influence of this variable in the southeast of the study area.

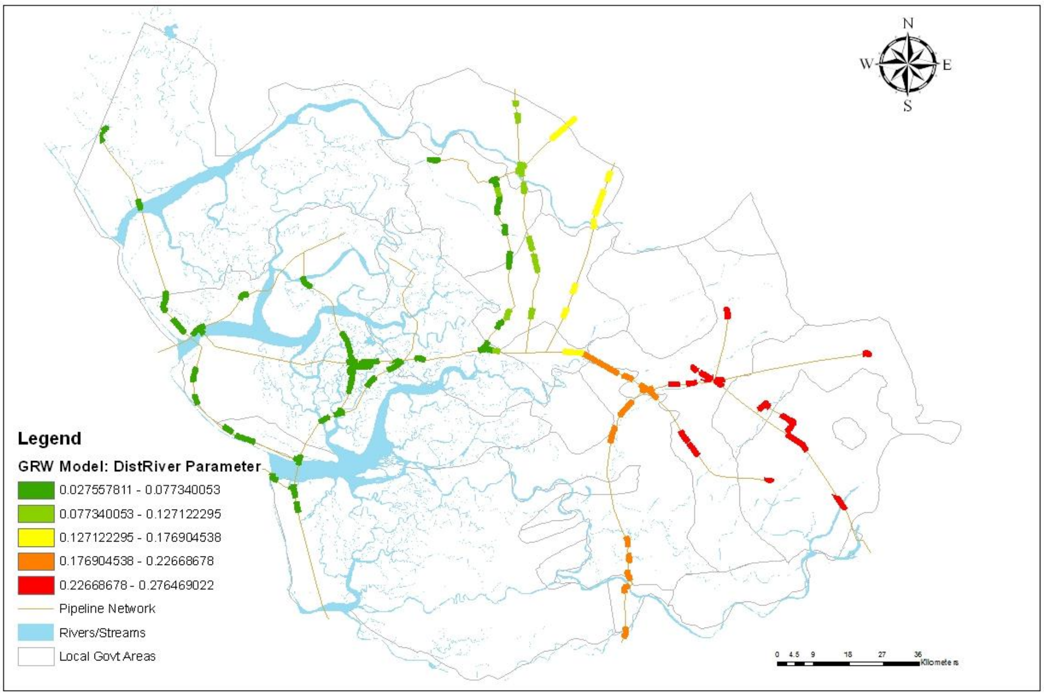


Figure 7-12: Inverse-distance weighted (IDW) contour plots of the GWR model for spatial variation of distance from rivers/streams to a pipeline incident (DistRiver).

The results are inconsistent in the expected influence of this variable in the western and northwest regions of the study area, where there are large numbers of rivers and streams. The reason for this result is not clear but one possible interpretation is that a village in the study area with limited numbers of navigable rivers tends to seek other means of accessing pipelines. This suggests that, when accessibility by rivers and streams are taken into consideration, deprived communities in the west and south of the study area tend to interfere less with pipelines than other regions in the study area.

The results also suggest that distances from rivers and streams to pipelines have a positive (statistically) relationship with TPI in the southeast of the study area, especially for pipelines in the central Ughelli North LGA and Isoko South LGA regions. Interestingly, these results are similar to those obtained from the use of the Getis-Ord Gi* (d) statistical analysis, made using the shortest distance to the nearest stream/river from an incident (pipeline TPI). In general, therefore, it seems that distances from rivers to pipeline positively influence the occurrence of pipeline TPI in Ughelli North LGA. Therefore, monitoring of activities along the rivers and navigable streams in this LGA could be a major factor in preventing or minimising TPI in this region.

It is possible, therefore, that activities such as fishing are a major contributing influence, especially since fishing is the major occupation of the region. The study area is in the floodplain formation of the Niger River, with productive water bodies for fish, and the fisheries resources of the Ugelli North LGA can be classified as freshwater and marine/brackish water and suitable for aquaculture (Siraj, 2002). These findings also corroborate the ideas of Berman et al (1994), who suggested that fishing nets and associated apparatus do interfere with pipelines. It seems possible that these could occur because the hand-operated gears and drag net usage typifies fishing in the study area. There is also the presence of industrial fisheries, characterised by large fishing boats or vessels carrying in-board engines and mechanically operated gear, such as trammel and purse seine nets, operating in the continental shelf and inshore (Omoweh, 1995, Inoni et al., 2006).

7.5.3 Spatial Variation of Distance from Roads to Pipeline Incidents

The map for the local coefficients of *distance from roads* to a pipeline incident reveals that the influence of this variable in the model varies widely in the southeast region of the study area.

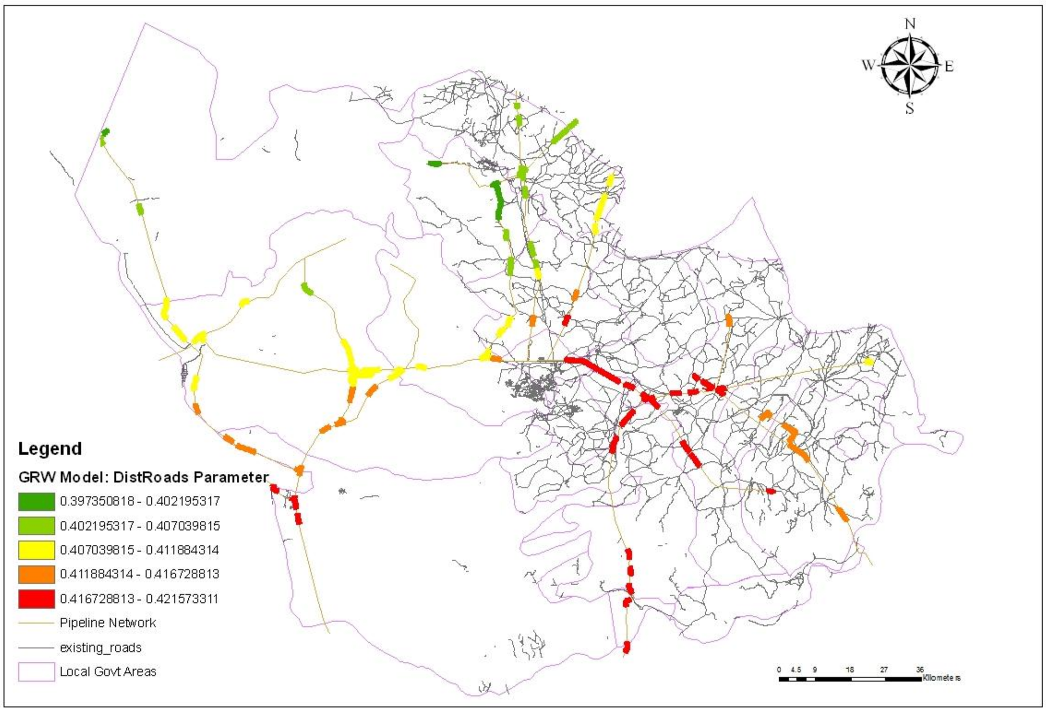


Figure 7-13: Inverse-distance weighted (IDW) contour plots of the GWR model for spatial variation of distance from roads to a pipeline incident (DistRoad).

One of the two major regions in the study area with a significant positive relationship with the influence of 'distance from roads to a pipeline incident' is in the southeast region of the study area (Figure 7-13). An important feature of this region in the study area, where the influence of the proximity to roads is highest, is the presence of a high-density road network. This observation is relatively contrary to the previously discussed influence of rivers and stream proximity (Figure 7-12), where a high density of rivers was not seen to be positively related to the occurrence of TPI.

These findings cannot be simply extrapolated to all of the study area because high road network density is also visible in other parts of the study area. Field studies indicate that the majority of these are access roads to the manifold, oilfield, and flare points in the pipeline system. Similar to other parts of the study area, many pipeline third-party interference incidents are attributed to sabotage. Another possible explanation is the observation that industries in this region of the study area are agro-based and oil servicing private companies and are well connected by roads, and it is probable therefore, that some personnel take advantage of their expertise to simply pilfer oil products.

7.5.4 Spatial Variation of Pipe Age in the Study Area

The map of the local coefficients of the pipeline age reveals that the influence varies widely in the western part of the study area (Figure 7-14). The average age of a pipeline in this part of the study area is 20 years, compared to the eastern and northern parts, which have an average age of 8 years. In the study area, many pipelines are over 50 years old, and this has raised concerns about their integrity and safety. Hence, it could conceivably be hypothesised that older pipeline are more vulnerable to TPI, relative to the newer pipelines. A possible explanation may be due to the observation that the older pipelines were installed without adequate provisions for future pigging, monitoring and installed security, compared to newer pipelines.

There are similarities between the explanation of the results in this study and those described by Kuprewicz (2001) in that older pipeline are more prone to damage compared to newer ones because they are sometimes manufactured with a smaller Factor of Safety (FS) (possibly resulting in reduced wall thickness) and with lower toughness steel. Thus, three reasons were further identified by Kuprewicz (2001) as major contributing factors for the increase of the likelihood of failure of older pipelines compared with new ones:

- Operating pressures and stresses in older pipelines increases with age
- Misleading reliance on protection devices
- There is variation with age in pipeline operations

The previous research findings into the effect of pipeline age have also raised concern about age and the risk of interference. For example, the Berman et al. (1994) suggested that: *"The rapid growth in the number of firms operating marine pipelines has also caused some concern, because many are new entrants who have assumed control of major operators' older and less profitable pipelines in hopes of lowering operating costs"*. This combination of findings provides some support for the possibility that pipelines in the selected study area are not well maintained towards the end of their ownership.

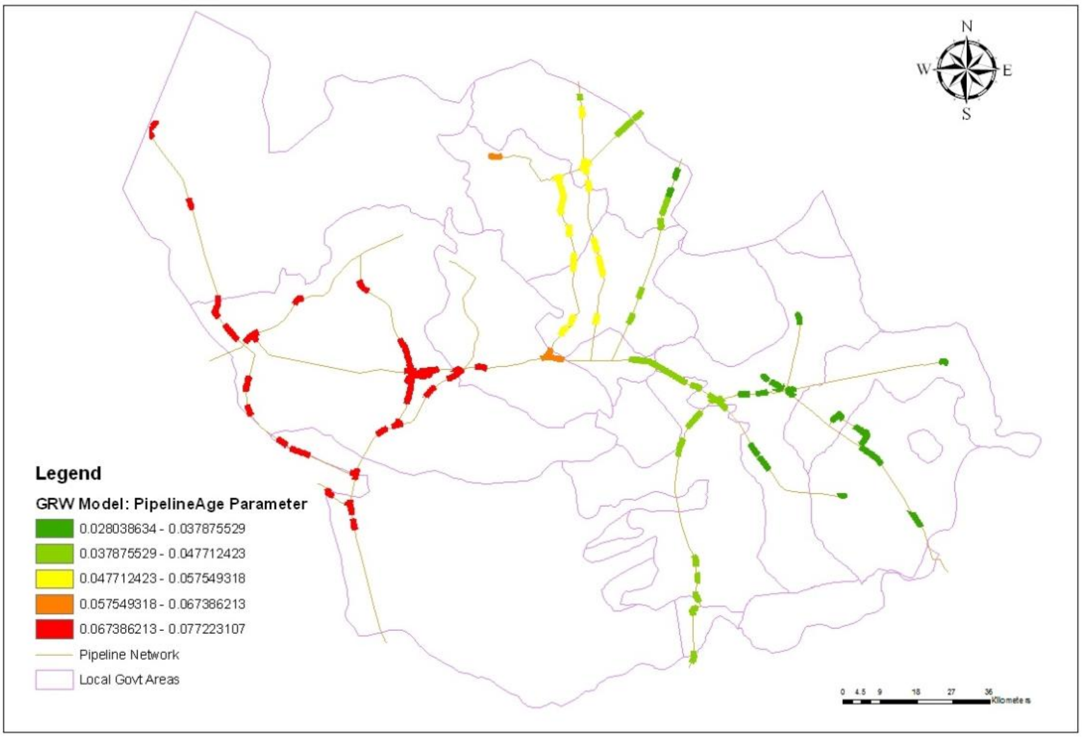


Figure 7-14: Inverse-distance weighted (IDW) contour plots of the GWR model for spatial variation of pipeline age in the study area.

7.5.5 Spatial Variation of Pipeline Diameter in the Study Area

The map for the local coefficients of pipeline diameter reveals that the influence of this variable in the model varies in the southeast of the study area (Figure 7-15). This result, in general, indicates that larger diameter pipelines (about 20 inches or greater) are more vulnerable than are the smaller diameter pipelines in the southeast of the study area, and they are positively related to the occurrence of third-party interference in southeast of the study area, especially, at both Ughelli North and Isoko South LGAs. These two LGAs have been reported to experience frequent oil spills, especially in Uvwiamuge, Oleh, Ozere and Ekakpamre communities (Atakpo and Ayolabi, 2009).

However, without detailed pipeline characteristics, such as pipeline diameter by segments, caution must be applied in any associations, as the findings might not be interpretable based on the diameter of pipeline alone. It may be the case, therefore, that these variations of pipeline diameter with occurrence of TPI in the southeast are based on the possibility that saboteurs, common in these LGAs, deliberately target large pipelines on the assumption that a larger pipeline presents a greater opportunity for causing damage and more product releases than do smaller pipelines. Muhlbauer (2004) suggests a further possible motivation for saboteurs to target large diameter pipelines because *"they lead to more expensive repairs due to higher material cost, greater excavation requirements, and increased repair challenges, and the need for larger equipment"*.

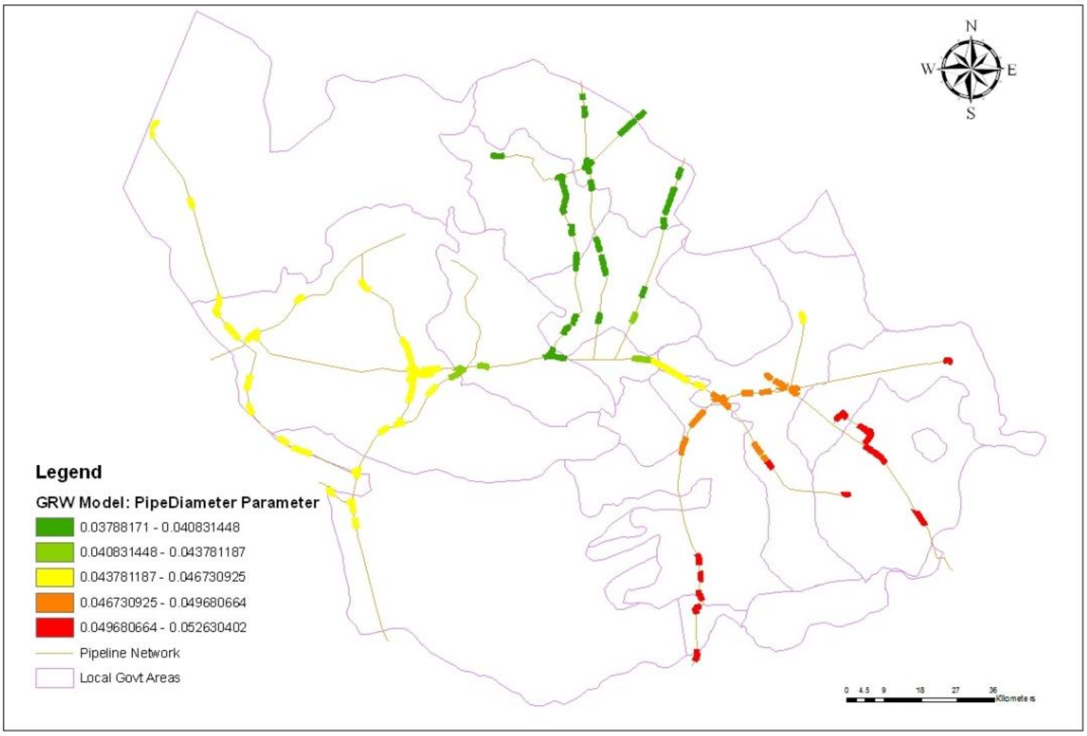


Figure 7-15: Inverse-distance weighted (IDW) contour plots of the GWR model for spatial variation of pipeline diameters in the study area.

The results of this thesis, and the explanations offered above contradict Muhlbauer's (2004) assumption, although specifically for unintentional pipeline interference, that smaller diameter pipelines are more susceptible to interference, because of the strength factor. This is because large diameter pipelines have stronger mechanical contact loading capacities, and should be structurally more resistive to interference.

7.6 Conclusions and Summary

Geographic Information Systems could help to understand the complex dynamics of how proximity to a pipeline affects the probability of third-party interference, and this thesis has indicated that this assessment can be performed using the independent variables that have been considered for the model. The results of this thesis clearly show that the observed patterns of occurrence of pipeline third-party interference are not completely spatially random. The thesis also confirms previous findings by other researchers and contributes additional evidence that suggests that the proximity of roads, rivers and villages to pipelines can determine how to solve resource allocation problems aimed at preventing TPI. This thesis has explained the central importance of hotspot analysis for a pipeline network in the monitoring of clusters of areas experiencing higher percentage of pipelines failures. It can thus be concluded that pipeline hotspots segments should be the focal point of a countermeasure implementation strategy of the pipeline industry to prevent future pipeline third-party interference.

The GWR made significant improvement on the Getis-Ord Gi* (d) statistic method, first, it highlighted the non-spatial variables individually, suggesting non-stationarity in the procedures. In addition, it reveals directional hotspots and trend of the spatial distribution of the TPI that could be valuable concern of further detail research. The GWR also model the spatial relationships, for example, determined how the relationship between TPI and distances from rivers is consistent across the study area, and what are the key factors contributing to TPI in the overall study area. While, given a set of weighted features, the Getis-Ord Gi* (d) statistic (hotspot analysis) can identifies clusters of features with high values (hot spots) and clusters of features with low values (cold spots).

The results of the two models indicate that they produce similar results indentifying vulnerable segments and hotspots on the pipeline distribution network. However, the GWR models provided useful information on the distribution variation of pipeline TPI by determining the relationship between the occurrence and individual variables considered in the model. One of the more significant findings to emerge from this analysis is that the spatial patterns of incidents show similar trends in variation across the study area. Therefore, the findings of this study suggest that the application of GIS and spatial modelling, using both the Getis-Ord Gi* statistic and GWR techniques, yield an understanding of the spatial pattern of pipeline TPI in the study area.

In conclusion, the GWR models have shown that Ughelli North and Isoko South are the most vulnerable regions of the selected area. This is confirmed by the history of a chain of various pipeline incidents because of TPI in the two LGAs. For example, in 2001, the Afiesiere River in Ughelli North was heavily polluted when a wellhead was stolen; similarly, in 1992, a leakage caused by TPI on the Ogini pipeline destroyed farmlands in Isoko North LGA of the study area. Therefore, the destruction of the soil and farmland; the pollution of water systems, the disturbance of economic and social activities from oil spillage; unemployment in the host communities, could be the major factors (socioeconomic and socio-political), if not the only ones, causing intentional pipeline TPI in the study area.

8 ANALYSIS AND RESULTS OF GENERALISED LINEAR MODELS

8.1 Introduction

One of the key objectives of this thesis, as outlined in Section 1.3, was to predict and examine the likelihood of the future occurrence of TPI in pipeline segments, by modelling a combination of land use types, failures count data, socio-economic, socio-political and pipeline intrinsic variables. The recognition of these variables and their successful linkage to the occurrences of TPI has permitted the use of the Generalised Linear Models (GLMs) methodology in developing the model for this thesis. Chapter 6 of the thesis discussed in detail the GLMs component (Poisson and Logistic Regression (LR) models) that map out the methods that were utilised for the results discussed in this chapter. This indicates the probability of occurrence of pipeline TPI, in addition to predicting the probable number of interferences over a given period of time. The statistical analyses for these tests were conducted using SPSS v.17.0. The instruments used are discussed and detailed descriptive statistics of the data are presented in this chapter.

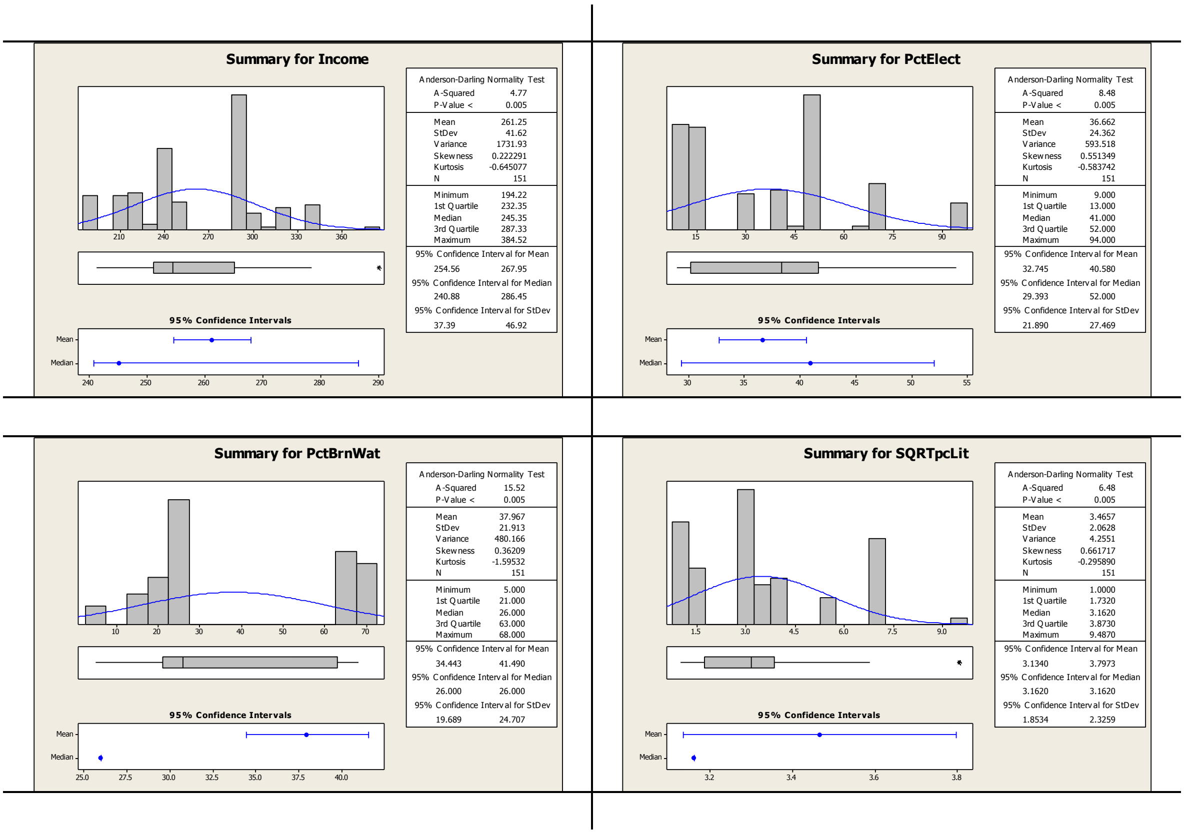
8.2 Factor Analysis: Principal Component Analysis (PCA)

One of the requirements for the statistical analysis of a real world dataset is a multivariate normal distribution of the variables in the proposed model, especially for inferential statistical analysis. This is because the assumption of multivariate normality of a dataset significantly improves the precision and accuracy of the results. Therefore, the selected continuous variables in this thesis were subjected to Factor Analysis (FA), using the Principal Component Analysis (PCA) technique, discussed in Section 6.6.1.

Table 8-1: List and abbreviations of the selected variables used in the thesis

TPI	Occurence of Pipeline Third-party Interference	Geol	Geological classifications
PcEl	Percentage of Household with Electricity	PiSt	Pipeline Status(aboveground or buiried)
PopD	Population Density	PVF	Presence of Oil and Gas Facilities
PcLt	Percentage Literacy	wb	%LandUse: Water Bodies
EXHD	Returns on Capital Projects by the Government (£)	esd	%LandUse:Evergreen semidecidous forest
OilF	Area of Oil and Gas Fields/Wells	mvc	%LandUse:Mosaic vegetation / cropland
PipL	Total Length of Pipelines	tsg	%LandUse:Thicket, Secondary Growth
RdL	Total Road Length	mbw	%LandUse:Marsh brakish water
Age	Average Age of Pipeline	cgl	%LandUse:Closed grassland
HDI	Human Development Index (HDI)	glf	%LandUse:Mosaic grassland/forest or shrubland
GeoP	GeoPolitical Location	blf	%LandUse:Broadleavedforest

The list of abbreviations for the selected variables used in the analysis is shown in Table 8-1. In addition, Section 6.6.1 has identified eleven variables as being major contributing factors for consideration for the FA, and how they were subjected to the PCA, using the SPSS PCA procedure. The result of the FA showed that seven of the variables subjected to the PCA analysis, because they are assumed be correlated, failed to meet the assumption of normality. These variables include percentage literacy, returns on capital projects executed, total length of pipelines, total river length, total road length, and Gender Empowerment Measure (GEM). Therefore, to meet the requirement of normality, each of these variables was subjected to statistical data transformation (mathematical modification of the dataset). The majority of the variables test normal after various transformations, using rule-of-thumb procedure suggestions by Coakes (2005). However, due to their importance and significance in TPI occurrence, some variables that did not meet the normality test were not discarded, especially the pipeline intrinsic properties (Figure-8-1).



Anderson-Darling Normality Test	
A-Squared	4.77
P-Value <	0.005
Mean	261.25
StDev	41.62
Variance	1731.93
Skewness	0.222291
Kurtosis	-0.645077
N	151
Minimum	194.22
1st Quartile	232.35
Median	245.35
3rd Quartile	287.33
Maximum	384.52
95% Confidence Interval for Mean	
254.56	267.95
95% Confidence Interval for Median	
240.88	286.45
95% Confidence Interval for StDev	
37.39	46.92

Anderson-Darling Normality Test	
A-Squared	8.48
P-Value <	0.005
Mean	36.662
StDev	24.362
Variance	593.518
Skewness	0.551349
Kurtosis	-0.583742
N	151
Minimum	9.000
1st Quartile	13.000
Median	41.000
3rd Quartile	52.000
Maximum	94.000
95% Confidence Interval for Mean	
32.745	40.580
95% Confidence Interval for Median	
29.393	52.000
95% Confidence Interval for StDev	
21.890	27.469

Anderson-Darling Normality Test	
A-Squared	15.52
P-Value <	0.005
Mean	37.967
StDev	21.913
Variance	480.166
Skewness	0.36209
Kurtosis	-1.59532
N	151
Minimum	5.000
1st Quartile	21.000
Median	26.000
3rd Quartile	63.000
Maximum	68.000
95% Confidence Interval for Mean	
34.443	41.490
95% Confidence Interval for Median	
26.000	26.000
95% Confidence Interval for StDev	
19.689	24.707

Anderson-Darling Normality Test	
A-Squared	6.48
P-Value <	0.005
Mean	3.4657
StDev	2.0628
Variance	4.2551
Skewness	0.661717
Kurtosis	-0.295890
N	151
Minimum	1.0000
1st Quartile	1.7320
Median	3.1620
3rd Quartile	3.8730
Maximum	9.4870
95% Confidence Interval for Mean	
3.1340	3.7973
95% Confidence Interval for Median	
3.1620	3.1620
95% Confidence Interval for StDev	
1.8534	2.3259

Figure 8-1: The graphs showing the variables that were not normally distributed. The transformation to normality is a requirement for statistical inference analysis.

8.2.1 Output of Factor Analysis with SPSS

The first step in the application of FA is to evaluate the correlation between the variables. The SPSS Output (Table 8-2) shows an abridged Pearson correlation coefficient between all the variables, where the patterns of relationships are displayed. The correlation matrix procedure shows no corresponding variable having a correlation coefficient greater than

0.9. This is because a correlation above 0.9 is considered high, especially in the context of this thesis, and indicates the presence of multicollinearity, a situation where two or more variables are related or effectively measure the same phenomenon (Field, 2009).

Table 8-2: Pearson correlation coefficient between all the variables.

	PcEl	PcBW	PcLt	EXHD	ADHI	LEI	GEM	HDI	GDP	GDI	HPI
PcEl	1.000	-0.802	0.058	-0.401	0.197	-0.192	-0.335	-0.178	0.070	-0.268	0.213
PcBW	-0.802	1.000	-0.305	0.647	-0.348	0.330	0.434	0.336	-0.203	0.411	-0.329
PcLt	0.058	-0.305	1.000	-0.433	0.127	-0.116	-0.099	-0.161	0.054	-0.199	0.058
EXHD	-0.401	0.647	-0.433	1.000	-0.792	0.799	0.690	0.777	-0.657	0.827	-0.745
ADHI	0.197	-0.348	0.127	-0.792	1.000	-0.981	-0.866	-0.967	0.895	-0.967	0.919
LEI	-0.192	0.330	-0.116	0.799	-0.981	1.000	0.849	0.978	-0.901	0.976	-0.920
GEM	-0.335	0.434	-0.099	0.690	-0.866	0.849	1.000	0.847	-0.774	0.923	-0.799
HDI	-0.178	0.336	-0.161	0.777	-0.967	0.978	0.847	1.000	-0.942	0.952	-0.884
GDP	0.070	-0.203	0.054	-0.657	0.895	-0.901	-0.774	-0.942	1.000	-0.851	0.851
GDI	-0.268	0.411	-0.199	0.827	-0.967	0.976	0.923	0.952	-0.851	1.000	-0.898
HPI	0.213	-0.329	0.058	-0.745	0.919	-0.920	-0.799	-0.884	0.851	-0.898	1.000

Following the Pearson correlation coefficient between all the variables, Table 8-3 presents the results obtained from the PCA output for *Kaiser-Meyer-Olkin* (KMO) and the *Bartlett's Test of Sphericity* for the variables considered. The KMO measures the sampling adequacy, and the value, in statistics, is normally between *0* and *1*. The value of the KMO from this analysis is 0.77, which falls into the recommended range of between 0.5 and 0.99 (Field, 2009). The KMO value indicates that all variables are not correlated or measure the same phenomenon; otherwise, the correlation coefficients would be zero.

Table 8-3: SPSS output for KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	*0.77*
Bartlett's Test of Sphericity -Approx. Chi-Square	3193.377
df*	55
Sig.**	0.00

** Degree of freedom; ** Significance, outcome statistically significant (i.e. p <.05)*

The *Bartlett's Test of Sphericity* results as given in Table 8-3, is the null hypothesis that the original correlation matrix is an identity matrix. Therefore, if the result is significant, proving otherwise, the dataset is free of multicollinearity. In this analysis, the *Bartlett's test* is significant, less than 0.001 (p < 0.001) (Table 8-3, row 4). Therefore it was concluded that multicollinearity is absent in the model, and that the variables are not identical.

The SPSS output statistics in Table 8-4 also show the *eigenvalues* associated with each linear component before extraction, representing the variance explained by a *component*. In statistics, a *component* is the combination of two or more correlated variables, combined into one *factor*. The SPSS analysis output in Table 8-4 displays the percentage of variance explained by a variable as being the *eigenvalue*. For example, *component* (or factor) 1 in Table 8-4 accounts for 67.184% of total variance in the variables, while the subsequent *component*s explains the other variance. For example, as shown in Table 8-4, *components* 2 and 3 explain the 16.107 and 9.311% of the remaining variance respectively.

Table 8-4: SPSS output of Total Variance Explained for the Factor Analysis

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	7.390	67.184	67.184	7.390	67.184	67.184	7.263
2	1.772	16.107	83.291	1.772	16.107	83.291	2.708
3	1.024	9.311	92.602	1.024	9.311	92.602	1.613
4	0.257	2.340	94.942				
5	0.180	1.640	96.581				
6	0.156	1.422	98.003				
7	0.113	1.026	99.029				
8	0.072	0.650	99.679				
9	0.023	0.213	99.892				
10	0.010	0.094	99.986				
11	0.002	0.014	100.000				

Extraction Method: Principal Component Analysis.

The SPSS procedure implemented extracted the three factors having *eigenvalues* greater than 1, which are listed in the columns named *Extraction Sums of Squared Loadings* in Table 8-4. In the column labelled *Rotation Sums of Squared Loadings*, *eigenvalues* of the factors after *rotation* (a step that allows the identification of distinct factor names or clusters of relationships) are displayed, as shown in Table 8-4. The purpose of running the PCA is to sufficiently reduce the dimensionality of the data. The SPSS analysis shows that the first three principal components accounted for 92.27% of the total variance in the model, the remaining components thus being of little significance.

The decision regarding the number of factors to extract from the overall FA is at the discretion of the researcher (Field, 2009). However, because there are fewer than 30 variables under consideration and the output of the total average of the communalities after extraction are greater than 0.7, the extraction rule suggested by Kaiser's criterion was taken to be acceptable. Therefore, three *components* are extractable based on Kaiser's rule, a selection rule for acceptable number of factors *'m'*, to equal the number of *eigenvalues* greater than *1* (Table 8-4). In addition to Kaiser's rule, the *scree* plot (Figure 8-2), produced from SPSS output, was also used to determine the numbers of factors to be extracted.

Component four on this plot indicates the point at which the curve began to straighten. Therefore, the numbers of components to be extracted for further analysis are taken to be three. The corresponding variables of these components were then used, in addition to other variables, as dependent variables in the GLMs analysis.

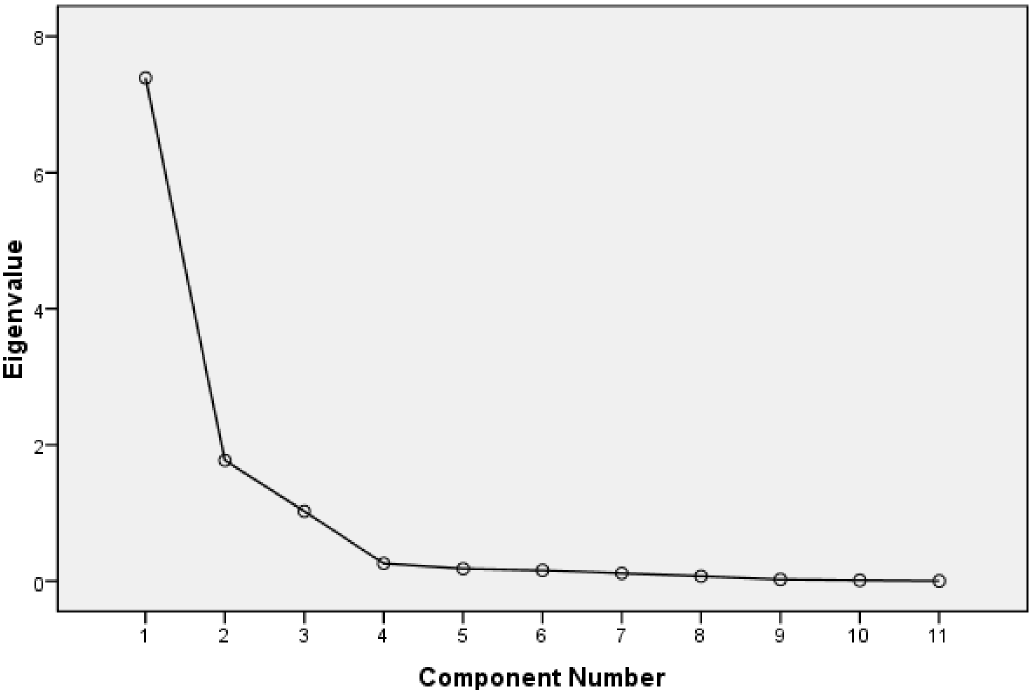


Figure 8-2: The *scree* plot illustrating the 3-factor solution from the result of the FA with SPSS.

The correlation between the original eleven variables and the new *components* (1, 2, and 3) reveals the variables that are highly correlated with the *components*. Table 8-5 shows *component 1* is highly correlated (0.982, highly close to 1.00) with GDI and LEI; and *component 2* is correlated with PcEl (percentage of household with electricity) and PcBw (percentage of household with pipe borne water). Similarly, *component* 3 is correlated with PcLt (Percentage of literacy). However, since GDI and LEI are dependent and indirectly related to HDI, thus, *component* 1 was assigned as HDI (Table 8-2). The *components* that have been identified therefore enabled the reduction of the variables dimensionality, and thus further multivariate statistical analysis can be performed, as described in the following sections, on these three principal *components*, in addition to land use and other variables (Section 6.6.1 explains the reasons why land and other variables are not included in the above described FA analysis.

Table 8-5: Output of the communalities after extraction and Output of Component Matrix.

	Component		
	1	*2*	*3*
GDI	0.982		
LEI	0.972		
ADHI	-0.972		
HDI	0.966		
HPI	-0.922		
GEM	0.901		
GDP	-0.888	0.313	
EXHD	0.868		
PcBW	0.494	0.816	
PcEl	-0.333	-0.801	-0.419
PcLt		-0.403	0.875

Extraction Method: Principal Component Analysis.

8.3 Results of Poisson Generalized Linear Model (GLMs) Analysis

8.3.1 The Poisson Generalized Linear Model (GLMs)

The methodology for the adoption of the Poisson GLMs analysis for this thesis was described in Chapter 6. In this thesis, the GLMs model is used to predict the potential numbers of pipeline TPI, especially to understand and examine the relationship of the variables influencing TPI. The abridged results of the descriptive statistics information of the categorical variables are presented in Tables 8-6. The detailed results output from the SPSS GLMs analysis are given in Appendix I.

Table 8-6: Descriptive statistics information of the categorical variables Categorical Variable Information.

		N	***Percent***
PDia	Pipelines Less than 12 Inches	109	72.20%
	Pipelines Greater than 12 Inches	42	27.80%
	Total	151	100.00%
PiSt	Buried Pipeline	18	11.90%
	aboveground pipeline	54	35.80%
	No pipeline	79	52.30%
	Total	151	100.00%
Geol	Abandoned Beach Ridges	17	11.30%
	Alluvium/Coastal Plains Sands	18	11.90%
	Mangrove Swamps	26	17.20%
	Meander Belt,Back Swamps Fresh Water Swamps	24	15.90%
	Sombreiro Deltaic Plain	66	43.70%
	Total	151	100.00%

The *OmnibusTest* Table from the SPSS output result in Table 8-7 shows the *likelihood ratio* of the model. This is defined as the difference in *likelihood* values between the designed model and the model with the intercept only. A significant *likelihood ratio* shows that the model's coefficients are different from zero, hence the *null* hypothesis can be rejected or that the coefficients are not different from zero.

Table 8-7: Omnibus Test[a] result table from SPSS output

Likelihood Ratio Chi-Square	df	Sig.
220.679	25	0

Dependent Variable: Numbers of Pipeline Third-party Interference
Model: (Intercept), PDia, PiSt, Geol, PcBW, PcLt, HDI, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl
a. Compares the fitted model against the intercept-only model.

Table 8-8 illustrates some of the main characteristics of the SPSS GLMs procedures, indicating the *Deviance*, *Scaled deviance*, *Pearson chi-square*, *Scaled Pearson chi-square*, *Log-likelihood*, *Akaike's information criterion (AIC)*, *Finite sample corrected AIC (AICC)*, *Bayesian information criterion (BIC),* and *Consistent AIC (CAIC).* The table indicates the *Goodness of Fit statistics,* and enables a comparison of various alternatives GLMs using their associated deviances and the goodness of fit information given in Table 8-8.

Table 8-8: Goodness of Fit[b] for the Negative Binomial

	Value	***df***	***Value/df***
Deviance	87.018	125	0.696
Scaled Deviance	87.018	125	
Pearson Chi-Square	117.338	125	0.939
Scaled Pearson Chi-Square	117.338	125	
Log Likelihood[a]	-159.457		
Akaike's Information Criterion (AIC)	370.914		
Finite Sample Corrected AIC (AICC)	382.237		
Bayesian Information Criterion (BIC)	449.364		
Consistent AIC (CAIC)	475.364		

Dependent Variable: Occurrence of Pipeline TPI

Model: (Intercept), PDia, PiSt, Geol, PcBW, PcLt, HDI, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl

a. The full log likelihood function is displayed and used in computing information criteria.

b. Information criteria are in small-is-better form.

The *likelihood* value in Table 8-8 indicates how the model reflects the observed patterns from the original data used in the model. A larger likelihood value shows a better model fit, and it can be concluded that the coefficients in the model are accepted, and that the model thus rejects the null hypothesis that the coefficients are not different from 0. A carefully developed parametric predictive model should be expected to fit any given empirical observations. Therefore, in a fitted model for generalized linear model (GLMs), the ratio of the deviance value to its degrees of freedom should be approximately 1. The preliminary SPSS Goodness of Fit result shows that the Pearson chi-square/*df* ratio is greater than 1 for the Poisson GLMs (output shown in Appendix I). Since this ratio is greater than 1, reassessment of the model is required; because the model is described as being overdispersed (i.e. the variance is greater than the mean). In this situation, a Negative Binomial model (Section 6.6.3) was considered to fit the model. The result of the negative binomial GLMs analysis (Table 8-8) shows for the model a lower *chi square* to *df ratio* of less than 1, and implies a better fitting of the model. The results of the Poisson regression analysis, as given in Appendix I, without consideration for overdispersion, showed that thirteen of the variables are significant at the $p < 0.05$ level, as compared with only six variables after correcting for overdispersion.

8.3.2 Parameter Output Estimates of the Generalized Linear Model

After running the SPSS program for the Negative Binomial model, the other parameters in Table 8-9 were examined and interpreted. The *Wald Chi-Square* values, given in Table 8-9, are the test statistics for the individual regression coefficients in the model, and it is the mathematical squared ratio of the coefficient *B* to the *Standard Error* of each independent variable (Field, 2009).

The *Wald Chi-Square* is similar to Chi-Square distribution in the general regression analysis, of a two-sided alternative hypothesis, that *B(*regression coefficients) is not equal to zero. The column label *df*, in Table 8-9 indicates the degrees of freedom for each of the independent variables in the model, and that are all found to be 1 for each of the variables in the model. Similarly, the *Sig.* (significance) is the *p*-values of the coefficients or the probability that, the null hypothesis of an independent variable's coefficient is zero, derived using the *Wald Chi-Square* test statistics. Pipeline status (PiSt), Oilfield (OilF), pipeline length (PiLe), water bodies (wb), and Mosaic vegetation/cropland land use variables are significant at *p*-value less than 0.05 (highlighted in Table 8-9). Therefore, the best-fit regression equation for the model is given by Equation 8.1, where the parameter definitions are the same as in the description of the data above. The following section presents the results for each significant variable in the model.

$$\begin{aligned}\log(\mu) &= \beta_0 + 2.331PiSt + 0.331OilF + \\ &0.078PiLe + 0.739wb - 0.127mvc\end{aligned} \qquad \text{(Equation 8.1)}$$

Table 8-9: The results output for the parameter estimates of the Generalized Linear Model (GLMs) using the SPSS procedure.

Variables	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	-1.132	2.440	-5.914	3.651	0.215	1	0.643	0.322	0.003	38.496
[PDia=1]	0.051	0.610	-1.145	1.246	0.007	1	0.934	1.052	0.318	3.476
[PDia=2]	0^a	.	.	.	.	.	.	1.000	.	.
[PiSt=1]	2.682	0.650	1.409	3.955	17.052	1	0.000	14.613	4.092	52.188
[PiSt=2]	2.331	0.691	0.977	3.686	11.377	1	0.001	10.292	2.656	39.891
[PiSt=3]	0^a	.	.	.	.	.	.	1.000	.	.
[Geol=1]	-0.710	0.946	-2.564	1.144	0.563	1	0.453	0.492	0.077	3.139
[Geol=2]	0.396	0.660	-0.897	1.689	0.360	1	0.548	1.486	0.408	5.413
[Geol=3]	0.099	0.684	-1.242	1.440	0.021	1	0.885	1.104	0.289	4.220
[Geol=4]	0.114	0.557	-0.977	1.205	0.042	1	0.838	1.121	0.376	3.337
[Geol=5]	0^a	.	.	.	.	.	.	1.000	.	.
PcBW	-0.009	0.015	-0.038	0.019	0.401	1	0.527	0.991	0.963	1.019
PcLt	-0.013	0.015	-0.043	0.017	0.733	1	0.392	0.987	0.958	1.017
HDI	-0.148	0.227	-0.593	0.296	0.428	1	0.513	0.862	0.552	1.345
OilF	0.331	0.158	0.021	0.641	4.380	1	0.036	1.392	1.021	1.898
PiLe	0.078	0.031	0.018	0.139	6.487	1	0.011	1.081	1.018	1.149
RvLe	-0.006	0.019	-0.042	0.031	0.093	1	0.760	0.994	0.959	1.031
RdLe	0.159	0.125	-0.085	0.403	1.628	1	0.202	1.172	0.918	1.496
PopD	-0.002	0.002	-0.006	0.003	0.490	1	0.484	0.998	0.994	1.003
Age	-0.002	0.041	-0.083	0.079	0.002	1	0.962	0.998	0.921	1.082
wb	0.739	0.377	0.000	1.479	3.837	1	0.050	2.095	1.000	4.389
esd	0.040	0.025	-0.009	0.090	2.513	1	0.113	1.041	0.991	1.094
mvc	-0.127	0.052	-0.228	-0.026	6.050	1	0.014	0.881	0.796	0.975
tsg	-0.030	0.027	-0.083	0.022	1.278	1	0.258	0.970	0.920	1.023
mbw	-0.042	0.038	-0.118	0.033	1.208	1	0.272	0.959	0.889	1.034
cgl	-0.056	0.061	-0.175	0.063	0.844	1	0.358	0.946	0.839	1.065
glf	-0.023	0.030	-0.081	0.035	0.597	1	0.440	0.977	0.922	1.036
blf	-0.036	0.037	-0.109	0.036	0.955	1	0.329	0.964	0.897	1.037
sbl	-0.055	0.054	-0.161	0.052	1.015	1	0.314	0.947	0.851	1.053
(Scale)	1^b									
(Negative binomial)	1.000									

Dependent Variable: Occurrence of Pipeline Third-party Interference

Model: (Intercept), PDia, PiSt, Geol, PcBW, PcLt, HDI, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

8.3.3 Pipeline Diameter (PDia)

Although pipeline diameter is not statistically significant in the model, it is important and meaningful to interpret the result, because it is a major pipeline intrinsic properties. From the parameter estimates in Table 8-9, the odds ratio or relative risk for pipeline diameters can be obtained by using the *B* value of 0.051, which is the estimate for pipelines less than 12 inches. Thus, the ratio of possible TPI for those pipelines less than 12 inches relative to those greater than 12 inches is exp(0.051) = 1.052. Exp(B) in Table 8-9 is the odds ratio, and represents *"the change in odds of being in one of the categories of outcome when the value of an independent variable increases by one unit"*, according to Tabachnick and Fidell (2007). The possibility of the occurrence of pipeline interference for those pipelines less than 12 inches in the study area is 1.05 times higher than that of those pipelines greater than 12inches; this resulting difference is considered to be insignificant. However, the results are consistent with those of other studies (e.g. Jo and Ahn (2005)) and suggest that failure rates varies with pipeline diameter, and pipelines less than 12inhes are more vulnerable. Another possible explanation for this is that crude-oil pipelines in the study area are operated by larger pipeline diameter, and recorded TPI in the study area are mostly on oil-products pipelines of diameter between 8 and 12 inches.

8.3.4 Pipeline status (PiSt), buried or aboveground

This is the estimated regression coefficient used when comparing whether a pipeline is buried (PiSt=1), aboveground (PiSt=2) or no pipeline (PiSt=3) in a region, given that the other variables are held constant in the model. The estimated regression coefficient, for example, that a pipeline is buried is 2.682 from the parameter estimates (Table 8-9), thus, we can obtain the odds ratio or relative risk about pipeline status using the *B* value of 2.682, the ratio of possible damage for buried pipelines relative to aboveground pipelines is exp (2.682) = 14.613. The possibility of pipeline interference for exposed pipelines is thus about 146% more than that of those of buried pipelines.

The aboveground pipelines experience more TPI than buried pipelines. This finding regarding pipeline status in this model corroborates the findings of a great deal of the previous work in this field, on the influence of buried pipelines on the occurrence of TPI. However, the high observed difference (146%) between aboveground and buried pipelines in this result was expected and confirm that the influence of other factors have significantly contributed to the high probability of TPI on aboveground pipelines, for example, intentional TPI (e.g. sabotage and vandalism of aboveground pipelines).

8.3.5 The presence or absence of oilfields (OilF)

The presence of oil (and gas) fields in a region is a significant variable in the model (p<0.05). If all other variables are held constant, the greater the area of oilfields (in square kilometres) in a region, then the higher the possibility of pipeline TPI. The presence of a large oilfield, especially representing the drilling and rig business in the study area, influences the positive results of the thesis

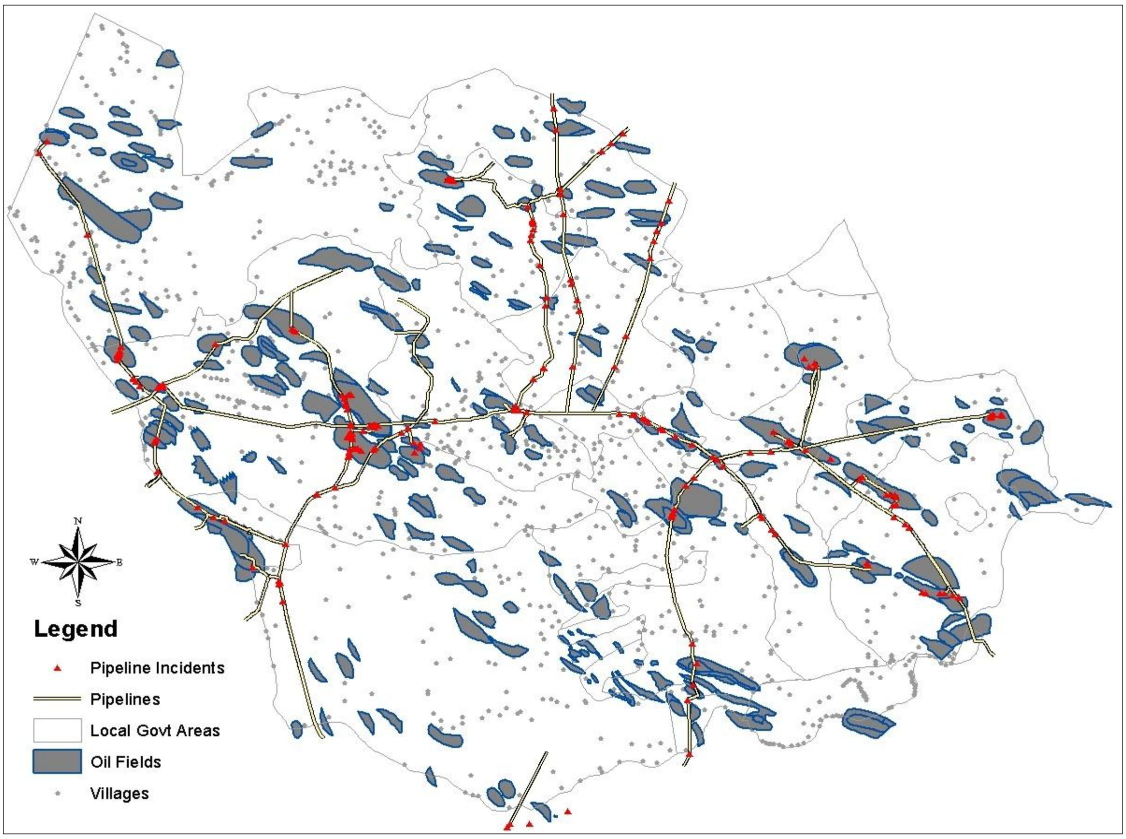


Figure 8-3: Map showing how pipeline traverses across the oilfields in the study area.

The odds ratio indicates that, since the Exp(B) is greater than one, this means the independent variable increases the log-odds and therefore increases the risk of a possible pipeline TPI. For instance, for *OilF* in Table 8-9, *B* = 3.331, and the corresponding odds ratio (the exponential function, e^b) is 1.392. Therefore, when the area of a region's oilfield increases by 1 km.sq, the odds or risk of pipeline TPI increases by a factor of 1.4, when other variables are held constant.

The study area has 36.2 billion barrels of proven oil reserves from the oilfields, the 11th largest in the world (EIA, 2009). Therefore, maximum production from this oilfield typically means more pipelines and Figure 8-3 shows that pipelines traverse more clusters of oilfields than isolated oilfields. Therefore, the observed increase of pipeline TPI by a factor of 1.4 for regions with oilfields could be attributed to increased oil and gas activities. Moreover, the area of oilfields are a surrogate for land use, therefore, as economic and political attention is drawn to areas with high reserves of oilfield, it follows that such an area will inevitably experience a high level of TPI.

8.3.6 Pipeline Length (PiLe)

Pipeline length was significant in the model ($p=0.011$), and the odds ratio (Exp(B)) is 1.08 (Table 8-9). The results indicated that the higher the total length of pipelines in a region, the higher the likelihood of pipeline TPI. For every extra length of pipeline in a region, the odds of experiencing TPI increase by a factor of 1.08, all other factors being equal. This argument supports various analyses of general pipeline failures, and the assumption has always been that the rate of failure or damage is proportionally related to the length of the pipeline. In the model, the pipeline TPI was approximately proportional to the length of pipeline in a region. The result is straightforward and logical, and as would be expected.

8.3.7 Water Bodies (wb)

Water bodies are significant ($p<0.05$) and B= 0.739, indicating that the larger this land use type the higher the likelihood of pipeline TPI. The corresponding odds ratio, the exponential function Exp(B) is 2.095 (Table 8-9). This indicates that if a pipeline were to traverse this land use type by one kilometre, then the odds or risk of pipeline TPI increases by a factor of 2.095, when other variables are held constant.

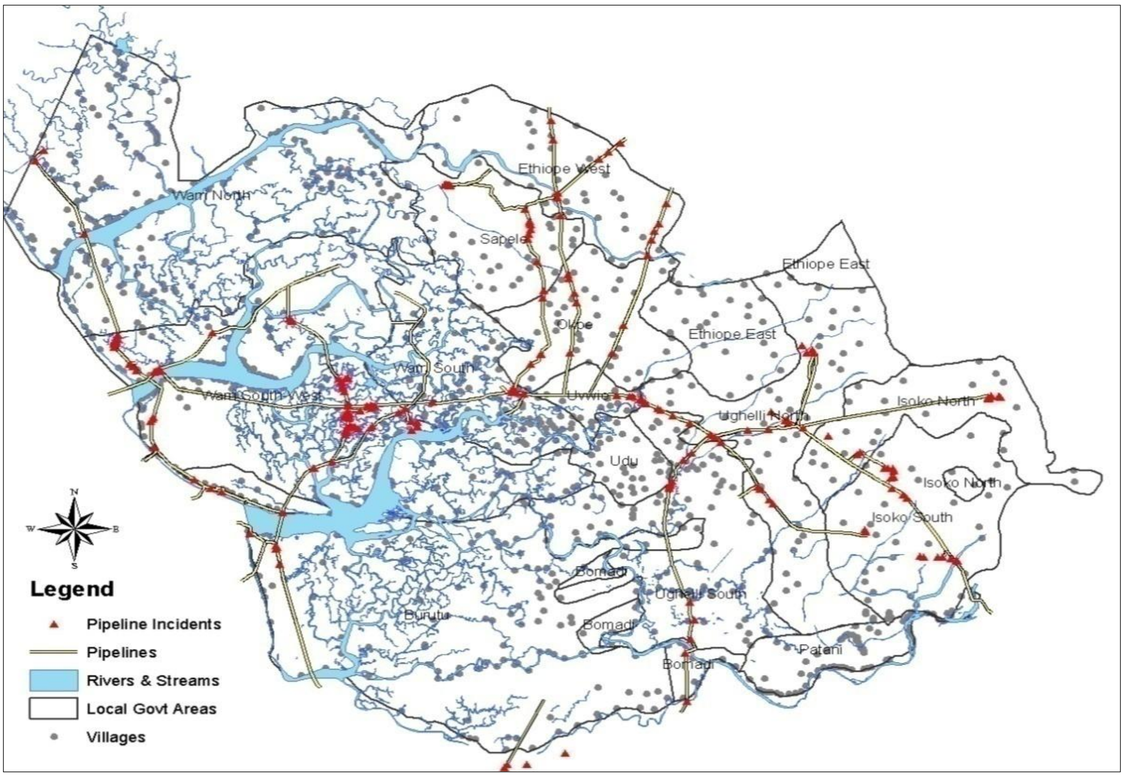


Figure 8-4: Map showing how pipelines traverse across and along rivers and streams in the study area, especially in the south and south west.

As mentioned in the literature review, the selected study area is crisscrossed by several water bodies, and the ingress of pipelines into and across water bodies is inevitable. As can be seen from Figure 8-4, the pipelines avoid the rivers and streams in the study area as much as possible, however, a vast number are still woven with the water bodies. The various pipelines that conjoined these rivers and villages are expected to play a significant role in influencing the occurrence of pipeline TPI more so than for the other natural occurring factors.

8.3.8 Mosaic vegetation / cropland (mvc)

Mosaic vegetation/cropland (mvc) in Table 8-9 is seen to be significant ($p<0.05$) and $B= -0.127$ is the regression estimate for a one unit increase in land use area, given the other variables are held constant in the model. If a pipeline were to traverse this land use type by one kilometre, then the difference in the logs of expected counts of pipeline TPI would be expected to decrease by 0.127 units. This land use type is only 3.14 per cent of the total land use in the selected study area, with the majority of this type found in Warri SouthWest and Ethiope West and East LGAs, indicated in red, in Figure 8-5. The overall study area in general consisted mostly of shoreline and thick rain forest, and pipelines stretch across these areas of land use mostly, while the percentage of pipelines traversing the mosaic vegetation/cropland land use type are very few. In addition, the relative absence of this land use type, could explain the few cases of pipeline TPIs in these land use type.

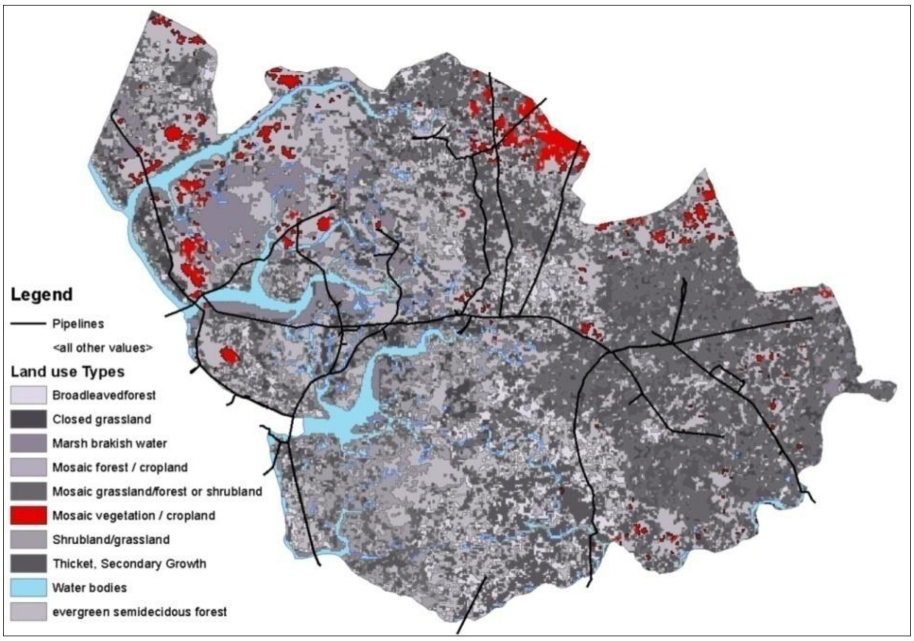


Figure 8-5: Map showing the mosaic vegetation / cropland (mvc) (highlighted red) land use and other land use type and the pipelines in the study area.

8.4 Results of the Binomial Logistic Generalized Linear Model

As described previously in Chapter 6, Logistic Regression (LR) is part of the GLMs, which can predict group membership and also examines the relationships and strengths of variables. Logistic regression not only models the binary response variables, but also models numeric, categorical and multinomial data. In this thesis, LR was used to predict the probability that a region will or will not experience pipeline TPI (Hosmer and Lemeshow, 2000). The model indicates the probability of occurrence of an event (e.g. TPI), and if it is *1*, the event will occur, and if it is 0 then it will most likely not occur.

The typical output of a logistic regression model includes the *B*, the Standard Error (S.E) of the *B*, the *Wald test statistic*, the *degrees of freedom* (d.f), the *significance level*, and the exponentiated coefficient of *B* (Exp(B)). When the value of *B* is 0, this signifies that there is no change in the odds of occurrence; also, when Exp(B) is *1*, this indicates that the particular independent variable is of no effect on the dependent variable. However, if the Exp(B) is over *1*, a positive relationship exists, and the independent variable will have a positive relationship and effect on the dependent variable. In addition, if the value of the Exp(B) is less than *1*, then a negative relationship exists and the odds or risk of an occurrence decreases (Hair et al., 2006). In dichotomous independent variables, as in this thesis, the odds ratio is given by:

$$[\text{Exp(B)} - 1] \times 100 \qquad \text{(Equation 8.2)}$$

8.4.1 Pearson Product-Moment Correlation for Variables

Logistic regression requires that the relationships between two or more variables do not influence model fitting if they increase or decrease together (i.e. correlated). Before the data were fit to the model, the Pearson product-moment correlation was utilised to determine the specific independent variables that should be included in the LR model for the thesis; and to determine the strength and direction of the linear relationship between two or more variables without removing the effects of the other variables.

Tabachnick and Fidell (2007) identify several advantages of this procedure, especially since the research question was to explore whether there is a relationship between the variables. The variables in Table 8-1, and described in Chapter 5, are those used in the LR analysis of GLMs. The correlation between the variables was tested, and Table 8-10 compares the inter-correlations among the twenty-two derived variables. The relationship between the variables using the Pearson product-moment correlation shows there were both small (*r* = ±0.01 to ±0.29) negative and positive correlations between the variables, and very few large (*r*= ±0.50 to ±1.0) negative and positive correlations. For example, the correlation between population density and Human Development Index (HDI) is +0.537; and the correlation between mosaic land use type (mbw) and length of rivers is -0.61 (Table 8-10). However, this does not assume that this correlation implies causation, for example, increase in population density does not automatically imply or causes increase in HDI.

Table 8-10: Correlation analysis of the variables used for the LR GLMs analysis.

	PcBW	PcLt	HDI	OilF	PiLe	RvLe	RdLe	PopD	Age	PDia(1)	PDia(2)	PiSt(1)	PiSt(2)	wb	esd	mvc	tsg	mbw	cgl	glf	blf	sbl
	-0.301	-0.361	-0.552	-0.055	0.029	-0.081	-0.238	-0.524	-0.285	-0.006	0.094	-0.09	-0.229	-0.001	-0.336	0.079	-0.211	0.008	-0.068	0.242	-0.055	-0.302
PcBW	1	0.096	-0.005	-0.22	-0.692	-0.265	0.168	0.194	-0.172	-0.261	0.209	-0.465	-0.254	-0.545	-0.08	0.164	0.258	0.106	0.048	0.272	0.48	0.746
PcLt	0.096	1	-0.16	0.212	-0.034	-0.2	-0.132	-0.37	0.051	-0.149	-0.21	-0.018	-0.033	-0.1	-0.161	-0.262	0.033	0.281	-0.289	0.085	0.134	0.133
HDI	-0.005	-0.16	1	-0.052	0.027	0.104	0.042	0.537	0	-0.258	0.018	-0.184	-0.149	-0.011	0.247	0.045	0.252	-0.171	0.359	-0.316	0.037	0.223
OilF	-0.22	0.212	-0.052	1	0.143	0.049	-0.055	-0.117	-0.003	0.047	-0.077	0.224	0.065	-0.095	-0.071	-0.256	-0.299	-0.172	-0.131	-0.248	-0.042	-0.179
PiLe	-0.692	-0.034	0.027	0.143	1	0.25	-0.083	-0.134	0.167	0.335	-0.048	0.367	0.446	0.424	0.138	-0.045	-0.089	-0.147	-0.236	-0.345	-0.502	-0.556
RvLe	-0.265	-0.2	0.104	0.049	0.25	1	0.413	0.188	0.22	0.073	-0.275	0.354	0.085	0.555	-0.073	-0.149	-0.396	-0.612	-0.419	-0.246	-0.533	-0.345
RdLe	0.168	-0.132	0.042	-0.055	-0.083	0.413	1	-0.067	0.085	0.112	0.02	0.057	0.112	0.219	0.082	-0.32	-0.334	-0.097	-0.184	-0.348	-0.136	0.167
PopD	0.194	-0.37	0.537	-0.117	-0.134	0.188	-0.067	1	0.089	-0.072	0.036	0.067	0.065	0.072	0.276	0.282	0.18	-0.26	0.314	-0.022	0.043	0.187
Age	-0.172	0.051	0	-0.003	0.167	0.22	0.085	0.089	1	0.423	-0.627	0.352	0.542	0.294	0.127	-0.218	-0.022	0.052	-0.063	-0.348	-0.302	-0.408
PDia(1)	-0.261	-0.149	-0.258	0.047	0.335	0.073	0.112	-0.072	0.423	1	0.127	0.249	0.624	0.226	0.108	0.013	-0.095	0.072	-0.091	-0.215	-0.313	-0.426
PDia(2)	0.209	-0.21	0.018	-0.077	-0.048	-0.275	0.02	0.036	-0.627	0.127	1	-0.473	-0.145	-0.315	0.08	0.292	0.129	0.04	0.107	0.148	0.146	0.389
PiSt(1)	-0.465	-0.018	-0.184	0.224	0.367	0.354	0.057	0.067	0.352	0.249	-0.473	1	0.536	0.395	0.143	-0.105	-0.341	-0.202	-0.21	-0.132	-0.372	-0.559
PiSt(2)	-0.254	-0.033	-0.149	0.065	0.446	0.085	0.112	0.065	0.542	0.624	-0.145	0.536	1	0.207	0.034	-0.062	-0.031	0.075	-0.049	-0.282	-0.333	-0.323
wb	-0.545	-0.1	-0.011	-0.095	0.424	0.555	0.219	0.072	0.294	0.226	-0.315	0.395	0.207	1	0.054	-0.207	-0.251	-0.332	-0.29	-0.182	-0.427	-0.536
esd	-0.08	-0.161	0.247	-0.071	0.138	-0.073	0.082	0.276	0.127	0.108	0.08	0.143	0.034	0.054	1	-0.178	-0.008	-0.013	0.1	-0.082	-0.252	-0.144
mvc	0.164	-0.262	0.045	-0.256	-0.045	-0.149	-0.32	0.282	-0.218	0.013	0.292	-0.105	-0.062	-0.207	-0.178	1	0.256	-0.096	0.138	0.263	0.23	0.209
tsg	0.258	0.033	0.252	-0.299	-0.089	-0.396	-0.334	0.18	-0.022	-0.095	0.129	-0.341	-0.031	-0.251	-0.008	0.256	1	0.194	0.454	-0.228	0.081	0.343
mbw	0.106	0.281	-0.171	-0.172	-0.147	-0.612	-0.097	-0.26	0.052	0.072	0.04	-0.202	0.075	-0.332	-0.013	-0.096	0.194	1	0.063	0.19	0.349	0.139
cgl	0.048	-0.289	0.359	-0.131	-0.236	-0.419	-0.184	0.314	-0.063	-0.091	0.107	-0.21	-0.049	-0.29	0.1	0.138	0.454	0.063	1	-0.2	0.288	0.174
glf	0.272	0.085	-0.316	-0.248	-0.345	-0.246	-0.348	-0.022	-0.348	-0.215	0.148	-0.132	-0.282	-0.182	-0.082	0.263	-0.228	0.19	-0.2	1	0.404	0.129
blf	0.48	0.134	0.037	-0.042	-0.502	-0.533	-0.136	0.043	-0.302	-0.313	0.146	-0.372	-0.333	-0.427	-0.252	0.23	0.081	0.349	0.288	0.404	1	0.432
sbl	0.746	0.133	0.223	-0.179	-0.556	-0.345	0.167	0.187	-0.408	-0.426	0.389	-0.559	-0.323	-0.536	-0.144	0.209	0.343	0.139	0.174	0.129	0.432	1

8.4.2 Classification Accuracy

The Classification Table, from the SPSS output in Table 8-11 shows the overall percentage of correctly classified aggregated spatial units of the study area (151 areal units) in Figure 6-5. This is a basic and simple classification model, based on direct arithmetic combination of the original classification. The result shows that 66.2 per cent was successfully classified before the actual contributions of the independent variable are considered in the model.

Table 8-11: Classification Table$^{a, b}$

		Predicted		
		Occurence of Pipeline Third-party Interference		Percentage Correct
Observed		No Thirdparty Interference	Thirdparty Interference	
Occurence of Pipeline Third-party Interference	No Thirdparty Interference	100	0	100
	Thirdparty Interference	51	0	0
Overall Percentage				66.2

a. Constant is included in the model; b. The cut-off value is .500

The Omnibus Tests of Model Coefficients (Table 8-12), in the SPSS binary logistic regression, reports the collective significance levels of the independent variables and how they have performed in the model in order to predict the dependent variable. The test is, in general, a goodness of fit test and a significant value, e.g. less than (*p*<) 0.05 is preferable. The result from the model is less than 0.0001; hence, the model containing the whole independent variables is statistically significant. The reported chi-square value is 122.803, with 22 degrees of freedom; this shows that there is an adequate fit of the data to the model (Tabachnick and Fidell, 2007).

Table 8-12: Omnibus Tests of Model Coefficients.

		Chi-square	*df*	*Sig.*
	Step	122.803	22	.000
Step 1	Block	122.803	22	.000
	Model	122.803	22	.000

8.4.3 Multicollinearity and R^2

The SPSS output for the Model Summary (Table 8-13), indicates how the usefulness of the model in this thesis, and it is a preferable measure of the effect of size and strength of association. SPSS supports two R^2-like measures for binomial logistic regression analysis: the Cox and Snell's and the Nagelkerke's R^2. These two values provide an indication of the amount of variation in the dependent variable explained by the model. Both the Cox and Snell's and Nagelkerke's values are pseudo R square statistics rather than the general R square in multiple regression analysis. In this thesis, the Cox and Snell's and the Nagelkerke's values are 0.557 and 0.771 respectively, indicating that between 55.7 per cent and 77.1 per cent of the variability is explained by the variables (Table 8-13).

Table 8-13: Model Summary: Cox & Snell R Square, and Nagelkerke' values from the result from the Logistic regression analysis

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	70.335[a]	0.557	0.771

a. Estimation terminated at iteration number 9 because parameter estimates changed by less than .001.

8.4.4 Hosmer and Lemeshow Goodness-of-Fit

Table 8-14 presents the results obtained from the LR analysis for the Hosmer and Lemeshow chi-square test of Goodness-of-Fit that shows how worthwhile a model is, and it is considered to be the most important test of model fit (Tabachnick and Fidell, 2007). In the Hosmer and Lemeshow test of goodness-of-fit, a poor fit is indicated by a significance value of less than 0.05, especially in cases of continuous independent variables or in a model with a small sample size. In this thesis, the value of Hosmer and Lemeshow is 6.86, and a significance level of 0.552. This value is significantly greater than 0.05, as required for a well-fitting model, therefore the model adequately fits the data significantly and is very meaningful. This also implies that the model's estimates fit the data adequately.

Table 8-14: Hosmer and Lemeshow Test

Step	*Chi-square*	*df*	*Sig.*
1	6.862	8	.552

It is useful to note that the Hosmer and Lemeshow's goodness-of-fit test calculates the chi-square value from observed and expected frequencies, using the predicted probabilities from each separate case. The *p* value is then derived from the chi-square distribution with 8 degrees of freedom in order to test the fit of the model.

Table 8-15: Classification Table[a] for the final model

Observed			Predicted		
			Occurence of Pipeline Third-party Interference		Percentage Correct
			No Thirdparty Interference	Thirdparty Interference	
Step 1	Occurence of Pipeline Third-party Interference	No Thirdparty Interference	91	9	91
		Thirdparty Interference	6	45	88.2
	Overall Percentage				90.1

a. The cut value is .500

The Classification Table from the SPSS output (Table 8-15) indicates that the model correctly classifies 90.1 per cent of the cases. This is an indication of how well the model predicts the correct categories, that is, TPI or no TPI in a region. This is a significant improvement compared with result shown in Table 8-11, when the variables were not included in the model.

8.4.5 Assessing the Model: the Log-Likelihood Statistic

The (log) likelihood ratio statistic (-2 Log Q statistic) and the Wald statistic were used to assess the goodness-of-fit of the model in the LR. The Wald statistic is included in the output of the SPSS; the likelihood ratio statistic will be calculated to test the robustness of the model. The fitted LR model between the variables is given in Table 8-16, such that the regression equation is:

$$\begin{aligned}\boldsymbol{\mathit{In}}\ (\text{odds}) = {} & 0.262 - 0.11\boldsymbol{\mathit{PcBW}} - 0.011\boldsymbol{\mathit{PcLt}} + 0.014\boldsymbol{\mathit{HDI}} + 0.556\boldsymbol{\mathit{OilF}} \\ & + 0.378\boldsymbol{\mathit{PiLe}} + 0.04\boldsymbol{\mathit{RvLe}} + 0.169\boldsymbol{\mathit{RdLe}} - 0.003\boldsymbol{\mathit{PopD}} + 0.034\boldsymbol{\mathit{Age}} \\ & + 2.417\boldsymbol{\mathit{PDia\ (1)}} + 0.885\boldsymbol{\mathit{PDia\ (2)}} + 1.537\boldsymbol{\mathit{PiSt\ (1)}} - 0.136\boldsymbol{\mathit{PiSt\ (2)}} + 1.455\boldsymbol{\mathit{wb}} \\ & + 0.061\boldsymbol{\mathit{esd}} - 0.025\boldsymbol{\mathit{mvc}} - 0.046\boldsymbol{\mathit{tsg}} - 0.074\boldsymbol{\mathit{mbw}} - 0.159\boldsymbol{\mathit{cgl}} - 0.132\boldsymbol{\mathit{glf}} - 0.171\boldsymbol{\mathit{blf}} - \\ & 0.247\boldsymbol{\mathit{sbl}}\end{aligned} \qquad \text{(Equation 8.3)}$$

Table 8-16: Variables in the Equation, the logistic regression predicting likelihood of a region experiencing pipeline TPI

Variables	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
PcBW	-0.11	0.043	6.503	1	0.011	0.896	0.823	0.975
PcLt	-0.011	0.033	0.105	1	0.745	0.989	0.927	1.055
HDI	0.014	0.492	0.001	1	0.977	1.014	0.387	2.658
OilF	0.556	0.282	3.891	1	0.049	1.744	1.004	3.029
PiLe	0.378	0.113	11.127	1	0.001	1.459	1.168	1.821
RvLe	0.04	0.041	0.966	1	0.326	1.041	0.961	1.128
RdLe	0.169	0.271	0.389	1	0.533	1.184	0.696	2.014
PopD	-0.003	0.005	0.463	1	0.496	0.997	0.987	1.006
Age	0.034	0.116	0.087	1	0.768	1.035	0.825	1.298
PDia			4.221	2	0.121			
PDia(1)	2.417	1.196	4.082	1	0.043	11.211	1.075	116.931
PDia(2)	0.885	1.409	0.394	1	0.53	2.423	0.153	38.366
PiSt			2.192	2	0.334			
PiSt(1)	1.537	1.272	1.461	1	0.227	4.65	0.385	56.208
PiSt(2)	-0.136	1.815	0.006	1	0.94	0.873	0.025	30.614
wb	1.455	1.015	2.054	1	0.152	4.283	0.586	31.305
esd	0.061	0.047	1.717	1	0.19	1.063	0.97	1.165
mvc	-0.025	0.097	0.069	1	0.793	0.975	0.807	1.178
tsg	-0.046	0.055	0.697	1	0.404	0.955	0.858	1.063
mbw	-0.074	0.068	1.195	1	0.274	0.929	0.813	1.06
cgl	-0.159	0.145	1.198	1	0.274	0.853	0.642	1.134
glf	-0.132	0.061	4.646	1	0.031	0.876	0.777	0.988
blf	-0.171	0.083	4.276	1	0.039	0.842	0.716	0.991
sbl	-0.247	0.122	4.129	1	0.042	0.781	0.615	0.991
Constant	0.262	4.07	0.004	1	0.949	1.3		

a. Variable(s) entered on step 1: PcBW, PcLt, HDI, OilF, PiLe, RvLe, RdLe, PopD, Age, PDia, PiSt, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl.

This model can now be used to predict the odds that a region will experience pipeline TPI or that it will not. The Wald statistics for testing significance of the independent variables in Table 8-16 are approximately χ^2 (Chi-squared), with the degrees of freedom being given in the column 'd.f.'; the *p*-values in the corresponding column of some of the independent variables exceed 5% (Table 8-16). However, the degree of difference from zero for the Wald statistics was used to select the independent variables that go into the reduced model (Tabachnick and Fidell, 2007).

Rather than relying on the Wald test, the likelihood ratio test was used to test significance of independent variables and the goodness-of-fit of the overall model. The log likelihood ratio statistic (often called -2 Log L) for the full model, containing all independent variables is compared with the log likelihood for the reduced model, containing all independent variables except PcLt,HDI, RdLe, PopD, Age,mvc,tsg. For example, if the full model is significantly better than the reduced model, then the difference between *-2*

Log L(reduced) and *-2 Log L(full)* will be significantly large (Tabachnick and Fidell, 2007). In this case, the null-hypothesis that the excluded variables are non-significant is rejected. However, if the reduced model explains the data almost as well as the full model, then the difference will be close to zero, and the null-hypothesis that the excluded variables are non-significant can be accepted.

In the thesis, the model fit for the full model, taken from the SPSS output is given by (Table 8-13):

$$-2 \text{ Log L (full)} = 70.335$$

In order to test significance of the excluded variables, we compare the value -2 Log L(full) to the value of the model fit for the model with reduced variables based on the screening of the Wald statistic in selecting excluded variables. The model fit for the reduced model, repeating the SPSS calculations is:

$$-2 \text{ Log L (reduced)} = 78.174$$

Therefore, the log likelihood statistic is the difference between the two model fits, and is equal to 7.81. This result is an observation from a χ^2 distribution with 8 degree of freedom (d.f) (i.e. number of independent variables in the full model minus the numbers in the reduced model). From Samprit et al. (2000), the 5% critical value of the chi-square with 8 df is 15.51. Therefore, it is concluded that the excluded non-significant variables can be deleted from the model without affecting the predictive power of the original model. The final model is thus:

$$\begin{aligned}\boldsymbol{In}\ (\text{odds}) = {} & -0.417 - 0.078\boldsymbol{PcBW} + 0.501\boldsymbol{OilF} + 0.316\boldsymbol{PiLe} \\ & + 0.031\boldsymbol{RvLe} - 1.668\boldsymbol{PiSt\ (2)} + 1.061\boldsymbol{wb} + 0.054\boldsymbol{esd} - \\ & 0.078\boldsymbol{mbw} - 0.127\boldsymbol{cgl} - 0.109\boldsymbol{glf} - 0.133\boldsymbol{blf} - 0.149\boldsymbol{sbl}\end{aligned} \qquad \text{(Equation 8.4)}$$

8.4.6 The 'variables in the equation' in Table 8-16

The 'variables in the equation' table as given in Table 8-16 provide general information regarding the contribution of each independent variable to the final model. The *Wald statistic* (test), an output from SPSS, tests the significance of each variable. From Table 8-16 seven variables were considered to contribute significantly to the predictive ability of the model, using $p \leq 0.05$ as a cut-off standard for including variables in the equation: PcBW(p=0.011); OilF (p=0.049); PiLe (p=0.001); PDia(1) (p=0.043); glf (p=0.031); blf (p=0.039); and sbl (p=0.042). Therefore, the major significant factors influencing whether a spatial unit will experience TPI in the study area, are: socioeconomic factor (percentage of household with water); total area of oilfield; total length of pipelines; pipeline diameter; percentages of mosaic grassland/forest or scrubland land use; broad leaved forest (blf); and shrubland/grassland (sbl). The age of pipeline, volume of roads; population density and all other factors did not significantly contribute to the performance of the model. However, there are observed difference between the Poisson GLMs and Logistic GLMs, while some variable are significant in the earlier model (e.g. pipeline status), they are not significant in the later. The reason could be the objectives of the two separate models, described Section 8.6.

The relationship between other variables not mentioned above and "a region experiencing pipeline TPI" were found to be statistically not significant for the model (p>0.05). While these variables may not be important in the prediction model, there were still significant differences in these variables regarding their influence on the occurrence of TPI, especially as supported by earlier empirical studies, e.g. hotspot spatial analysis (Chapter 7).

8.4.6.1 The *B* Value

The '*B*' values in Table 8-16 are the equation parameters that will determine the probability of whether a region/areal unit will experience TPI or it will not. The mathematical sign (+ or -), in the tabled '*B*' values also determines the direction of the relationship. For example, which factor, when increased, will increase or decrease the likelihood of a region to experience pipeline TPI. A negative '*B*' value indicates that increasing an independent variable results in the probability of a region recording a score of 1, and in this case, a region will be likely to experience pipeline TPI.

The variable 'percentage of households with pipe borne water' in the study area, a proxy measuring a major socioeconomic factor, showed a negative '*B*' value (-0.11). This shows that the higher the provision of such an infrastructure quality measure to a region, the less likely it is that the region will experience pipeline TPI. The same conclusion was drawn when investigating the relationship between the possibility of pipeline TPI and overall length of pipeline in a region. The variable, 'total pipeline length' in a region showed a positive '*B*' value (0.378), suggesting regions with higher cumulative lengths of pipelines are more likely to experience pipeline TPI. This result indicated that each additional kilometre of pipeline significantly increased the odds of the occurrence of pipeline TPI, other variables being fixed.

The significant category variables in the model, the pipeline diameter, showed each category having a positive 'B' value. This indicates that pipelines in this particular category are more likely to experience pipeline TPI. However, the land use, Mosaic grassland/forest or scrubland land use; Broad leaved forest (blf); and Scrublands/grassland (sbl) all showed a negative '*B*' value (-0.132; -0.171; and -0.247 respectively). This value suggest these land use types offer less likelihood of (or are not contributory to) pipeline TPI occurring compared with other types of land use.

8.4.6.2 The Exp(B) and The Wald Statistics

The Exp(B) column in the *'Variables in the Equation'* Table 8-16 is the exponentiation of the *B* coefficient, and is the odds ratio (OR) for each of the independent variables. This is the change in odds of being in one of the categories of the dependent when the value of an independent variable increases by one unit (Tabachnick and Fidell, 2007). Because it could be deduced that the logistic regression odds ratio bear a resemblance to relative risk, therefore, the exponentiation of the 'B' coefficient could be used to determine the risk of a region experiencing a TPI.

The 'total length of pipeline' in a region is another significant independent variable in the model, with a significance value of 0.003. It can be seen from the result in Table 8-16 that the odds ratio is 1.918, a value greater than 1. This indicates that when holding all other variables constant, the more pipelines a region gets or has, the more likely it is to experience pipeline TPI; therefore, for every additional one kilometre of pipeline a region gets increases the odds of experiencing TPI by a factor of 1.918, all other factors being equal. However, the odds ratios described above are interpretable with 95 per cent confidence interval as shown in the 'Variables in the Equation' table (95% CI for EXP(B)) displaying the lower and upper value. The 95 per cent confidence encompasses the true value of the odds ratio.

Table 8-17: Casewise List[b]

Case	***Selected Status***[a]	***Observed*** TPI	***Predicted***	***Predicted Group***	***Temporary Variable*** Resid	ZResid
63	S	T**	.053	N	.947	4.215
73	S	T**	.019	N	.981	7.145
82	S	N**	.775	T	-.775	-1.855

*(a). S = Selected, U = Unselected cases, and ** = Misclassified cases. (b). Cases with studentized residuals greater than 2.000 are listed.*

Table 8-17 gives information about cases (regions) in the sample that the model does not fit properly, and these are determined by cases with ZResid values greater than 2 and are considered misclassified cases. For example, some regions (region 63 and 73) were predicted to have pipeline TPI, but in reality have not experienced TPI. The three regions misclassified could be considered negligible, 2 per cent of the total regions.

8.4.7 Discussion of Significant Variables in the Model

8.4.7.1 Age of pipeline

The age of a pipeline was found to be statistically insignificant at $p = 0.768$ ($p > 0.05$), however, the Exp(B) is1.035 and indicated that if the age of a pipeline is increased by one year, the odds or risk of an occurrence increases by a multiple of 1.035, controlling other variables in the model. Therefore, it can be concluded that an increase in age, yearly, of a pipeline may be positively associated with a change in the odds of possible occurrence of TPI, when all other variables are held constant.

8.4.7.2 Percentage of households with pipe borne water

The percentage of households with pipe borne water was found to be statistically significant at $p = 0.011$ ($p < 0.05$). The corresponding Exp(B) is 0.896 in the model, and indicated a slight negative relationship between percentage of households with pipe borne water and the occurrence of pipeline TPI. A 1 per cent increase in households with pipe borne water reduced the odds of occurrence of pipeline TPI by a multiple of 0.896 or 10.4 per cent holding all other variables constant in the model.

8.4.7.3 Area of oilfield

The area of an oilfield was found to be statistically significant at $p = 0.045$ ($p < 0.05$), and the corresponding Exp(B) value of 1.744 indicated that there is a positive relationship between the area of oilfield and the occurrence of TPI. This result is similar to the results obtained from the Negative Binomial GLMs (Section 8.3.5), thus if the area of an oilfield in a region is increased by one square kilometre, the odds or risk of an occurrence of pipeline TPI increases by a multiple of 1.744, holding all other variables constant in the model.

8.4.7.4 Population density

The variable population density was not found to be statistically significant at $p = 0.496$ ($p > 0.05$), and the corresponding Exp(B) is 0.997 in the model, and indicated a slight negative relationship between population density and the occurrence of pipeline TPI.

Therefore, an increase in population density, measured by persons per square kilometre will reduce the odds of occurrence of pipeline TPI by a multiple of 0.997 or 0.3% holding all other variables constant in the model.

8.4.7.5 Pipeline Diameter

The categorical variable, pipeline diameter, has two levels: *1*, pipelines less than 12inches in diameter and *2*, pipelines greater than 12 inches in diameter. For the first category of pipeline diameter, the odds ratio (Exp(B)) is 11.21. Therefore, the odds of not experiencing TPI compared to experiencing it are decreased by a factor of 11.21 when the region is dominated with pipelines less than 12 inches compared to regions with pipeline greater than 12 inches in diameter, controlling for other variables in the model. However, the other category, pipeline diameter greater than 12 inches, is not significant in the model.

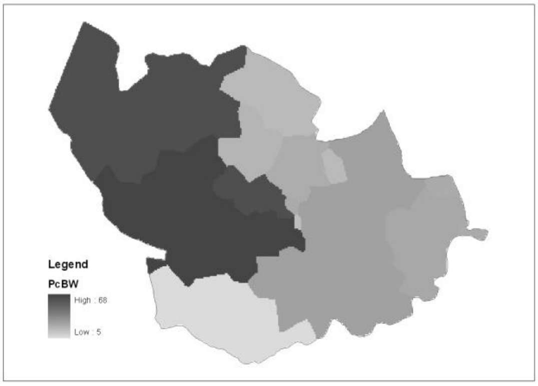
8.4.8 The final Logistic Regression results

A direct logistic regression was performed on the likelihood of a region to determine if such was to experience pipeline TPI or not considering various variables of factors described in Chapter 5. Table 8-16 shows the logistic regression coefficient, the Wald test results, and odds ratios for the independent variables. The model contained twenty four independent variables (Table 8-1).

The full model for the logistic regression was determined to be statistically significant $X^2(29, N=151)=143.08, p<0.001$, indicating that the model developed for the analysis was able to distinguish between regions that experienced and those that did not experience pipeline TPI. The model was also able to explain 61.20 per cent (Cox and Snell R square) and 84.40 per cent (Nagelkerke R squared) of the variance in the status of pipeline TPI and correctly classified 94 per cent of the designated regions into the two membership groups.

In addition, using the 0.05 criterion of statistical significance, seven independent variables were found to make a strong statistical significant contribution to the regression model (pipeline status- buried or aboveground); age of pipeline, length of roads; presence of oilfields; population density, capital expenditure on spatial units, and types of land use (excluding the mosaic grassland/forest or shrubland).

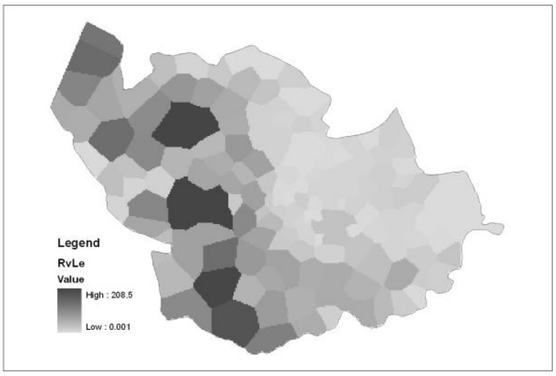
Figure 8-6: Created surface maps from the coefficients derived from Equation 8.5 for each of the independent variables using ArcGIS Raster Calculator.



-0.078***PcBW***

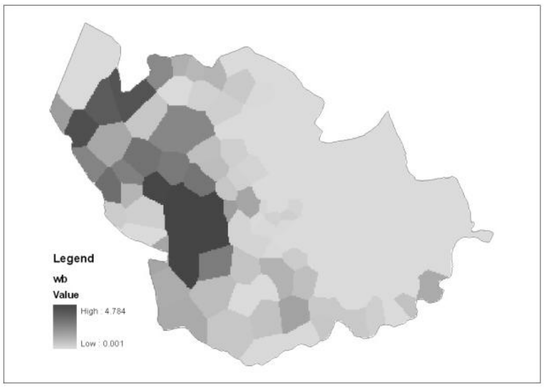
0.501***OilF***

0.316***PiLe***

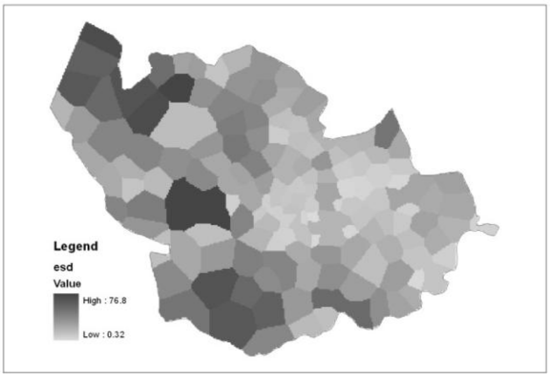


0.031***RvLe***

-1.668***PiSt (2)***

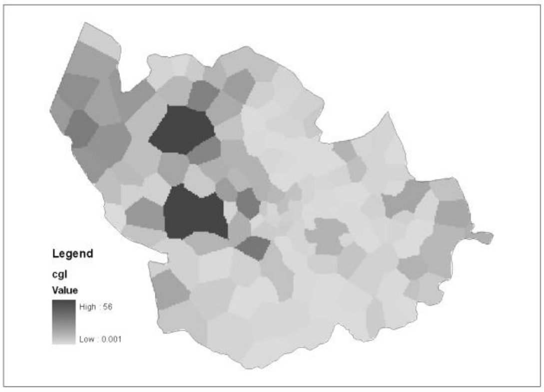


1.061***wb***

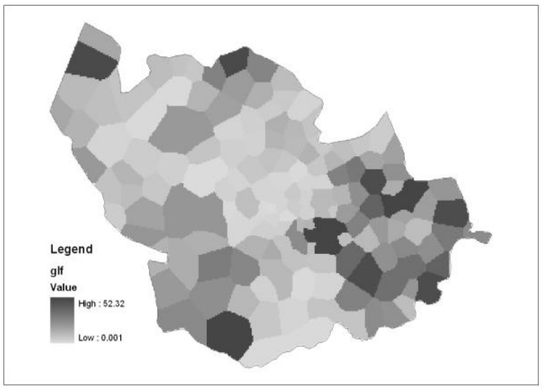


0.054***esd***

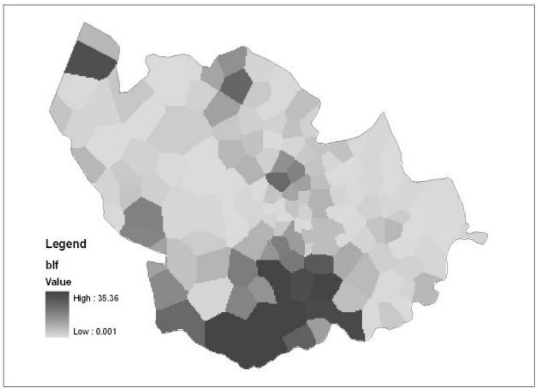
-0.078***mbw***



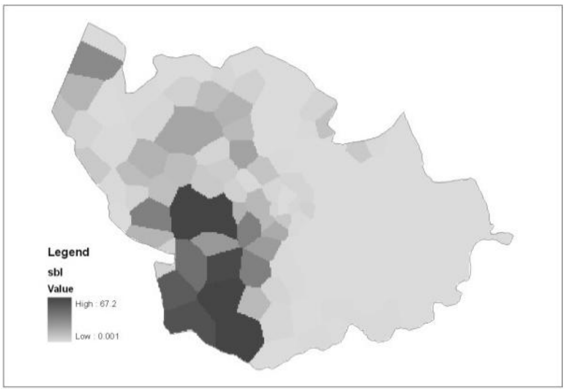
-0.127***cgl***



-0.109***glf***



-0.133***blf***



-0.149***sbl***

8.5 Map Building: Applying the LR model to ArcGIS

The significant variables in the final model were reclassified and transformed into a GIS raster format. The various generated coefficients, based on the resulting Equation 8.3 were applied to the variables to generate an ArcGIS prediction map. The generated maps from the ArcGIS outputs were classified into different classes for visualization. Figure 8-17 presents the results obtained from the ArcGIS raster manipulation analysis of the generated coefficients from the logistic regression model.

$$\textbf{\textit{In}}\ (\text{odds}) = -0.417 - 0.078\textbf{\textit{PcBW}} + 0.501\textbf{\textit{OilF}} + 0.316\textbf{\textit{PiLe}} + 0.031\textbf{\textit{RvLe}} - 1.668\textbf{\textit{PiSt (2)}} + 1.061\textbf{\textit{wb}} + 0.054\textbf{\textit{esd}} - 0.078\textbf{\textit{mbw}} - 0.127\textbf{\textit{cgl}} - 0.109\textbf{\textit{glf}} - 0.133\textbf{\textit{blf}} - 0.149\textbf{\textit{sbl}} \qquad \text{(Equation 8.5)}$$

The raster calculator in ArcMap was applied to the formula in Equation 8.5, generated from the prediction model of LR analysis using the following procedure:

$$\textit{variables1} = (-0.078 * [\textit{PcBW}]) + (0.501 * [\textit{OilF}]) + (0.316 * [\textit{PiLe}]) + (0.031 * [\textit{RvLe}]) + (-1.668 * [\textit{PiSt\_2}]) + (1.061 * [\textit{wb}]) + (0.054 * [\textit{esd}]) + (-0.078 * [\textit{mbw}]) + (-0.127 * [\textit{cgl}]) + (-0.109 * [\textit{glf}]) + (-0.133 * [\textit{blf}]) + (-0.149 * [\textit{sbl}]) \qquad \text{(Equation 8.6)}$$

The [variables1] in Equation 8.6 is based on Equation 6.19, in Section 6.6.4. Therefore, the log of the odds for occurrence of pipeline TPI is: *logodds = (-1 * (-0.417 + [variables1]));* and the *odds = EXP([logodds]).*The *logodds* and *odds* is then used to calculate the final probability map for the model.

The Probability = (1 / (1 + [odds])) (Equation 8.7)

Figure 8-7 presents the application of equation 8.7 to the study area, and is the probability of occurrence of pipeline TPI in the study area. The probability map based on the GIS output groups the occurrence of pipeline TPI into classes showing a graduated colour maps to represent a range of classes of probabilities of pipeline TPI.

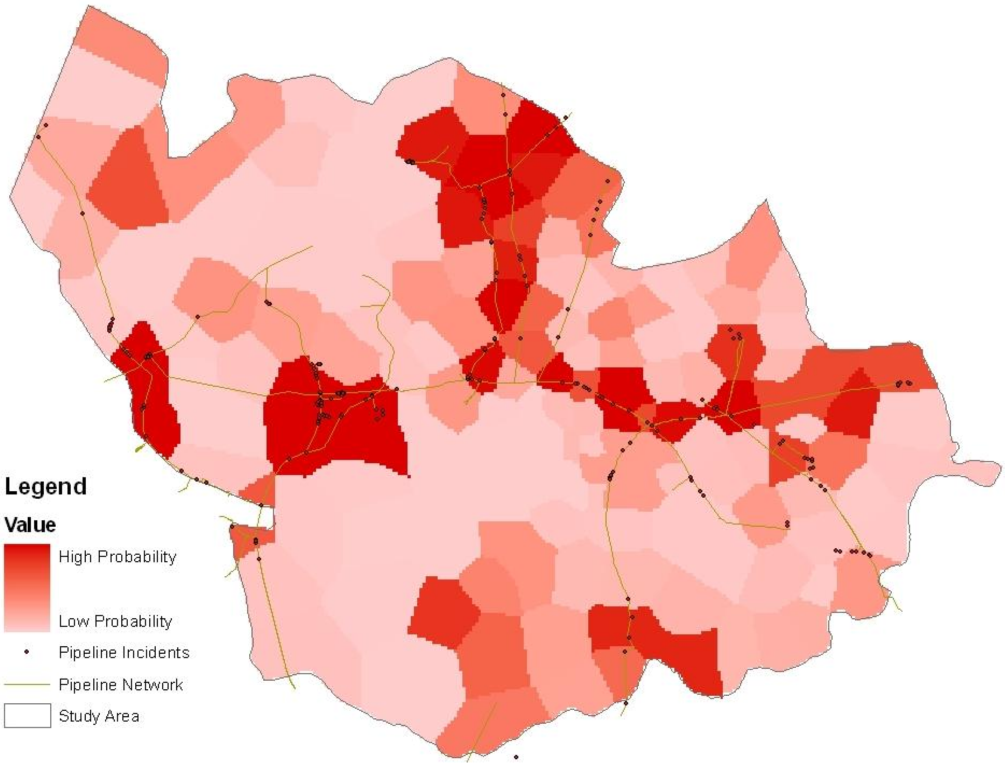


Figure 8-7: Probability of pipeline TPI to occur in the study area.

8.6 Summary

This chapter explains the conceptual framework, the assumptions and the appropriateness of using the GLMs in conjunction with GIS spatial data. Independent variables that are expected to influence the occurrence of TPI are explained, together with the interpretation of the results obtained. The result of the Poission GLMs showed that pipeline diameter, length and status (buried or aboveground), area of oilfield, water bodies, and land use are the significant predictors of TPI. On the other hand, the result of the Binomial Logistic regression analysis for the thesis showed that pipeline age, socioeconomic factors (percentage of households with pipe borne water), area of oilfield, population density, land use, and pipeline diameter are the significant predictor of TPI in the study area. The negative and positive effects of the significant variables on the odds of TPI occurrence are as expected. Therefore, to obtain predicted odds of occurrence for TPI for a region, values of the corresponding variables for a particular region are substituted into equation 8.2.

Binary logistic regression models and Poisson generalised linear models can be used to describe and analyses association between variables, to understand how it influences the occurrence of an event. However, an important practical distinction is that the Logistic regression is a predictive analysis procedure that produces probability predictions of whether a region will experience TPI or will not (or high/low risk of TPI), while the Poisson generalised linear models procedure study and estimate an incidence rate of an event from the independent variables. Specifically, the comparison of the two analyses (Negative Binomial GLMs and Logistic Regression) for the thesis shows that land use, area of oilfield, and pipeline diameter are common significant variables to the models.

The negative binomial GLMs proved to be useful both for identifying the possible numbers of failures and for understanding the relationship between influencing variables. However, after the occurrence of TPI in a network, subsequent maintenance using a predictive model, like the logistic regression becomes more useful to predict probability of a region to experience another TPI rather than the expected numbers of future occurrence. These fully acknowledge the significance of logistic regression over the negative binomial GLMs. While this thesis did not confirm the influence and significance of the overall factor hypothesised, it did partially substantiate the recognition of pipeline intrinsic variables that past researches have acknowledged. The results also show that a combination of these two methods is preferable for technical understanding and prediction for TPI.

The following two chapters will discuss the main design, methodology and analysis of the data gathered from the questionnaire survey utilised as part of this thesis. The rationale is to come up with pertinent findings about pipeline TPI and to augment the recommendations provided in the thesis.

9 QUESTIONNAIRE SURVEY: RESEARCH METHODS

9.1 Introduction

This thesis is based on a mixed-method approach to the understanding of the occurrence of pipeline TPI. Hence, additional qualitative data collection and analyses form part of the study. This method allow for a range of creative solutions to be employed to help to resolve the difficulties of getting pipeline data, generally considered to be confidential, from organisations. This prompts the need to use a questionnaire survey, most importantly, to get a consensus view and perception from the pipeline industry about TPI. The mixed and complex proposal of this thesis to examine both intentional and unintentional TPI necessitates a combination of statistical methods for the primary analysis of the questionnaire.

This chapter describes and justifies the different aspects of the questionnaire survey implemented as part of this thesis, including the significance of the survey, data collection, survey instruments, design procedure and the statistical techniques. The survey used a web-based approach for recruiting respondents from government agencies, academia, private companies, professional bodies, and pipeline service providers. The respondents selected were involved in the planning, design, installation and maintenance of pipelines worldwide. The survey assessed each respondent's demographic characteristics, opinions, experiences, management practice, and perception of both intentional and unintentional TPI.

As the questionnaire survey elicited the opinion regarding pipeline TPI from those who are directly involved, the survey thus enhanced and provided additional understanding and salient knowledge regarding TPI. In general, it provided a new insight into this problem area and ways to understand practical strategies being adopted in the oil and gas industry. It also provided a valid and reliable survey base for future research.

The result of questionnaire survey is used to compared and further discuss the results of the various GIS-based statistical analyses implemented in the thesis. For example, the insights from the content analysis of the open-ended survey responses also unveil interesting perceptions and opinion from the industry experts on TPI.

The significance and the structure of the questionnaire survey are described in Sections 9.2 and 9.3 respectively. The adopted methodology and the analysis techniques are discussed in Sections 9.4 and 9.5 respectively, while Section 9.6, 9.7, and 9.8 discusses the analysis of the open-ended questions, limitation and conclusion respectively.

9.2 The Adopted Use of Internet Survey

Online or internet questionnaire surveys are easy to manage, cost-effective, and most importantly, they are environmentally friendly. They are similar to mail surveys, and are becoming increasingly popular because of their low cost, speed of data collection and easy data collation (Dolnicar et al., 2009). However, Czaja and Blaire (2005) point out some recognised drawbacks of internet surveys. They observed that internet accessibility is still not affordable by the entire population and therefore the difficulty in extracting a representative sample from internet users is one of the disadvantages of internet survey. They further identified the likelihood of low response rate, potential response biasness, web security for anonymity, knowledge of website design, and computer literacy as other major disadvantages of internet survey.

However, contrary to the reasons presented above by Czaja and Johnny, the present study was designed for a special population and the sample frame is more likely to have high internet usage compared to the rest of the population (Kaplowitz et al., 2004). In addition, the world internet users and usages are increasing exponentially, for example, over 300% users' growth was reported between 2000 and 2008. Literature also argued that the ease of collecting data from an international sample and the positive cooperation with respect to open-ended questions are some of the many advantages of internet survey over other methods of questionnaire survey (Czaja and Blair, 2005, Bertot, 2009). In summary, a web-based survey has the following advantages over other modes of expert opinion polling:

- Minimal cost and eco-friendly
- Immediate transmission to respondents
- Utilisation of advanced security features
- Time efficient by the elimination of paper mail procedures
- Automatic filtering of questions and respondents
- The conveniences of time to respondents to response to the survey

- Software based for automated and reminder e-mails
- The possibility of graphics, animation and large text usage
- Management of space to accommodate longer open-ended questions
- A possibility to combine the survey answers with pre-existing information

9.3 Structure Development of the Questionnaire Survey

The questionnaire survey used a web based HTML content interface. The target gruop (government agencies, academia, private companies, professional bodies, and pipeline service provider) completed the questionnaire between November 2008 and March 2009. The survey was in three sections, consisting of the demographic data and organisational details (Section I); perception about unintentional pipeline damage (Section II); and perception about pipeline intentional TPI (Section III). The summary section requested extra feedback from respondents about TPI not raised in the survey. The complete sample of the questionnaire survey is included in Appendix III. Figure 9-1 shows the summarised methodology adopted for the questionnaire survey.

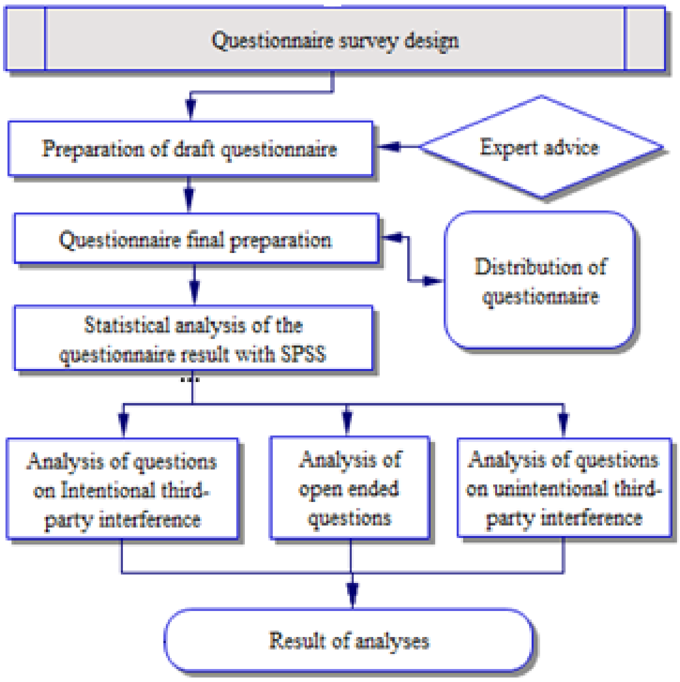


Figure 9-1: Summarised methodology flowchart adopted for the questionnaire survey.

Multiple regression statistical analysis method was used to explore relationship and perception about motivation for intentional TPI, and to predict an organisation's effort in mitigating intentional TPI. A two-way between-groups analysis of variance (ANOVA) was used to explore the perception about TPI of countries and organisations, while a Kruskal-

Wallis Analysis of Variance test was used to examine significant statistical difference in a developed risk mitigation scale. A multidimensional scaling (MDS) analysis on respondents' perceptions about various methods of preventing TPI during and after pipeline installation was transformed into spatial maps to reveal different spatial clusters of preferences.

9.3.1 Section II of the Questionnaire Survey

Section II of the questionnaire survey comprises questions that seek the opinion of the respondents about unintentional TPI. The respondents were also asked how they agree with the following statements about pipeline safety and security in Section II of the questionnaire survey (Questions 1-4):

i. Pipeline security is a worldwide problem that needs a serious attention as any other sector of the economy.
ii. A pipeline surveillance technology should protect only vulnerable segments of a pipeline network.
iii. Although TPI is the leading cause of pipeline damage, it is currently under-researched.
iv. Pipeline safety regulations now existing are satisfactory for preventing TPI.

These questions were included because it is important to understand the perception of the industry about TPI, especially from organisational representatives. In addition, it was comprehended that the absence of these types of questions as part of the survey will make the overall objectives meaningless.

Question 5 is an open-ended question, and respondents were asked to suggest the other various methods of preventing pipeline TPI. This is in case their representative organisations do implements other methods of prevention not mentioned in the survey. The next closed-question (Question 6) in Section II of the questionnaire survey asked respondents which of the following they prefer for the physical security of pipeline networks, representative of their organisation: (a) perimeter fencing of pipelines right-of-way; (b) electronic monitoring and intrusion detection; (c) pipeline communications security techniques; (d) pipeline surveillance and monitoring; and (e) company specific measures. These questions were asked because it is perceived that different organisation have additional *company-specific* methods for preventing TPI, and this may form part of a growing body of literature on preventing TPI.

The next question (Question 7) asked respondent's expert opinion regarding developing a risk mitigation strategy for a pipeline network. TPI cannot be eliminated, therefore, risk mitigation strategies are required by the pipeline industry to minimise the likelihood and lower the impact of any eventualities. Based on a review of the literature, (e.g. Muhlbauer (2004); Baybutt (2002); Meshkati (1996); and Corder (1995)), respondents were asked to rank on a ten-point scale ranging from most important to least important, the extent of the role of the following techniques as a risk-mitigation strategy for pipeline security assessment, representative of their current work environment. The techniques are:

(a) Threat assessment of pipeline network;
(b) Community relations and public education;
(c) The role of host government;
(d) Prosecution and punishment of offenders;
(e) Inaccessibility of facilities by road, etc;
(f) Developing an integrated security plan;
(g) Incident response capability;
(h) Environmental response;
(i) Personnel security surveillance on the pipeline; and
(j) Physical protection of the pipeline.

The respondents' rankings were converted to a scale, a risk score of 1 was considered acceptable, a score of "5" considered the *judgemental boundary*, and a risk score of "9" was considered unacceptable. Ranking items on this scale represents a more comparative decision strategy compared to other measurement techniques in qualitative surveying, because straight opinions are eliminated.

The next sets of questions in this section were on TPI prevention during and after pipeline installation. These questions were designed to seek a respondent's preference, viewpoint and awareness of various existing methods and measures for protecting pipeline. Therefore, Questions 9 and 10 of the questionnaire asked respondents to complete a 7-item list on 5-point rating scale (from excellent to poor) to measure their perception regarding various methods of preventing TPI during and after pipeline installation. The list included sleeve as additional protective layer; slabs, tiles and plates over pipelines; high tensile net buried above pipeline; increasing pipeline wall thickness; marker posts along pipeline length; marker tape above pipeline; and fibre optics installed at intervals.

According to recent statistical studies, TPI has increased slightly over the last few years (Williamson and Daniels, 2008, Achim et al., 2007, Cao et al., 2005). Therefore, Question 11 of the questionnaire survey asked respondent's opinion regading TPI over the past ten years. The questions asked whether TPI as a problem has been: (a) reduced; (b) eradicated; (c) slightly increased; (d) increased vastly; (e) remained the same; (f) undergoing development in solution; (g) paid less attention; (h) can't be controlled by technology. This item was analysed using descriptive statistics.

9.3.2 Section III of the Questionnaire Survey

Intentional TPI is described in Section 1.3.1. The study area, like many countries throughout the world (e.g. Iraq, Mexico, Columbia, Venezuella, United States), is facing an increasing challenge in dealing with intentional TPI. In addition, most agencies and pipeline operators have had difficulties designing preventive strategies into their decision-making process, Section III of the questionnaire survey explore the opinion of the respondents regarding intentional TPI. The first question of this section asked respondents how their organisation's surveillance procedure of pipeline monitors the following: (a) pipeline vandalism; (b) theft of product; (c) sabotage (internal and external); (d) guerrilla attacks; (e) likelihood of terrorism; (f) intrusion into aboveground facilities; (g) right-of-way encroachment; and (h) and cyber attack.

Questions 2 to 5 of Section III of the questionnaire survey, termed *Organisational Efforts' scale*, used a five point Likert-type scale (very poor to very good). The items of the survey included: (Question 2) how would you rate your organisation's ability to identify pipeline terrorism, vandalism, theft, sabotage or criminal activities; and (Question 3) how has your organisation sought to identify areas vulnerable to intentional interference. The two last question of this scale are: (Question 4) is guidance being sought on pipeline security and damage control from: the insurance industry, security agency, and the communities; and (Question 5) how well do you work with vendors of monitoring schemes and technologies to detect incidents of TPI on your pipelines. In the collation of the result, a *summed* high score, for example, represents a high approach and stance to mitigate intentional TPI, and is taken as representative of a respondent's organisation. Question 6 is an open-ended question that asked respondents to state what simple methodology they considered as most effective for protecting pipeline against TPI.

Questions 7 to 12 of Section III of the questionnaire survey are termed *Occurrence Factor* of intentional TPI. High scores represent a respondent's knowledge and perception of prevention priority for intentional TPI. The respondents were asked how they agree with six Likert scale items as the major factors affecting the occurrence of intentional pipeline damage from strongly disagree (1) and strongly agree (5). The scale items are: (i) Population distributions (urban growth with people now leaving close to pipelines); (ii) Land use and human activities (e.g. farming, commercial area, industries, and construction activities); (iii) The socio-economic conditions of population living near a pipeline (e.g. demography, morbidity, occupations, health, and social infrastructure; (iv) Accessibility to pipeline network (proximity of roads, rivers, streams and rail); (v) Socio-political factors (e.g. literacy rate, employment, political stability violence, revolutions, and rebels etc); and (vi) Depth of pipeline (exposed pipeline can often provide criminal opportunities). Accordingly, the reasons for the above questions are because bodies of literature have not examined exhaustively the factors affecting the occurrence of TPI the attention it deserves. In addition, a more thorough understanding of the causes and effects of TPI is required. Moreover, prevention methods cannot be optimally employed until these factors are better understood.

Questions 15 to 20 of the questionnaire survey examined motivation for TPI, where high scores represent the perceived objectives of intentional TPI. The scale's item are agreements with the following statements: (1) third-party-interference is an indirect attack on the government; (2) an avenue to draw attention and promote or publicise unrelated issues in the country; (3) a form of protest for political, social and environmental reasons. The other items are: (4) poverty level and socioeconomic condition influence indirect intentional TPI; (5) to incite the public against her government's inability to provide basic services and security; and (6) no extent of security and surveillance can mitigate intentional sabotage and vandalism of pipeline. Every intentional pipeline TPI is motivated by something, and it depends on the interaction of various factors. Thus, the above questions, Questions 15 to 20 of the questionnaire survey are asked to understand respondent's perception and comments on what factors motivates intentional TPI. For example, is TPI motivated by financial rewards, revenge, and job security? If organisations understand the primary motivations for TPI, it is perceived that they will be able to establish clear principles and priorities for prevention of TPI.

All other questionnaire questions not included above are open-ended question, and were separated from the forgoing and analysed separately. Open-ended questions in a questionnaire survey are unanswerable directly with, for example, a simple "yes" or "no", detailed specific comments or answers are required. These included the following questions (Appendix III shows the question's items):

a) Do you have any further opinion about preventing and monitoring pipeline TPI? (Section-II: Question 5)
b) Which other method do you prefer for physical security of pipeline networks? (Section-II: Question 6g)
c) Question nine, section two: what other pipeline damage prevention measures will you suggest that will mitigate damage cause by third-party activity during installation (Section-II: Question 9i)
d) What other Pipeline damage prevention measures will you suggest that will mitigate damage cause by third-party activity post installation (Section-II: Question 10h)
e) What simple method would you suggest is most effective for pipeline damage prevention? (Section-III: Question 6)
f) What other factors influence the occurrence of intentional pipeline damage? (Section-III: Question 13)
g) Do you have any feedback or observation about pipeline third-party damage not covered by this questionnaire?

9.4 Adopted Methodology for the Questionnaire Survey

The development of the questionnaire survey was completed after an extensive review of the literature, to determine the various survey variables. The final data collection instrument consisted of seventy items regarding demographic characteristics, pipeline safety and security practice, damage prevention, protection characteristics, as well as opinions about factors influencing intentional pipeline interference. Prior to carrying out the survey, all ambiguous questions were revised or discarded for clarity, in a pilot-like survey (Kent, 2001).

The survey utilised different response formats, including multiple-choice questions, Likert scales (and items), and open-ended questions. A Microsoft Excel database was used to collate the raw information from the survey, and was imported into SPSS statistical software for analysis. SPSS (Statistical Package for the Social Sciences) like Excel, SAS, and

MINITAB is suitable for analysis of survey data, and the responses to the questionnaire are taken as variable and coded as numeric code, for example, sex is be coded as something like *1*=male, *2*=female. In each section, first general statistical analysis was conducted consisting of descriptive statistics to characterise respondents and explore response patterns, by measuring differences in opinions, experiences, and perceptions by respondent's occupation, country, organisation (government agency, academia, professional body, service provider, and private companies).

A five-point Likert scale (from strongly agree to strongly disagree), Likert item (excellent to poor), and a ten-point ranking scale (very important to least important) were used in the three sections of the questionnaire. Likert scale, a bipolar scaling technique, is one of the most popular measurement procedures in science and technology; it measures preferences, attitudes, and subjective reactions (positive or negative) to a statement. Likert item are either interval or ordinal. They are ordinal data when using levels for response without the assumption of equidistant between each level of option, and could be analysed using non-parametric tests, such as the Mann-Whitney test or the Kruskal-Wallis test. However, when summed in several related Likert items, they may be treated and analysed as interval data and parametric statistical tests, (e.g. regression analysis) is applicable.

The Likert scales can also be reduced to nominal data by aggregating responses into two categories of "accept" or "reject". A considerable amount of literature has been published on Likert scales. These studies have enumerated the advantages and disadvantages of Likert scales. Previous critique studies have reported the likelihood of respondents' central tendency bias; the '*sitting-on-the-fence*' scenario; or attempt to personalise and portray issues in a more favourable light. In summary, a large and growing body of literature favoured Likert scale, and it has become one of the most and widely used techniques despite these critiques (Mearns and Yule, 2009, Clason et al., 2007, Kent, 2001, Matell and Jacoby, 1971).

9.4.1 Survey Procedures and Sample

There is a need in any survey to select the right sample (group) from the population to represent the entire population, because, in general, questionnaire surveys create many non-respondents, and therefore getting the right people to participate is important. Samples are determined using either probability or non-probability sampling techniques.

Non-probability sampling is non-random, and includes systematic sampling, convenience sampling, quota sampling, and snowball sampling (Thomas, 2004). The questionnaire survey in this thesis utilised the quota recruited non-probability method of sampling. This method is similar to stratified probability (random) sampling where identified subgroups (e.g. pipeline industry of the oil and gas sector) are the sample frame. The recruited sample enlisted respondents from the subgroups via e-mail and they are provided with the URL of a web-based questionnaire.

9.4.1.1 Reliability and Validity

All measurements in science come with some degree of error, which could be human or observational, producing another different set of variables. This variability is an integral part of survey measurement, even if repeatedly taken, because slightly different results are obtained at each attempt. Therefore, there is the need for consistency of scores of any measuring instrument. This measurement is known as *reliability*, and it concerns the accuracy of a measure in a survey, for example, are a set of questions accurate? While *validity,* on the other hand concerns the actual question under measurement, for example, what does the question actually measure?

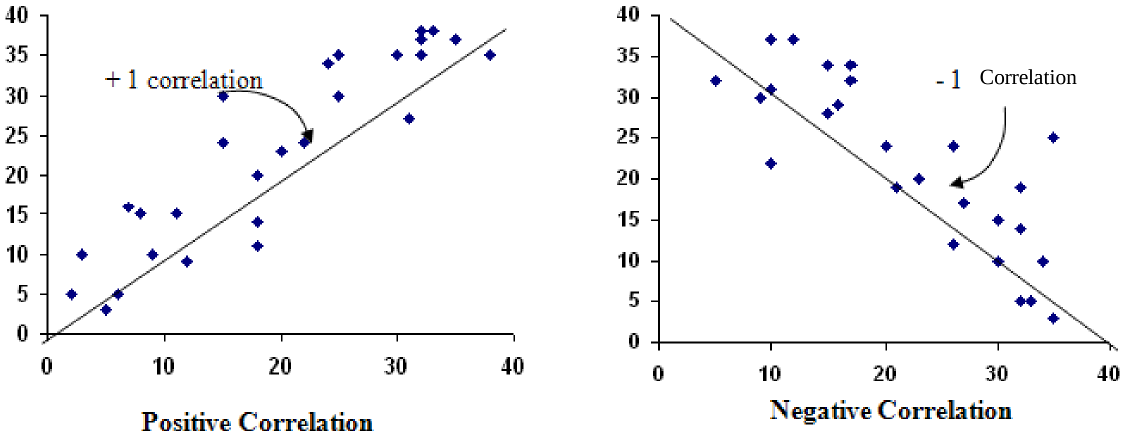
As stated above, *reliability* is the test of assurance for a measurement to produce same result repeatedly. The SPSS alpha model method measures *reliability* for a group of questions in a questionnaire survey, and was used in the thesis to measure the consistency of all the *summated rating scale* and Likert type scaled questions. The Cronbach's Alpha measures the average of all possible reliability coefficients, and if this alpha is 0.7 and above, the items are reliable, as a rule of thumb (Coakes, 2005, Kent, 2001, Nunnally, 1978). All related items needing this test in the questionnaire survey passed the reliability and validity test.

9.5 Statistical Techniques

A statistical problem requires the selection of the most appropriate statistical technique. The following section describes the statistical tests selected and implemented for the results of the questionnaire survey.

9.5.1 Spearman's Rank Order Correlation Analysis

Spearman's Rank Order Correlation analysis describes the strength and direction of linear relationship between two or more variables without removing the effects of other variables. This method of statistical analysis is measured as Spearman's Rho, a non-parametric correlation analysis method. The measurement for correlation is designated *Pearson's Product Moment Correlation Coefficient*, or Pearson's *r* (Tabachnick and Fidell, 2007, Bryman and Cramer, 1997). The correlation results for Spearman correlations are between +1 and -1, and results from data analysed are interpreted in the same way.



Positive Correlation

Negative Correlation

Figure 9-2: Examples of correlation relationships, illustrating the two typical cases of correlation (positive and negative correlation), adapted from Tabachnick and Fidell (2007).

A positive correlation of *r* = 1.0 would means the line's slope is at 45 degrees upward, and a negative correlation of *r* = -1, is at 45 degrees downward, for example, if correlation, *r* = 0 with a horizontal line, there is no correlation or a significant relationship. However, a correlation approaching +1 is said to be positively correlated, as one variable increases, the other variable increases (Figure 9-2). A correlation approaching -1 is negatively correlated, and is the opposite of the positive correlation. Also, a correlation of 0 means no linear relationship exists between the variables under consideration. However, an assumption that a correlation implies causation is false, because correlations amongst variables only sum up the strength of a relationship, and not causation. The outputs of correlation analysis only reveal relationship between two variables if negative, nonexistent, or positive. The *p*-value from statistical analysis suggests a relationship, and the correlation to be examined if one exists (Tabachnick and Fidell, 2007).

In this thesis, the Spearman's Rank Order Correlation Coefficient was used to investigate and describe the possible correlation between variables (measuring scales in Table 9-1). For example, since most pipeline operators bear the brunt of pipeline damage, it is hypothesised that there might be an association between an organisation's effort to prevent TPI and motivation for such intentional interference (Davis et al., 2007, Guijt, 2004b, Agoncillo, 2002). Table 9-1 shows the question group used as the measuring instrument for the scales.

Table 9-1: Measurement scales for Questions 2 to 5, 7 to 12, and 15 to 20 in Section III of the questionnaire survey.

Measurement Questions from Questionnaire	*Measuring Scale*
Section III: Questions 2 to 5	Organisational Effort Scale
Section III: Questions 7 to 12	Occurrence Factor Scale
Section III: Questions 15 to 20	Motivational Scale

On the scale of *Occurrence Factor* of intentional TPI, high scores also represent knowledge and prevention priority for intentional TPI. The survey questions on motivation were worded negatively, this is to force respondents to read carefully and understand the question; they were *recoded* positively before analysis.

9.5.2 Multidimensional Scaling (MDS)

Multidimensional scaling (MDS), considered an alternative to Factor Analysis (FA), is a statistical technique that represents and plots the preferences and visual perceptions of respondents about a set of given variables, into what could be termed a *judgment* or consensus map. The MDS method is one of the more practical ways in perceptual mapping; moreover, it has the advantage over other methods (e.g. Factor Analysis and Discriminant Analysis) in that it relies less on researcher's judgments and examines the underlying dimensions from respondents' judgements. Some of the Likert item used in the survey are ordinal scale type data, hence, the consideration for the MDS (Bronstein et al., 2006, Borg and Groenen, 2005, Coakes, 2005). Specifically, MDS was adopted for the statistical analysis of Question 9 and 10, of Section II of the questionnaire survey. It was decided that the best method to adopt for the dimensionality of perception regarding various methods for preventing TPI both during and after pipeline installation was by the use of MDS techniques, this is to reduce dimensionality and to enhance clearer interpretability (de Rooij, 2009).

9.5.3 Multiple Regression Analysis

Multiple regression analysis explores relationships between two or more groups of variables by examining and explaining how much variance in a dependent variable is explained by the independent variables. Multiple regression analysis also allows the investigation of the contribution of a variable to the predictive ability of a model. Following this, and based on literature review, it was hypothesised that a high ranking on a risk mitigation scale (Question 7, Section II) is a result of high perception and awareness of factors responsible for the occurrence of TPI. It also measures the degree of respondent's assessment of the motivation for TPI, especially intentional interference.

From the foregoing, it was possible to investigate the significant relationships between these factors further; using multiple regression analysis. The intent was to explore how well the understanding of intentional TPI occurrence factors and perception regarding motivation are able to predict scores on a risk mitigation scale. In addition to how much variance in the risk mitigation scale can be explained by scores on these two scales, regression analysis also determines which variables are the best predictor of the risk mitigation score. Prior to commencing the analysis, the distributions of the variables are ascertained to be normally distributed and meet all of the required assumptions of a multiple regression analysis.

9.5.4 Two-way between groups ANOVA

Two-way between groups analysis of variance (ANOVA) examines the individual and joint effect of two independent variables on one dependent variable, e.g., what is the effect of a respondent's occupation on the score for risk mitigation scale for each type of organisation they are employed? In addition, risk mitigation score may increase across a geographical location based on level and degree of TPI and hence could be describe as an *interaction effect*, which also could describe the effect that need to be specified for the exact geographical location. This means that the influence of geographical location on the risk mitigation scale can be examined if different for the academia, government agencies or the private companies (Pallant, 2007). Questions 7 of Section II of the questionnaire was analysed using this statistical technique.

9.6 Multiple Response Analysis of Open-ended Questions

This section describes the methodological approach and the qualitative analysis of the findings from the open-ended questions used in the questionnaire survey. The goal was to describe the patterns of the commentary; responses frequency and associations from a respondent's unique experiences that are organisation specific. Open-ended questions give respondents the liberty to formulate replies, comments, and observation from experience in addition to the closed question in a survey. Open-ended questions are qualitative data, and are a source of rich description and diagnosable explanations of process or procedure in a context that could generate or revise a research's theme and framework (Kent, 2001). Multiple response analysis is one of the most commonly used methods of analysis for open-ended questions in a survey. The appropriateness of open-ended questions for this research is justified because:

a) The questionnaire survey is for international respondents, and because TPI are country specific, it was therefore considered inappropriate to *close* some question by specifying only eligible options.

b) Open-ended questions are more engaging and avoid the likelihood of pre-judgement and biasness that might result when answer options are suggested to respondents.

c) An open-ended question captures all views and perceptions that have not been considered as part of the closed questions of the questionnaire survey.

Qualitative data, like open-ended questions are non-numerical records, commentary, description, and feedback that produce an immediate understanding with further processing. Coding is therefore the process of converting such qualitative data into numerical records, referred to as multiple response analysis (Kent, 2001). The maximum numbers of responses to a particular open-ended question are determined from the collated questionnaire after the survey and the identified responses defined as variables for further analysis. Questions 5 of Section II and Questions 6, 9, and 10 of Section III of the questionnaire were analysed using this statistical technique (Section 10.5).

9.7 General Limitations of the Questionnaire Survey

The study within this thesis suffered from several limitations:

- An important limitation of the survey is that it did not take the years of professional experience of the respondents into account, which is likely to affect and limit the effectiveness of the result.

- The questionnaire survey also failed to take into consideration the participation of the general civil society, for example, pressure groups and independent regulatory bodies in the oil and gas industry. While this creates an opportunity for further research, it also implies a weakness on the quality of the study.

- The questionnaire survey is a cross-international survey of pipeline TPI, hence, we cannot determine causality, given that TPI is prevalent and perhaps increasing in some regions (e.g. Africa and South America) than others. Causation can only be explained by understanding a country's specific situation and the legal framework in place individually.

- The open-ended questions are labour intensive and the data collation is slow, and difficult to establish validity and reliability.

- The multiple response questions could not be further analysed because no statistical test is available that can analyse group of responses apart from simple counts and percentages.

9.8 Conclusion

The questionnaire survey provide a critical analysis of TPI by exploring organisational representatives' perceptions and identification into why the pipeline industry view certain risk mitigation strategy and preventative measures as being more important than others. The findings of the survey is important, especially considering the dramatic changes in security problems worldwide, that have proved traditional security technologies incapable, with more consequence on the safety of oil and gas pipelines.

10 QUESTIONNAIRE SURVEY: ANALYSIS AND RESULTS

10.1 Introduction

The recent developments in third-party interference (TPI), especially intentional TPI, have heightened the clearly impractical ability to observe actual pipeline interference directly, therefore, the need for questionnaire survey. The aim of the questionnaire survey is to elicit the knowledge, experience, and perceptions of the pipeline industry about third-party interference from participants. The objective is to collect opinions that are organisation representative on both intentional and unintentional pipeline TPI, solicited from those directly involved with the problem in the oil and gas industry. This insures a potentially expanded understanding of pipeline TPI, beyond the selected study area in Nigeria.

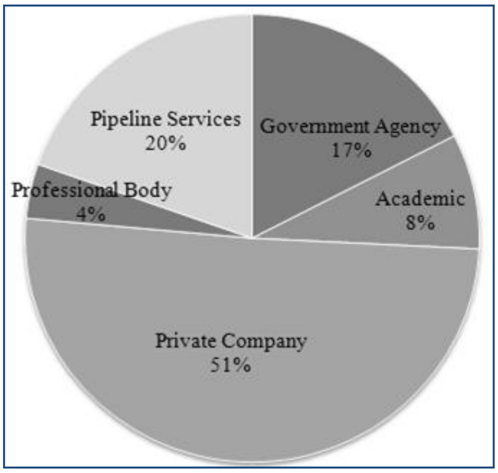


Figure 10-1: The various organisations of respondents that participated in the questionnaire survey.

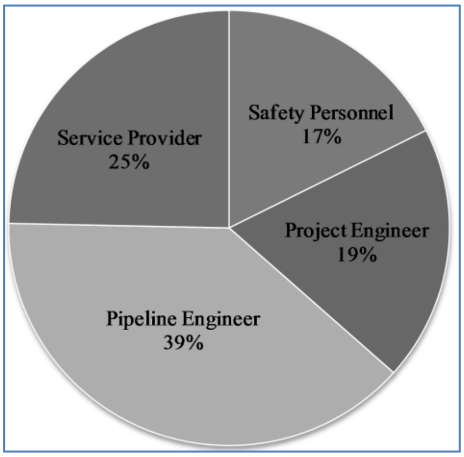


Figure 10-2: Occupation and percentage of respondents that participated in the questionnaire survey.

The study population consisted of practicing members of the oil and gas industry, including health and safety engineers, pipeline engineers, pipeline service providers, and project engineers; encompassing oil and gas companies, government agencies, and professional bodies (Figure 10-1 and 10-2). In total, two hundred and twenty nine (229) responses were received, collectively from thirty-eight countries as shown in Table 10-1 and Figure 10-3. Out of the original 1640 sample size (recipients of the initial e-mail), 38 per cent were untraced (for example, rejection from the recipient's e-mail address server). The remaining 1016 eligible respondents received the questionnaire, however, 787 potential respondents declined to participate. The response rate was 23 per cent. The response rate was unexpected, and this probably suggests that data confidentiality policy of some respondent's organisation and the difficulty of anonymous response to the questionnaire affected the response rate, especially since oil and gas pipeline data are confidential in most organisations and countries.

Table 10-1: The list of all countries of from where responses were received for the questionnaire survey.

Australia
Brazil
Belgium
Bulgaria
Canada
Colombia
Czech
Ecuador
France
Singapore
Iran
Ireland
Italy
Japan
Macedonia
Mexico
Netherlands
New Zealand
Nigeria
Uzbekistan
Romania
Russia
Spain
Switzerland
Saudi Arabia
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UAE
UK
Tunisia
Oman

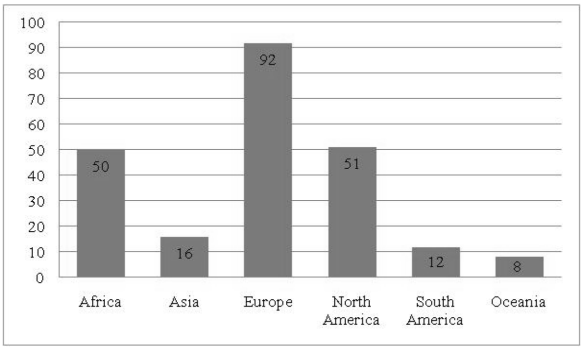

Figure 10-3: The numbers and continent distribution of respondents that participated in the questionnaire survey.

This chapter presents the result of the qualitative analysis of the questionnaire survey, and provides interpretations of the various statistical testing results. The result of the response's validity and reliability and the analyses of the raw data for the open-ended questions are also discussed in this chapter. Finally, the chapter concludes with a number of conclusions.

10.2 Section I: General Information of the Questionnaire

The questions that were asked in this section are described in Chapter 9, and included the methodologies adopted for analysing the questionnaire survey. It is interesting to note that various organisations participated, and approximately 39 per cent of the survey respondents were pipeline engineers and 25 per cent were pipeline service providers. The distribution is as shown in Figure 10-2. When categorised by organisation, the majority of respondents are from private companies with experience of operation in the pipeline industry. In addition, the overall responses is geographically balanced, with 50 respondents from Africa, 24 respondents from Asia Pacific, 92 respondents from Europe and 63 respondents from America (Figure 10-3).

10.3 Section II: Unintentional Pipeline Third-Party Interference

Questions 5 and 8 of Section II, and Questions 6 and 13 of Section III of the questionnaire survey contained open-ended questions. In this section (and Section 10.4), these questions were omitted from the sequential treatment of the overall questionnaire, choosing to focus on the structure of the closed questions first. However, they were separately analysed in Section 10.5 of this chapter, this structured approach is to allow for greater clarity of the open-ended and closed questions. The survey's question items discussed in the following section are described in Section 9.3 and are listed in an abridged format of the questionnaire in Appendix III.

10.3.1 Section II: Unintentional TPI, Question 1

The questionnaire survey examined whether respondent's occupation and geographical location influenced their perception about pipeline security. The SPSS results of cross-tabulation analysis between a respondent's geographical location and pipeline security being a worldwide problem showed no such relationship. From the data in Table 10-2, it is apparent that 88.1 per cent of all respondents agreed that pipeline security is a worldwide problem that needed serious and urgent attention. However, the results (Table 10-2) also showed that 20 per cent of the respondents in the pipeline services sector disagreed with the statement, twice more than other organisational types.

The perception of the pipeline services sector could be influenced by the type of services which they provide, that are intrinsic to the smooth operation of pipelines (e.g. maintenance and services). Interestingly, government agencies and academia, with 92.5 per cent and 94.7 per cent respectively, agreed more than any other organisational type with the Question 1 posed in Section II of the questionnaire.

Table 10-2: Crosstabulation of Question-1 with respondent's organisation.

			Respondent's Organisation					
			Government Agency	Academic	Private Company	Professional Body	Pipeline Services	Total
Pipeline security is a world-wide problem	Strongly Agree	Count	23	11	52	8	18	112
		% within Respondent's Organisation	57.5%	57.9%	44.8%	88.9%	40.0%	48.9%
	Agree	Count	14	7	52	0	17	90
		% within Respondent's Organisation	35.0%	36.8%	44.8%	.0%	37.8%	39.3%
	Disagree	Count	2	0	5	1	9	17
		% within Respondent's Organisation	5.0%	.0%	4.3%	11.1%	20.0%	7.4%
	Strongly Disagree	Count	0	1	2	0	0	3
		% within Respondent's Organisation	.0%	5.3%	1.7%	.0%	.0%	1.3%
	No Opinion	Count	1	0	5	0	1	7
		% within Respondent's Organisation	2.5%	.0%	4.3%	.0%	2.2%	3.1%
Total		Count	40	19	116	9	45	229
		% within Respondent's Organisation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

10.3.2 Section II: Unintentional TPI, Question 2

The majority of respondents surveyed, 52.8 per cent disagreed with the question that pipeline surveillance technology should protect only vulnerable segments of a pipeline network. However, the cross-tabulation analysis of the geographical location of the respondents showed that 87.5 per cent of the respondents from Oceania disagreed with the question, compared with 75 per cent of respondents from Asia that agreed with the same question. The most striking result to emerge from the data is that for Africa, where 48 per cent of the respondents agreed with the statement and 48 per cent disagreed.

Third-party interference (mostly sabotage and theft) in oil and gas producing countries in Africa, especially Nigeria, is a daily occurrence, with conflicting and divided opinion about the root causes. While some suppose that the oil companies effectively encourage TPI, others think the local population are responsible for the high numbers of occurrence. This equal and opposite views could explain this result of the survey. For example, in a response to an open question, a respondent observed that: *"the cause and solution to the problem of third party damage to pipelines in Nigeria are well known. There seems to be a reticence on the part of government to address the root causes. The oil companies themselves support the local communities in which they work but the government does not support them in the appropriate manner"*.

Table 10-3: Crosstabulation of Question 2 with respondents' organisation

			Respondent's Organisation					
			Government Agency	Academic	Private Company	Professional Body	Pipeline Services	Total
A pipeline surveillance technology should protect only vulnerable segments of a pipeline network	Strongly Agree	Count	7	3	7	1	6	24
		% within Respondent's Organisation	17.5%	15.8%	6.0%	11.1%	13.3%	10.5%
	Agree	Count	11	6	38	5	16	76
		% within Respondent's Organisation	27.5%	31.6%	32.8%	55.6%	35.6%	33.2%
	Disagree	Count	15	8	45	2	18	88
		% within Respondent's Organisation	37.5%	42.1%	38.8%	22.2%	40.0%	38.4%
	Strongly Disagree	Count	5	1	21	1	5	33
		% within Respondent's Organisation	12.5%	5.3%	18.1%	11.1%	11.1%	14.4%
	No Opinion	Count	2	1	5	0	0	8
		% within Respondent's Organisation	5.0%	5.3%	4.3%	.0%	.0%	3.5%
Total		Count	40	19	116	9	45	229
		% within Respondent's Organisation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

In a cross-tabulation of results to examine the influence of a respondent's occupation on the response to the same survey question, 66.7 per cent of all respondents from professional bodies agreed that any pipeline surveillance technology should protect only vulnerable segments of a pipeline network compared to the overall 43.7 per cent of the entire respondents (Table 10-3).

10.3.3 Section II: Unintentional TPI, Question 3

The majority of respondents (88.2%) felt that there has been limited research in the area of TPI, in response to Question 3 of the questionnaire, compared with 8.7 per cent that considered otherwise. Interestingly, 50 per cent of respondents from Oceania disagreed that there is only limited research in the area of TPI, whereas 100 per cent of all respondents from professional bodies agreed that there is limited research in the area of TPI, followed by academia with 89.5 per cent.

10.3.4 Section II: Unintentional TPI, Question 4

In response to Question 4, 60.7 per cent of all of the respondents disagreed that pipeline safety regulations presently existing are adequate for the prevention of TPI. However, 50 per cent of respondents from Oceania agreed, while on the hand, 54 per cent of respondents from Africa disagreed. It should be noted that the oil and gas exploration legislation in Africa is generally very weak compared to that of other oil and gas producing countries, and in recent times there have been calls for stricter enforcement of the law against, for example, intentional TPI.

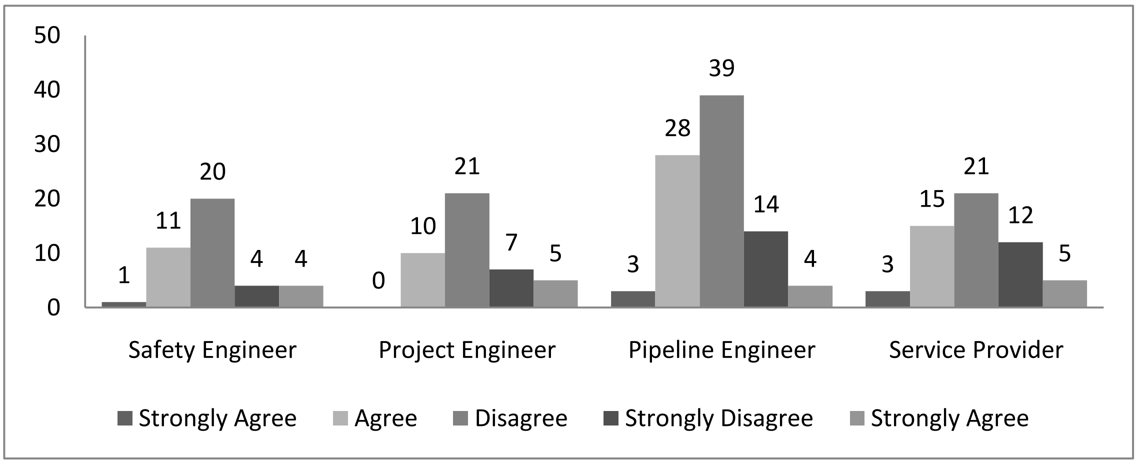

Figure 10-4: Bar chart plot of respondent's answers to Question 4 asking if existing pipeline safety regulations are adequate for the prevention of third-party interference.

The result of the survey showed that 60.7 per cent of all respondents disagreed that the current regulations were adequate. In a cross-tabulation of the same question with respondent's occupation, 60 per cent of the safety engineers that responded disagreed with the statement that pipeline safety regulations presently existing are adequate for the prevention of TPI (Figure 10-4). Likewise, the cross-tabulation of the question with regard to the respondent's organisation shows over 30 per cent of respondents from government agencies agreed that the current regulations were adequate.

10.3.5 Section II: Unintentional TPI, Question 6

In Question 6, Section II of the questionnaire, the respondents were asked to identify and select all their preferred methods for protecting pipeline networks against TPI. The following are the options: (a) perimeter fencing of pipelines right-of-way; (b) electronic intrusion detection; (c) pipeline communications security gadgets; (d) direct pipeline surveillance and monitoring; (e) company specific system; and (f) specification of other methods not mentioned in the questionnaire. The frequency analysis of the multiple responses used a multiple dichotomy analysis in SPSS. Each of the items in the question was given a label and a code, *1* if a method is selected and *0* if it is not selected. This collation was descriptively analysed using the multiple response analysis technique.

Table 10-4: Summary analysis of respondent's answer to question on ensuring security and safety of pipeline networks.

	Responses	
Preferred physical security of pipeline networks	***N***	***Percent***
Perimeter fencing of pipelines right-of-way	48	9.90%
Electronic intrusion detection	138	28.50%
Pipeline communications security gadgets	65	13.40%
Pipeline surveillance and monitoring	161	33.20%
Company specific system	46	9.50%
Others	27	5.60%
Total	**485**	**100.00%**

The inspection of the frequency table (Table 10-4) for the multiple response analysis indicates that *pipeline surveillance and monitoring* are the most frequently chosen protection procedures preferred for pipeline safety (33.20%), followed by *electronic intrusion detection* (28.50%). The analysis by continents showed that respondents from Europe preferred *pipeline surveillance and monitoring* (37.16%, i.e. 14.00% of 37.7%) than the other methods (Table 10-5). The crosstabulation of Question 6 and respondent's geographical location is shown in Table 10-5.

Table 10-5: The crosstabulation of Question 6 and respondent's geographical location.

		Continent						
		Africa	Asia	Europe	North America	South America	Oceania	Total
Perimeter Fencing of Pipelines Right-of-Way	Count	14	7	16	9	1	1	48
	% of Total	2.9%	1.4%	3.3%	1.9%	.2%	.2%	9.9%
Electronic Intrusion Detection	Count	40	8	45	31	11	3	138
	% of Total	8.2%	1.6%	9.3%	6.4%	2.3%	.6%	28.5%
Pipeline Communications Security Gadgets	Count	17	4	22	16	4	2	65
	% of Total	3.5%	.8%	4.5%	3.3%	.8%	.4%	13.4%
Direct Pipeline Surveillance/Monitoring	Count	32	8	68	38	7	8	161
	% of Total	6.6%	1.6%	14.0%	7.8%	1.4%	1.6%	33.2%
Company Specific System	Count	8	5	19	11	1	2	46
	% of Total	1.6%	1.0%	3.9%	2.3%	.2%	.4%	9.5%
Others	Count	3	1	13	8	1	1	27
	% of Total	.6%	.2%	2.7%	1.6%	.2%	.2%	5.6%
	Count	114	33	183	113	25	17	485
	% of Total	23.5%	6.8%	37.7%	23.3%	5.2%	3.5%	100.0%

10.3.6 Section II: Unintentional TPI, Question 7

Question 7 of the questionnaire survey measures the techniques used for developing a risk mitigation strategy for pipeline security by organisations. The designs of the risk mitigation questions are after Muhlbauer's (2004) suggestion and described in Section 9.3.

Table 10-6: Descriptive Statistics and Kendall's W Test Ranks.

	Mean	*Std.Dev*	*Mean Rank*
Threat assessment of pipeline network	2.88	2.511	4.67
Community relations and public education	3.03	2.515	4.98
The role of host government	3.34	2.540	5.52
Prosecution and punishment to offenders	3.50	2.680	5.59
Inaccessibility to facilities by road, etc	5.21	2.654	7.63
Developing an integrated security plan	3.12	2.353	5.22
Incident response capability	2.81	2.429	4.70
Environmental response	3.13	2.484	5.17
Personnel security surveillance on pipeline	3.46	2.316	5.62
Physical protection of the pipeline	3.70	2.565	5.89

N=224, Kendall's Coefficient of Concordance=0.095, p=0.000; D.F=9

The results in Table 10-6 clearly shows that *incident response capability* and *threat assessment of pipeline network* are the highest ranked risk-mitigation strategies by respondents, with an average descriptive mean of 2.81 and 2.88 respectively. Interestingly, *inaccessibility to pipeline facilities* with an average mean of 5.21 is the least ranked. However, to check if the respondents responses have been unanimous or random, a Kendall's coefficient of concordance (Kendall's W ranking) was used to evaluate agreement among respondents, it ranges from *0* (no agreement) to *1* (absolute agreement). The test statistic W, produced with SPSS software, was 0.095 (Table 10-6). Therefore, it is concluded that the responses are random and that there was no overall trend of agreement among the respondents (Kendall and Smith, 1939).

10.3.6.1 Two-way between groups ANOVA

The thesis hypothesised that the geographical location of organisations determines how they perceive and manage their risk mitigation strategy for TPI. Therefore, the Two-Way Analysis of Variance (ANOVA) was used to simultaneously test for the effects of the following for Question 7:

a) The differences in the types of organisation on the risk mitigation scale.
b) The differences in risk mitigation score by geographical locations (Africa, Asia, Europe, etc.).
c) The interaction of these variables for difference in the effect of location on risk mitigation scores for the different types of organisations.

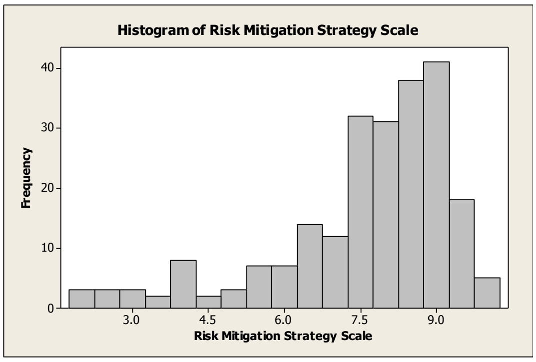

Figure 10-5: Histogram for Question 7

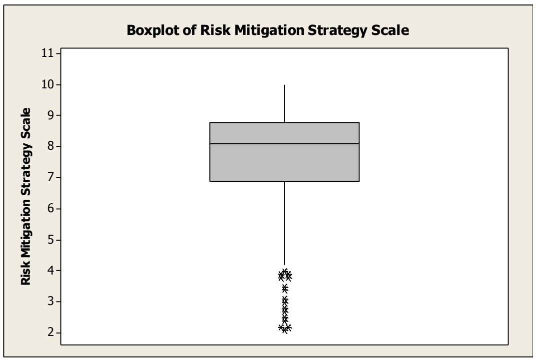

Figure 10-6: Box Plot for Question 7

In accordance with the procedure described in Chapter 9, it is required to determine whether the distributions of the variables are statistically normal, because the assurance of normality is a prerequisite for any inferential statistical procedures. Therefore, a plot of histogram and a *boxplot* were used to ascertain normality of the variables. The results obtained from the preliminary analysis of normality are shown in Figure 10-5 and Figure 10-6. This confirms that the *risk mitigation scale* is skewed, and the data are not normally distributed. However, the distinction shown by the skewed distributions is very important, for example, it can be shown that half the respondents in our sample are rated high on the risk mitigation scale.

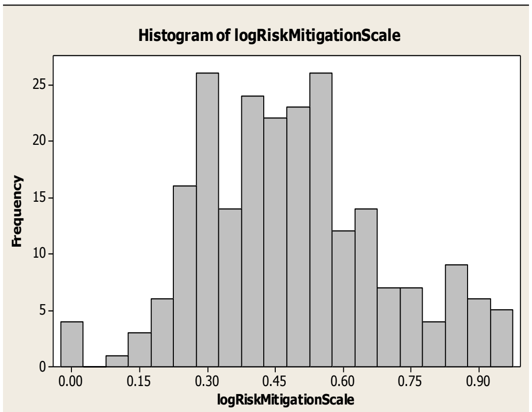

Figure 10-7: The natural logarithmic transformation.

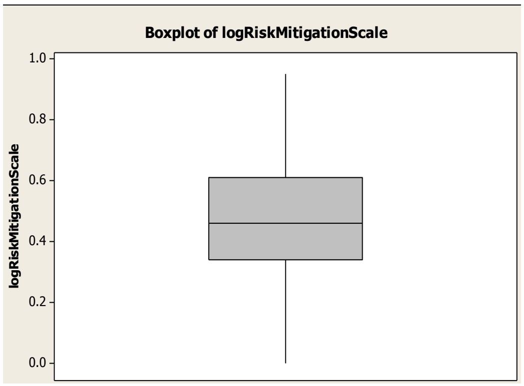

Figure 10-8: Box plot for log transformation for Mitigation Scale.

The data were transformed with natural logarithms, and the statistics and graphs in Figure 10-7 and Figure 10-8 indicate that the use of the natural logarithmic transformation was appropriate. The distribution been relatively normal, the data was reasonably satisfactory for further statistical analysis.

Table 10-7: ANOVA output result from SPSS indicating the tests of between-subjects effects

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Partial Eta Squared*
Corrected Model	1.271(a)	26	.049	1.237	.208	.137
Intercept	11.016	1	11.016	278.76	.000	.580
Continent	.337	5	.067	1.705	.135	.040
Organisation	.147	4	.037	.931	.447	.018
Continent * Organisation	.625	17	.037	.930	.539	.073
Error	7.983	202	.040			
Total	62.386	229				
Corrected Total	9.253	228				

a R Squared = .137 (Adjusted R Squared = .026)

On completion of the normality test, the process to compare the scores of the scale was carried out by employing the ANOVA procedure. The examination of the SPSS output in Table 10-7 for the possibility of *interaction effect* indicates that there is no significant difference in the effect of the geographical location of respondents on the risk mitigation scores for different types of organisation (i.e. *Continent * Organisation's sig.*=0.539). Since there is no significant *interaction effect* on the variables, the main effect of one independent variable is not correlated to another, for example, different types of organisation do not correlate with the geographical location of the respondent. From the SPSS output in Table 10-7, the *sig. level* for organisation is 0.447, this indicates there is no significant main effect, that respondents from different organisation do not differ on the risk mitigation scale, and the same is evident for the geographical location of the respondents (*Sig.* =0.135). In addition, the Levene's Test of Equality of Error Variances shows the *sig. level* is 0.058 (SPSS output not shown), which is more than the statistic significance level of 0.05; hence, the assumption of homogeneity of variances is not violated in this analysis.

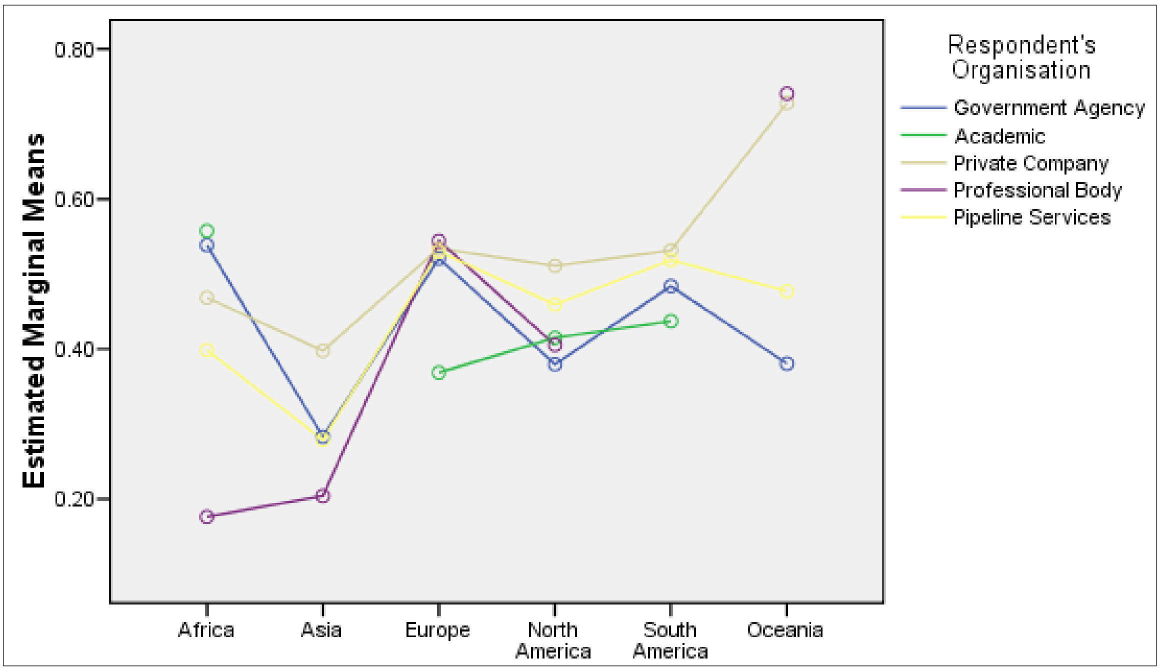

Figure 10-9: Estimated Marginal Means of risk mitigation scores by respondent's geographical location and respondent's organisation.

SPSS output also produce line (interaction) plots of the estimated means of two or more independent variables with a dependent variable. The profile plot of risk mitigation scores by respondent's geographical location by respondent's organisation is shown in Figure 10-9. This figure indicates that there are medium and small differences in the risk mitigation scores by respondent's geographical location and respondent's organisation. For example, for government agencies, the mean score for Europe (Mean=0.52, Std. Deviation=0.18) was significantly different from Asia (Mean=.35, Std. Deviation=0.18). This SPSS output visually inspect the relationship among variables.

10.3.7 Section II: Unintentional TPI, Question 9

The question items of Question 9 and 10 are presented in Section 9.3.1 with an abridged format in Table 10-8. These questions (Table 10-8) are sets of summated rating scale questions, with the response options ranging from "*excellent" to "poor"*. However, a question item: *Avoid pre-identified vulnerable zone* was removed because it was found to be redundant.

Following this, the thesis examined the reliability of the question's item results using the SPSS *reliability test*, a measure to confirm whether the same survey will produce the same result repeatedly. The SPSS alpha model method measures the consistency of the summated rating scales. The Cronbach's Alpha value measures the average of all of the possible reliability coefficients calculated, and if this alpha value is above 0.7, then the items are, as a rule of thumb, assumed to be reliable (Coakes, 2005, Kent, 2001, Nunnally, 1978). The *reliability* statistics obtained from the SPSS analysis shows that the question has a good internal consistency, with a Cronbach's Alpha coefficient of 0.725.

Table 10-8: An abridged list of the questionnaire items for Questions 9 and 10 for perception about pipeline TPI *during* and *after* installation. The option varies from excellent to poor.

Question 9: Perception about the following in pipeline TPI during installation	*Question 10:Perception about the following in pipeline TPI post-installation*
• Sleeve as additional protective layer	• Aerial and Helicopter Surveillance
• Slabs, Tiles and Plates over pipelines	• Full walking patrol
• High Tensile Net buried with pipeline	• Remote Sensing Satellite Surveillance
• Increasing pipeline wall thickness	• Global Positioning System (GPS/GIS)
• Marker posts along pipeline length	• Direct Surveillance
• Marker Tape buried above pipeline	• Electromagnetic Detection/ Acoustic
• Fibre optics installed at intervals	• Identify and Monitoring 'Hot Spots'

10.3.7.1 Frequency distributions for Question 9

The frequencies analysis in Table 10-9 gives an overview of each protection method. It is apparent that the overall rating of protection by *increasing pipeline wall thickness* is the highest, compared with other methods or measures in preventing TPI, whilst the rating for *marker tapes above pipeline* is relatively low. This result about *pipeline wall thickness* is surprising, although not considered in the GIS-based multivariate statistical analysis, if the thesis is to be moved forward, a better understanding of this variable needs to be developed.

However, this procedure does not provide a critical composite evaluation of the scale items and the summated combined items of Questions 9 and 10 were used in a Multidimensional Scaling (MDS) analysis, to determine the perceptual relationships between the items in both groups. For example, do respondents perceive the relationship between prevention measures for *during-installation* (Question 9) and *post-installation* (Question 10) of pipeline differently. These relationships are discussed in the following section (Section 10.3.8).

Table 10-9: Table of frequency results for Question 9.

Methods	Poor		Fair		Average		Good		Excellent	
	Count	%	Count	%	Coun	%	Count	%	Count	%
Sleeve as additional protective layer	24	10.5%	17	7.4%	58	25.3%	94	41.0%	36	15.7%
Slabs, Tiles and Plates Over Pipelines	16	7.0%	21	9.2%	44	19.2%	108	47.2%	40	17.5%
High Tensile Net Buried above Pipeline	17	7.4%	26	11.4%	75	32.8%	88	38.4%	23	10.0%
Increasing Pipeline Wall Thickness	15	6.6%	23	10.0%	56	24.5%	77	33.6%	58	25.3%
Marker Posts along Pipeline Length	14	6.1%	18	7.9%	59	25.8%	96	41.9%	42	18.3%
Marker Tape above Pipeline	16	7.0%	34	14.8%	73	31.9%	79	34.5%	27	11.8%
Fibre Optics Installed at Intervals	21	9.2%	25	10.9%	79	34.5%	73	31.9%	31	13.5%

10.3.8 Section II: Unintentional TPI, Question 10

Multidimensional scaling (MDS) analysis transforms respondent's judgments and preferences into multidimensional spatial maps, showing the relative position and relationship of all items (Holmes, 2009). The various items in Questions 9 and 10 were combined to examine the overall perception of the various mitigation methods. However, items for which it was difficult to ascertain the difference in both set of questions were excluded from the MDS analysis. The SPSS MDS module was used in this analysis, and Table 10-10 presents the results obtained from the MDS analysis, measuring actual representation of preferences of Questions 9 and 10 combined (Coakes, 2005).

Table 10-10: The Stress and Fit Measures from the SPSS output of the multidimensional scaling (MDS) analysis, in two dimensions.

Normalized Raw Stress	.03353
Stress-I	.18312(a)
Stress-II	.48306(a)
S-Stress	.09459(b)
Dispersion Accounted For (D.A.F.)	.96647
Tucker's Coefficient of Congruence	.98309

PROXSCAL minimizes Normalized Raw Stress.
(a) Optimal scaling factor = 1.035; (b) Optimal scaling factor = .970.

According to Coakes (2005), the most commonly used stress measurement and measure of fit, showing actual representations of preferences in a *multidimentional scale* is the *Stress-I*, and this needs to be minimised. This is because the lower the stress, then the better the fit between the data. However, both the measure of the *'Dispersion Accounted For'* and *'Tucker's Coefficient of Congruence'*, when greater than 0.90 indicate a good fit of preference, and Table 10-10 indicates both measures recorded 0.97 and 0.98 respectively.

The SPSS procedure determines the numbers of dimensions the solution should have that offers good improvements in the stress, which also makes the results easier to interpret. The *scree plot* of the variables in Figure 10-11 also shows the guide to the appropriate number of dimensions to consider, however, the representation in two dimensions was chosen to better display the output of the MDS. The *scree plot* suggests that a three-dimension solution is satisfactory, as the "elbow" begins at this dimension. It also illustrate a better graphical representation, however, interpretation is complex. The two-dimension solution produced and used in this analysis is to *reduce* the observed complexity of the data, since a two-dimensional map visualize the output easily. The *common space plot* in Figure 10-10 indicates four different spatial units and regrouping of the original variables. *Remote sensing satellite surveillance*; *Global Positioning System (GPS)*; *electromagnetic detection and acoustics*; and *fibre optics installed at intervals* are in the southwest quadrant of the common space. The *walking patrol* is farther in the cluster of *identify and monitoring hotspots* and others, and could probably indicate its less preference by the respondents in mitigating third-party interference.

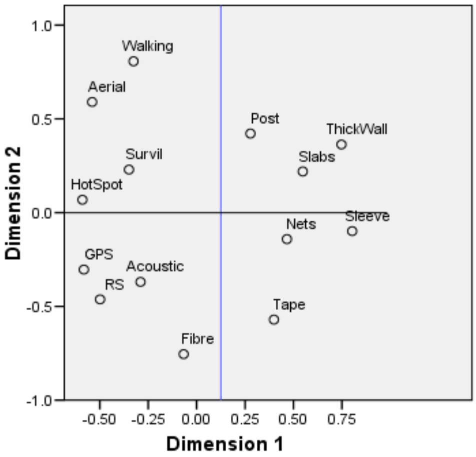

Figure 10-10: Common space plot created with SPSS's multidimensional scaling module

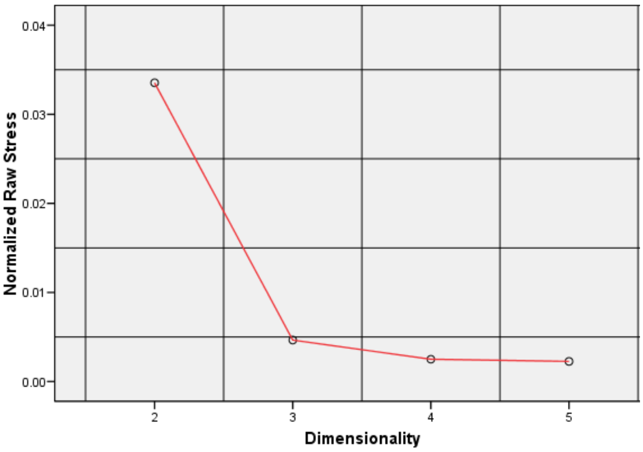

Figure 10-11: Scree plot of the variables, a SPSS multidimensional scaling output

It is also possible to interpret Figure 10-10 based on clustering, for example, there is a *post-slabs-thickwall* cluster as well as a *nets-sleeve-tape* cluster in Figure 10-10. However, there is subjectivity and ambiguity involved in creating the *space plots* shown in Figure 10-10, because the higher the stress, the less reliable the position of the variable in the spatial space plots. Furthermore, the *scree plot* with an elbow at the three-dimensional solution of Figure 10-11 indicates there is a significant improvement between the two- and three-dimensional solutions, compared with the improvement between three- and four-dimensional solutions. In addition to the above, the interpretation of the MDS test requires distinguishing what commonalities between the variables. Therefore, the *GPS-acoustic-RS-fibre* cluster indicates a group of measures that are expensive.

10.4 Section III: Intentional Third-Party Pipeline Interference

Section III of the questionnaire (Appendix III) consisted of questions analysed in this sections, and, as discussed in Section 9.3, Questions 6 and 13 were excluded because they contained open-ended questions.

10.4.1 Section III: Intentional TPI, Question 1

The SPSS multiple dichotomy analysis method was used to provide frequencies and percentages for this survey question and to determine the most frequently indicated response. The analysis of the demographic characteristics of a respondent's choice based on occupation, organisation and geographical location were also undertaken and the results examined. Table 10-11 presents the results obtained from the analysis using the SPSS dichotomy analysis.

Table 10-11: Frequency distribution for Question 1 of Section III

	Responses		
	N	Percent	Percent of Cases
Direct Pipeline Vandalism	108	14.6%	48.4%
Theft of product or facilities	101	13.7%	45.3%
Sabotage to pipeline network	101	13.7%	45.3%
Guerrilla attacks	39	5.3%	17.5%
Likelihood of Terrorism against pipeline facilities	72	9.8%	32.3%
Intrusion to above ground facilities	100	13.6%	44.8%
Right-of-Way Encroachment	116	15.7%	52.0%
Cyber attack and potential hijack of network facilities	32	4.3%	14.3%
No Opinion	69	9.3%	30.9%
Total	738	100.0%	330.9%

The majority of respondents, 97.4 per cent, indicated more than one activity, and an inspection of the frequency table (Table 10-11) indicates that *direct pipeline vandalism*, followed closely by *theft of product* were the most frequently identified. In an analysis by geographical location, respondents from Africa, North America and Oceania most frequently indicated *direct pipeline vandalism* as being the main priority of their surveillance programmes, while respondents from Asia and Europe indicated *right-of-way encroachment*; only South American indicated *theft of product and pipeline facilities*.

The present findings seem to be inconsistent with other results from Section II of the survey, primarily because it focused on intentional TPI. There are differences between the responses expressed by respondents in this section and those given in Section II. Similarly, in a frequency analysis by organisation, the majority of respondents from academia and the professional bodies indicated *no opinion* (possibly, because they have no direct responsibility or involvement in protecting pipelines, while the respondents from government agency indicated *direct pipeline vandalism* and *right-of-way encroachment.* Respondents from all private companies and pipeline services also indicated *right-of-way encroachment.*

10.4.2 Section III: Intentional TPI, Questions 2 to 5

Respondents were asked how they would rate their organisation's ability to identify pipeline terrorism, vandalism, theft, sabotage and criminal activities. Overall, 53.3 per cent of the respondents felt that their organisation's ability was *good.* Approximately half of those surveyed from South America rated their organisation's ability as being below average in identifying intentional TPI, while 85 per cent of respondents from Oceania rated their organisation's ability as being *fair.* Almost two-thirds of the respondents from academia (66.6%) rated their organisation's ability *poor*, compared with a similar *poor* rating by 25 per cent of pipeline project engineers. In another and different perception, 56.6 per cent of the respondents from private companies indicated their organisation's ability as being *good.* The results are presented in Figure 10-12.

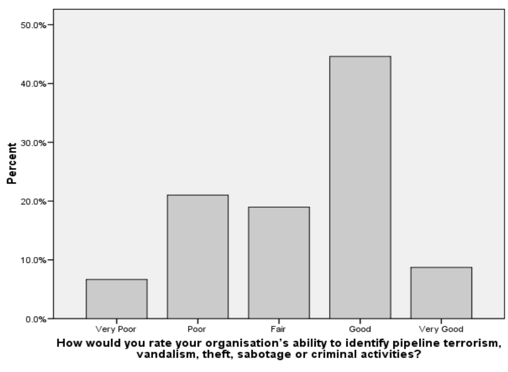

Figure 10-12: Bar chart plot of Question 2

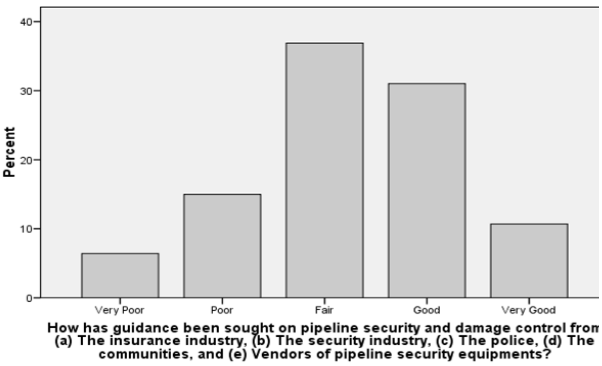

Figure 10-13: Bar chart plot of Question 3

The third item (in Section III) assessed the extent to which an organisation sought to identify segment of the pipeline considered particularly vulnerable to intentional TPI. In the results, 83 per cent of the entire respondents responded to this question, and 76.8 per cent of the respondents rated their various organisations as *good.* The highest rating is from the majority of respondents who responded from Oceania (75%), who felt *very good* about their organisation's ability in identifying pipeline vulnerable segments. The majority of pipeline project engineers and respondents from private companies rated their organisation's ability as being *good*, 68.6 per cent and 85.5 per cent respectively. The results are presented in Figure 10-13.

Question 3, of Section III requested responses on how guidance has been sought on pipeline security and damage control from the insurance industry, security agency, and the communities. The result shown in Figure 10-13 indicates that, of the 229 respondents who completed the overall questionnaire, 187 (81.7%) responded to this question and of these, only 41.7 per cent rated their organisations as being *good* in response to the question. The highest rating was from respondents from Asia (61.5%) who rated their organisation *good*, in contrast to just 11.1 per cent of respondents from South America who rated their organisation *good*. In the respondents from professional bodies, the responses were divided almost equally between those who indicated their organisation *poor* (50%) and those that indicated *good* (50%).

Table 10-12: Summary of respondents' answers to Questions 2 to 5 in Section III.

	Very Poor	***Poor***	***Fair***	***Good***	***Very Good***
How would you rate your organisation's ability to identify pipeline terrorism, vandalism, theft, sabotage or criminal activities?	6.7%	21.0%	19.0%	44.6%	8.7%
How has your organisation sought to identify areas particularly vulnerable to intentional damage?	3.7%	15.8%	29.5%	41.6%	9.5%
How has guidance been sought on pipeline security and damage control from (a) The insurance industry, (b) The security industry, (c) The police, (d) The communities, and (e) Vendors of pipeline security equipments?	6.4%	15.0%	36.9%	31.0%	10.7%
How well do you work with vendors of monitoring systems to detect incidents of third party damage on your pipelines?	7.4%	20.6%	34.9%	24.9%	12.2%

Many respondents (63%) ranked their organisation's work with vendors of the monitoring systems used to detect incidents of TPI on pipelines as *fair*. In response to the same question, most of those surveyed (57%) from the Oceania indicated *poor*, with only 14 per cent agreeing to their organisation's strategy having been *good*. Overall, 80 per cent of respondents from South America recognised their organisation's partnership with vendors of monitoring and detection systems as important in curbing intentional TPI. The majority of the respondents and in particular respondents from the professional bodies (57.1%) rated their organisation's work with vendors *very good*, which was the highest rating.

Similarly, 44.2 per cent of the safety engineers rated their organisation's work with vendors *very good*.

10.4.3 Section III: Intentional TPI, Questions 7 to 12

Respondents were asked to indicate their agreement with six Likert type ranked items as being the major factors influencing the occurrence of intentional pipeline interference from *strongly disagree* (1) through to *strongly agree* (5). The six scale items are: (i) population distributions; (ii) land use and human activities; (iii) the socio-economic conditions of population living near a pipeline; (iv) accessibility to pipeline; (v) socio-political factors; and (vi) depth of pipeline (Table 10-13).

Table 10-13: Descriptive statistics of the responses for how respondents agree with as being the major factors affecting the occurrence of intentional pipeline interference.

Section III: Questions 7 to 12	*Strongly Disagree*	*Disagree*	*No Opinion*	*Agree*	*Strongly Agree*
Q7. Population distributions (rapid urban growth with people in close proximity to pipelines)	3.5	20.2	14	43	19.3
Q8. Land use and human activities (e.g. Farming, commercial area)	3.1	13.2	11	53.3	19.3
Q9. The socio-economic conditions of population living near a pipeline	2.6	15.4	14	45.6	22.4
Q10. Accessibility to Pipeline Network (proximity of roads, rivers, streams and rail)	2.2	20.2	11.4	50.9	15.4
Q11. Socio-political factors (e.g. literacy rate, employment discrimination, etc)	3.9	13.6	15.4	38.6	28.5
Q12. Depth of Pipeline (exposed pipeline can often provide criminal opportunities)	1.3	13.2	7.9	50	27.6

The majority of respondents who responded to these questions felt that *depth of pipeline*; the *socio-economic conditions* of population living near a pipeline; *socio-political factors*, with a mean score of 3.89, 3.74 and 3.73 respectively, are the major factors affecting the occurrence of intentional TPI (Table 10-13). These perceptions from the survey corroborates the factors identified as being statistically significant from the result of Generalized Linear Models (GLMs) in this thesis, with predictions and estimations of the likelihood of TPI have showed effects of land use types, pipeline geometry, socio-economic, as being variables most influencing the occurrence of TPI.

As can be seen from Table 10-13, it is evident that the overall observation with population distributions is considered the lowest factor compared with the other elements on the item scale. However, this perception contradicts the GLMs analysis of the thesis, therefore, the study area could be a reason for this, for example, and populations leaving near pipelines have in the past violently targeted pipeline facilities, politically motivated (Onduku, 2001, Onduku, 2004). This data must be interpreted with caution because, during the period covered by the analysis, crisis in the study area were precipitated by the *Ijaws*, because of ethnic claims for economic and environmental compensation from the operators of the various pipelines crisscrossing their regions.

10.4.3.1 Correlation and Regression Analysis

Correlation analysis describes the relationship between two continuous variables and enables the strength and direction of the relationship between them to be explored (Pallant, 2007). Therefore, using bivariate analysis, the perception regarding the motivation for intentional TPI coupled with an organisation's effort in mitigating such intentional TPI was examined. Since most pipeline operators bear the brunt of pipeline damage, this suggested that there might be an association between an organisation's effort to prevent international TPI and motivation (Motivational Scale, using Questions 15 to 20) for such intentional interference. The Likert scaled items of Questions 2 to 5 of Section III of the questionnaire (made up of statements about efforts of organisations in mitigating TPI) was used as measurement for the Organisational Effort scale. While Questions 7 to 12 of Section III of the questionnaire was used for the Occurrence Factor Scale measurement, the scale is made up of statements about variables influencing the occurrence of TPI.

Table 10-14: Measurements for organisational efforts, occurrence factor and motivational scale.

Measurement Questions from Questionnaire	*Measuring Scale*
Section III: Questions 2 to 5	Organisational Effort Scale
Section III: Questions 7 to 12	Occurrence Factor Scale
Section III: Questions 15 to 20	Motivational Scale

On the scale of *Occurrence Factor* of intentional third-party interference, high scores represent the respondents' knowledge and level of prevention priority for mitigating intentional TPI. The survey questions on motivations were negatively worded deliberately, to force respondents to carefully read and understand the questions; they were then re-coded positively before analysis. A reliability test was performed in order to measure the consistency of the Likert-type items. The Cronbach's Alpha measures the average of all possible reliability coefficients, and the statistics obtained using SPSS for the items gives

Cronbach's Alpha values of 0.83, 0.71 and 0.81 on *Organisation's Effort*, *Occurrence Factors* and *Motivation for Intentional TPI* respectively. The significance of this measurement showed that each individual item in the scales correlates with the sum of the remaining items, and are consistent among individual items in the scale. One item (Question 20, Section III of the questionnaire) was removed because it was perceived not to be measuring the same underlying characteristics as the other items (Pallant, 2007). Therefore, the reported Cronbach alpha coefficients for the three scales show good internal consistency between items on the various scales.

10.4.3.2 Normality and Linearity and Correlation Analysis

The distribution of variable scores for correlation analysis are required to be statistically normal, and Figure 10-14 shows the plot of each histogram for the three variables. The inspection of the histograms shows normality in each case. The linearity was checked by inspection of the *scatterplots* and they show a good relationship between the scale of occurrence factors and motivations. In addition, it is evident from the *scatterplots* that the variables do not violate the assumption of homoscedasticity (*an* assumption that the variance around a typical regression line in a model, for one variable, is similarly the same for other values of the other variable).

The *Skewness* and *Kurtosis* values provide indication of the normality of the distribution, a requirement for variables that use parametric statistical techniques for analysis. The Normal Q-Q Plots also assess the normality of distribution of scores and, from Figure 10-14, the scores and plot appear to be reasonably normal and suggests a normal distribution. The relationships between scale of *Organisational Efforts*, *Occurrence Factors*, and *Perception about Motivation* were investigated using Pearson product-moment correlation coefficients. The only significant correlation found from this analysis is between the *Occurrence Factor* and *Perception about Motivation*, $r=0.34$, $n=229$, $p<0.0005$. There is no significant correlation between efforts by organisations to mitigate TPI by alleviating the motivations.

10.4.3.3 Nominal independent Variables with Continents

Some countries are more susceptible to intentional third-party interference than others are; therefore, this thesis estimates the association between continents (geographical location) and the perception of motivation for intentional third-party interference (motivational scale). Africa was chosen as a reference continent with which to compare the other continents, and to improve the accuracy of the regression coefficients. This procedure is an assessment of association between a continuous dependent variable and a nominal independent variable; continents of respondent were recoded as dummy variable (into two categories, *1* and *0*).

To measure the degree of perception of intentional third-party interference by comparing other continents with Africa, a reference category was chosen and a dummy variable for each of the other continent was created. For example, the respondents from Europe are assigned a value of *1*, and respondents from the other five continents are assigned a value of *0*, and so forth. Thus the regression function is:

$$y_i = a + b_1 \cdot x_{1i} + b_2 \cdot x_{2i} + + b_3 \cdot x_{3i} ++ b_4 \cdot x_{4i} ++ b_5 \cdot x_{5i} + e_i,$$

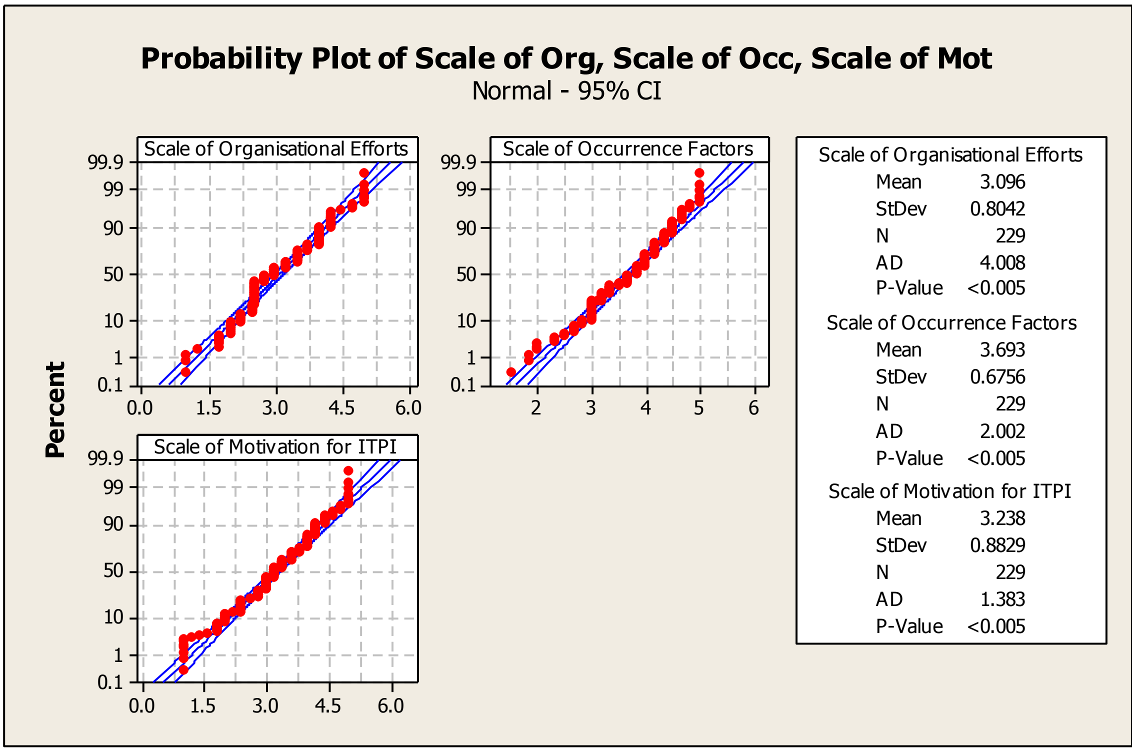

Figure 10-14: Probability Plots for Questions (2-5), (7-12), and (15-20) of Section III.

In the above expression, y_i represents the *motivational scale* values, x_{1i} the 'Asia' dummy variable values, x_{2i} the 'Europe' dummy variable values, x_{3i} the 'North America' dummy variable values, x_{4i} the 'South America' dummy variable values, and x_{5i} the 'Oceania' dummy variable values. The coefficient of determination, r^2 using the Pearson correlation of 0.317 gives only 8.1 per cent shared variance between the variables (Table 10-15). This indicates that the difference between the mean motivational scales of the six continents sample explains 8.1% of that variable's total variance.

Table 10-15: The nominal regression model summary (b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	.317(a)	0.101	0.081	0.84659

(a) Predictors: (Constant), Respondents from Oceania, South America, Asia, North America, and Europe
(b) Dependent Variable: Scale of Perception about Motivation for ITPI

The *Constant coefficients* in Table 10-16 estimates the mean level on *motivation scale* of respondents belonging to the reference category from Africa. Africa's values on both *x*-variables are *0*, therefore Africa's predicted *motivational scale* value is 3.653. The coefficient of the 'Asia' variable is interpreted as an estimate of the difference in mean *Motivational Scale* between Asia and Africa. If the *x*-values of a person who lives in Asia are inserted, the function will read: $y_i = a + b_1 \cdot 1 + 0 + e_i$. Thus, the predicted mean value of the dependent variable is $a + b_1$, which has been estimated as 3.16 (3.653 -0.490); the estimated mean level on *Motivation Scale* of Asia is 3.16(on a scale of 1 to 5). Similarly, the mean level on *Motivation Scale* of those who live in Europe is 3.052, less than the score for Africa.

The significant of the above result is that, on a scale of 1 to 5, Africa, with a score of 3.65, has a strong awareness of the various factors that motivates intentional TPI, compared to Asia and Europe with a score of 3.16 and 3.057 respectively. Specifically, the high score on perception about motivation of TPI in Africa is because all stakeholders are fully aware of the primary key issues and challenges relating to and affecting third party pipeline interference in Nigeria. The activities of the oil companies in the study area have destroyed much of the land cover, for example, and as confirmed by the review of the NNPC database, thousands of TPI occur yearly. The inadequacy of the oil companies to redress this issue, together with the destruction of livelihood, does lead people to vandalize pipeline, as a way of revenge and obtaining compensation.

Table 10-16: Coefficients (a) for scale of Perception about Motivation for ITPI

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta	B	Std. Error
(Constant)	3.653	0.112		32.57	0
Respondent from Asia	-0.49	0.24	-0.142	-2.046	0.042
Respondent from Europe	-0.601	0.145	-0.33	-4.146	0
Respondent from North America	-0.386	0.163	-0.182	-2.365	0.019
Respondent from South America	-0.586	0.269	-0.148	-2.179	0.03
Respondent from Oceania	-1.178	0.32	-0.245	-3.684	0

(a) Dependent Variable: Scale of Perception about Motivation for ITPI

The results of the GIS-based statistical models of this thesis support the view that socio-economic depravity in the study area has made third-party pipeline interference to become a common occurrence. On the other hand, these observations of pipeline third-party interference are not only common to the Africa. In 2007, Margonelli (2008) described how in Colombia, the equipment of seven thousand barrels of oil product are stolen every day. In Iraq, the pilfering of oil product and pipeline third-party interference is a well-established "industry", and includes pipeline interference in both Chechnya and Moscow.

10.4.4 Section III: Intentional TPI, Question 14

Respondents were asked to select the three factors that are most important that could be used to determine the potential for TPI, and rank them from 1 to 3 (with 1 as the most important). The results, as shown in Table 10-17, indicate that *land use and human activities* were the most selected and thus the most highly ranked factors for consideration in mitigating intentional TPI. The second most ranked factor is *depth of pipeline*, and followed by *accessibility to pipeline network* (proximity of roads, rivers, and streams).

Table 10-17: Selected factors that could measure the potential for third-party interference.

	Land use and human activities		Socio-economic conditions of population living near a pipeline		Accessibility to Pipeline Network (proximity of roads, rivers, streams and rail)		Socio-political factors (e.g. literacy rate, political stability, and violence		Depth of Pipeline (exposed pipeline can often provide criminal opportunities)		Other factor in your opinion not mentioned that influence intentional pipeline	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
None Selected	80	34.9%	118	51.5%	132	57.6%	137	59.8%	105	45.9%	198	86.5%
1st Most Important	86	37.6%	40	17.5%	19	8.3%	30	13.1%	29	12.7%	4	1.7%
2nd Most Important	36	15.7%	42	18.3%	27	11.8%	41	17.9%	52	22.7%	6	2.6%
3rd Most Important	27	11.8%	29	12.7%	51	22.3%	21	9.2%	43	18.8%	21	9.2%
Total	229	100.0%	229	100.0%	229	100.0%	229	100.0%	229	100.0%	229	100.0%

10.5 Multiple Response Analysis of Open-ended Questions

This section describes the methodological approach, qualitative analysis and the general findings of the various open-ended questions that were used in the questionnaire survey. The goal was to describe the patterns of the respondent's commentary; frequency analyses and associations from respondents' unique experiences, which are organisation specific. To achieve this goal for the open-ended questions, the coding of the data, a process of converting qualitative data into numerical records, referred to as multiple response analysis (Kent, 2001) was used in the thesis.

10.5.1 Open-ended questions for Question 5 of Section II

The survey asked the respondent to suggest other various methods of protecting pipeline against TPI, the maximum number of responses obtained from a single respondent was four. The overall response to this question was positive, and twenty different possible methods of protecting pipelines against TPI were identified for this question. The first column in Table 10-18 are the list of the overall response to this question. The table also shows the frequency table of the multiple response analysis to open-ended questions. Using SPSS, a frequency analysis of the multiple responses of the respondents' suggestions was examined for distribution. The overall response to this question was reasonable, 45 per cent of the respondents surveyed suggested one or more methods for preventing TPI.

Table 10-18: Frequency table of the multiple response analysis to open-ended questions

	Responses		***Percent of Cases***
Category label from respondents' view	**N**	**Percent**	
Impact alert system	1	0.50%	1.00%
Greater awareness campaign to stakeholders	23	12.20%	22.30%
Use new Modern technology, e.g. optical fibres	16	8.50%	15.50%
Enforcement of strict safety requirements	16	8.50%	15.50%
Improve rapid response capability	5	2.60%	4.90%
Address motivations of causes	6	3.20%	5.80%
Accurate collation of pipeline database	5	2.60%	4.90%
Install fence along ROW	1	0.50%	1.00%
Better land use planning guidelines	7	3.70%	6.80%
More Research and Development	20	10.60%	19.40%
Intensive surveillance on Hotspots	9	4.80%	8.70%
Evaluate Social and Environmental Impacts	8	4.20%	7.80%
Statutory Punishment to offenders	9	4.80%	8.70%
Increase burial depth	2	1.10%	1.90%
Remote monitoring	8	4.20%	7.80%
Application of proper standards and procedures	26	13.80%	25.20%
Prevent all activities near Pipelines	4	2.10%	3.90%
One-Call Systems	8	4.20%	7.80%
Engage community cooperation	9	4.80%	8.70%
Education on consequences of pipeline failure	6	3.20%	5.80%
Total	**189**	**100.00%**	**183.50%**

The frequency table, Table 10-18, of the multiple responses set indicates that the following are the most frequently suggested methods by the respondents:

i. Application of proper standards and procedures (13.80%)

ii. Greater awareness campaign to all stakeholders (12.20%)

iii. More Research and Development (R&D) (10.60%)

The most striking result to emerge from the data is that *increase burial depth*, contrary to the literature review, is one of the least suggested methods and therefore of lower importance, going by the result of the survey questionnaire. However, in a frequency analysis by geographical location, the respondents from Africa frequently suggested *use of modern technology* and *evaluation of social and environmental impact*. Respondents from Europe mostly suggested *greater awareness campaign to all stakeholders,* while a*pplication of proper standards and procedures* was the most frequently suggested by respondents from the North America. Similarly, in a crosstabulation analysis by organisation, the government agencies frequently suggested '*Application of proper standard and procedures'*. While respondents from the professional bodies frequently indicated *'More Research and Development'*. One respondent divulged: *"In a recent report that was issued by the EU Commission on safety of pipeline transportation systems, the main findings included: Third party damage is the main cause of pipeline incidents and therefore should receive the main focus and the availability of an effective Pipeline Integrity Management system is one of the key elements for control"*.

10.5.1.1 Open-ended questions for Questions 9 and 10 of Section III

Respondent perceptions were assessed as to what other prevention measures they would consider to mitigate damage caused by TPI both during and after pipeline installation. The maximum number of responses obtained from a single respondent was two, and the respondents (Table 10-19) collectively identified ten possible methods.

Table 10-19: Frequency table of responses to open-ended questions for Questions 9 and 10

Responses to open-ended question	***N***	***Percent***	***% of Cases***
Education of Third-parties	2	7.70%	10.00%
Fibre optic cable	2	7.70%	10.00%
Jet grouting protections to vulnerable portions	3	11.50%	15.00%
Material selection against external load	1	3.80%	5.00%
Community Investment Strategy	3	11.50%	15.00%
One call notification systems advertised	3	11.50%	15.00%
Coating, possibly concrete	1	3.80%	5.00%
Sufficient Burial depth	1	3.80%	5.00%
Satellite monitoring	2	7.70%	10.00%
Surveillance frequency by risk assessment	8	30.80%	40.00%
Total	**26**	**100.00%**	**130.00%**

The frequency table of the multiple responses analysis indicates that *surveillance frequency by risk assessment* is the most frequently indicated. This was closely flowed *by Jet grouting protections to vulnerable portions*; *Community Investment Strategy*; and *one call notification systems advertisement.*

10.5.1.2 Open-ended questions for Question 6 of Section III

In response to the question regarding the methodology the respondent would suggest as being most effective for pipeline TPI prevention, Table 10-20 shows the results of the frequency analysis of the collected responses.

Table 10-20: Frequency distribution of open-ended question for Question 6 of Section III

Suggested prevention methods for intentional pipeline damage by respondents	***Responses***		***Percent of Cases***
	N	**Percent**	**N**
Punishment of offenders to deter others	3	1.90%	3.00%
Maximum pipeline burial with addition protection	19	11.80%	19.00%
Involvement of specialist security organisations	8	5.00%	8.00%
Electromagnetic detection and acoustics	8	5.00%	8.00%
Public education/ Awareness of pipeline location	19	11.80%	19.00%
Direct physical protection of vulnerable segments	13	8.10%	13.00%
Remote and aerial surveillance	21	13.00%	21.00%
Alignment based on Risk/Consequence design	6	3.70%	6.00%
Customised solution tailored to fit the environment	14	8.70%	14.00%
Increase pipe wall thickness	5	3.10%	5.00%
Involve the community to guard pipelines	18	11.20%	18.00%
Communications with all stakeholders	27	16.80%	27.00%
Total	**161**	**100.00%**	**161.00%**

The frequency table of the multiple responses set indicates that *communications with all stakeholders* (16.80%) is the most frequently recommended preventive measure by respondents. In addition, *punishment of offenders to deter others* is the least recommended measure (Table 10-20).

In an analysis by geographical location undertaken (Table 10-21), respondents from Africa frequently recommended *involve the community to guard pipelines*, while majority of responses from Europe recommended *communications with all stakeholders*. Respondents from North America mostly recommended *public education/ awareness of pipeline location*. Similarly, in a crosstabulation analysis of respondents' organisations and the open-ended question, respondents from government agencies frequently recommended *communications with all stakeholders*.

Table 10-21: The crosstabulation analysis by geographical location Question 6 of Section 3.

	Geographical Location of Respondent (count)					
	Africa	*Asia*	*Europe*	*North America*	*South America*	*Oceania*
Punishment of offenders to deter others	1	0	0	2	0	0
Maximum pipeline burial with addition protection	2	1	7	7	0	2
Involvement of specialist security organisations	2	1	3	1	1	0
Electromagnetic detection and acoustics	1	0	4	2	0	1
Public education/ Awareness of pipeline location	2	1	7	8	0	1
Direct physical protection of vulnerable segments	2	2	5	4	0	0
Remote and aerial surveillance	3	0	9	7	0	2
Alignment based on Risk/Consequence design	0	0	2	3	0	1
Customised tailored solution for the environment	2	1	4	4	2	1
Increase pipe wall thickness	0	0	5	0	0	0
Involve the community to guard pipelines	10	0	5	3	0	0
Communications with all stakeholders	7	1	12	6	0	1
Total	19	4	40	30	2	5

10.5.1.3 Open-ended question for Question 13 of Section III

Respondents were asked what other factors in their opinion influence the occurrence of intentional pipeline TPI. The frequency distribution in Table 10-22 presents the distribution of the results.

Table 10-22: Frequency distribution of open-ended question for Question 13 of Section III.

	Responses		***%(Cases)***
	N	*Percent*	*N*
Petro-terrorism	17	17.50%	29.80%
Political reasons	11	11.30%	19.30%
Burial depth of pipeline	4	4.10%	7.00%
Strict penalty to offenders	1	1.00%	1.80%
Public education and communication	13	13.40%	22.80%
Absence of laws for pipeline security	7	7.20%	12.30%
Ignorance of the consequences of failure	7	7.20%	12.30%
Government and social responsibility to communities	20	20.60%	35.10%
Economy situation of a country (e.g. theft of product)	17	17.50%	29.80%
Total		**100.00%**	**170.20%**

The frequency distribution table of open-ended question thirteen (Section III) indicates that *government and social responsibility to communities* (20.60%) is the most frequently commented factor perceived by respondents that influence the occurrence of intentional pipeline TPI; followed by *petro-terrorism* and *economy situation of a country*, for example poverty and theft of product (Table 10-22).

In a crosstabulation analysis by location undertaken, Table 10-23, respondents from Africa frequently indicated *government/social responsibility to communities* and *economy situation of a country (e.g. poverty and theft of product)*. In support of the above findings, two respondents support the result that the: *"failure of government commitment to the people of the oil producing communities in Nigeria, and resentment of government policy implementation expressed as vandalism to company pipeline assets for economic gains";* and that *"Poverty/purchasing power of nearby population in relation to value of product in pipelines; and socio-political factors - wealth distribution, employment opportunities, absence of effective community development programs, environmental pollution etc"*. On the other hand, respondents from Oceania countries mostly indicated *petro-terrorism.* Similarly, *petro-terrorism* was the most frequently indicated factor by pipeline engineers compared to other professions, for example, pipeline project engineers whose majority indicated g*overnment and social responsibility to communities.*

Table 10-23: The crosstabulation analysis by location of Question 13 of Section III

	Geographical location of respondents					
	Africa	Asia	Europe	North America	South America	Oceania
Petro-terrorism	3	1	6	3	1	3
Political reasons	4	1	2	2	1	1
Burial depth of pipeline	0	0	3	1	0	0
Strict penalty to offenders	1	0	0	0	0	0
Public education and communication	5	1	3	3	0	1
Absence of laws for pipeline security	1	0	2	4	0	0
Ignorance of failure consequences	1	0	2	4	0	0
Government responsibility	7	0	8	5	0	0
Countries' economy situation	7	0	5	4	1	0

10.6 Analysis Limitations of the Questionnaire Survey

The study within this thesis suffered from several limitations:

- Gathering or sourcing information on oil and gas pipeline is intrinsically complex because of the heterogenic policies of many organisations. Therefore, the observed response rate of 23 per cent is practically undesirable.

- Statistical significance was not satisfied by the study for all hypotheses, therefore some examined procedures might require further considerations and analyses.

10.7 Conclusions

The analysis of the results from the questionnaire survey has shown that TPI concerns differ from one country to another, and are inherently dependent on socio-economic and communication factors. African, North American and Asian countries are at higher risk than other global regions, but with commensurate measures taken to protect their pipelines. However, given the unpredictable nature of intentional TPI, it is very difficult to prevent. Therefore, susceptible countries will need to intensify anticipation and prevention efforts and increase investment in prevention schemes. In addition, it is essential that stakeholders seek to remove motivation reasons for TPI and for it to become mandatory for the industry to increase organisational efforts and implement anti- interference education.

In addition, the questionnaire survey examines the problem of intentional TPI in the oil and gas pipeline industry and suggests important procedures in obtaining high levels reliable prevention strategies for TPI. For example, the survey identifies four factors that are important in preventing and understanding third-party interference: risk mitigation strategy, organisational efforts; preparedness against motivation; and perception of factors influencing the occurrence. The survey confirms that TPI is recognised as a leading cause of pipeline damage, but despite this knowledge and various preventive efforts, it still threatens all concern stakeholders. The accomplishment for the prevention of TPI therefore, is not only with professional adherence and modification of existing pipeline design standard, but with attention to the realities of organisations' multiple roles within the pipeline industry and the community.

Furthermore, the insights obtained from the statistical content-analysis of the open-ended responses unveiled interesting perceptions and opinions from the industry experts. For example, whilst the existing literature has emphasised the importance of the pipeline burial as being an excellent means of protecting pipelines against TPI, this thesis has showed that undertaking a public awareness campaign before, during, and after installation of a pipeline influences positively the reduction in occurrence of TPI. The questionnaire also contains open-ended items inbuilt into the survey to provide more detailed opinion from the respondents, and Appendix IX presented selected remarks from the collated survey.

11 GENERAL DISCUSSIONS

11.1 Introduction

The motivation for this thesis was the perceived lack of a systematic developmental approach that could support the understanding of pipeline third-party interference (TPI), especially for policy makers and the pipeline operators. Recent developments, as outlined in Chapter 2 of this thesis, have heightened the need for studies about pipeline TPI. Perhaps the most significant driver is that over sixty countries already have in excess of 2000 kilometres of pipelines, with the worldwide potential for a further 10,000 kilometres, of new pipelines to be added annually for the next few years (EIA, 2004).

In the study area of Nigeria, the largest oil producer in Africa and 11th largest in the world, 12,845 incidences of TPI were recorded between 1999 and 2007. Approximately 35,000 barrels of crude oil are stolen per day, a well-known trend in the study area (NNPC, 2005). This thesis, therefore, presented different approaches that investigated and examined the geographical, statistical, and industry perception problem associated with TPI. The thesis determined and explored relationships between land use, environmental factors, socioeconomic and socio-political factors, population density, and pipeline properties by using GIS-based hybrid multivariate (and spatial) statistical methods. The discussion that follows the results of this thesis concentrates on the primary objective of the thesis in relation to the study area (Section 1.4).

The findings of this thesis correspond with other international studies regarding the factors primarily responsible for and influencing pipeline TPI (Chapter 5). However, some other factors such as the population density, which might be thought, from the literature, to influence TPI, did not show a significant impact in the study area. This unexpected result suggests that these variables have no prediction ability and more research needs to be undertaken before the association between a geographical region and the possibility for that region to experience TPI is more clearly understood. Meanwhile, the Poisson and LR GLMs methods produced similar results. They both have strong statistical foundations; however, the interpretation of the results and subsequent discussion are based on the proper understanding of the selected variables and the interaction with the study area.

The use of GIS spatial regression analysis (GWR) and the hot spot determination method (Getis-Ord Gi*) considered the regional *non-stationarity* of the independent variables and the spatial structure of the TPI respectively. While the statistical methods (GLMs) have stronger analytical power, the GIS methods encompass advanced spatial analytical capabilities; however, they require accurate spatial positioning of the variables, especially the geographical location of the TPI. This, however, was a difficult requirement to accomplish, especially in the study area. For example, topographic maps of Nigeria are obsolete, dating back to the 1960s, following aerial photographs taken in 1963.

11.2 Factors Influencing Pipeline Third-party Interference

11.2.1 Geographical Accessibility

The GWR and Getis-Ord Gi* analysis showed a positive relationship between accessibility to the pipeline and incidents of TPI. According to the GWR results (Section 7.5), there are positive significant relationships between all the variables considered for the Getis-Ord Gi* analysis and the occurrence of TPI in the study area. This means that increasing accessibility distances and travel time to a pipeline will result in minimised occurrence of TPI. These two models confirm that TPI is a local event, following the routine activity theory (RAT) described in Section 5.7, and that the occurrence is a function of the variables considered. The result of the GIS hotspot analysis and the GWR indicated that spatial variations of the variables are significant, and most of the same variables also support the findings in the GLMs model; for example, the inverse relationship between pipeline intrinsic properties and geographical locations of TPI. However, the GLMs model only determined the relationship at the global scale. The results of the GLMs did not show local variations in the study area as demonstrated by the GWR and Getis-Ord Gi*.

The application of GWR to the occurrence of TPI and the comparison to the results of the Getis-ord hotspot analysis (Section 7.3) yielded some remarkable results. This is, however, not the case with the two GLMs statistical models; although aspatial, they are not as robust as expected. Only seven of the twenty-five variables are statistically significant in the logistic GLMs model (Table 8-16) and six out of the twenty-five variables are significant in the Poisson GLMs models (Table 8-9). Several variables that showed a positive relationship, although not statistically significant, with TPI in the GIS model are insignificant in the GLMs model, in particular population density, age and diameter of pipelines. Therefore, it is considered that GWR has a major advantage over advanced multivariate statistical methods for determining the relationship between variables. Although not efficient in computer processing time, more importantly this method allows a policy-led investigation to be conducted, using the strength association of the independent and the dependent variables, into the spatial geographical region suggested by the GWR result.

The same independent and dependent variables used for the GIS hotspots were used to develop the GWR model as well as two other variables, described in Section 7.4.3. Although the variables considered captured the three major elements of criminal opportunity, GWR identified the nature and patterns of spatial non-stationarity in the study area. One advantage of the statistical methods (GLMs) is the ease with which the significance of the results can be tested, which is not easily achievable with the GWR method. Although the calibration of the GWR software by Forthringham et al. (2003) is possible using the Monto-Carlo test, this provides a *p*-value for each variable that indicates significant spatial variation.

Taken together, these findings suggest that the role of accessibility factors in protecting pipelines can reduce cost and help policy makers to refine and define appropriate measures to maintain the integrity of pipelines. Another implication of these findings is that both the hotspot analysis (Getis-Ord Gi* statistic) and analysis for the spatial influence of variables (using GWR) should be taken into account when there are concerns about seemingly disparate pipeline incidents. This has important implications for future prevention practices by all stakeholders (e.g. law enforcement agencies). It will enable attention to be focussed on particular pipeline segments or a local spatial unit of the study area, and thus reduce the potential for further occurrence with limited resources.

11.2.2 Population Density

According to the result of the GLMs models, population density is statistically insignificant, and showed a negative relationship (Table 8-9 and 8-16). This finding is confirmed by both the GWR and the Getis-Ord Gi* analysis. The GWR showed a moderate spatial positive relationship with regions with low local population density (Figure 7-11). One possible explanation for this relationship is that many perpetrators of TPI live in areas with low population density and most of the pipelines traverse small communities (Muhlbauer, 2004). Therefore, they have easy and quick travel routes to pipelines and are usually less concerned, because of familiarity, with the rugged delta terrain in which they operate. Alternatively, as high population density areas have seen an increase in the number of security personnel, the number of potential offences has decreased.

Opposed opinions were expressed on this issue in the questionnaire survey, and the findings reveal a mixed representation on how population density influences accessibility and the occurrence of TPI. For example, in a question (Table 10-13) asking what are the most important factors that influence TPI, population density was one of the least selected options. Second, in the open-ended question, the reference to population density was insignificant and thus not fully represented in the analysis. However, this picture changes when the geographical location of the respondents was considered. For example, in Nigeria, 63 per cent of the respondents said they were confident that population density is a major factor that is responsible for the occurrence of TPI. This is contrary to the result of the thesis, as explained above, and somehow not in agreement with the method of *selecting optimal pipeline route* as a form of protecting pipelines (Section 4.2.3).

The results from the questionnaire reflect a more significant problem in the study area, namely the lack of consideration and assessment for the increased risk to pipelines from communities encroaching and living in close proximity to pipelines. The evidence from this thesis suggests that prior regulations (e.g. NNPC, 2005) indicating the importance of a safety minimum distance of 30 metres from a pipeline in the study area need review. The question, therefore, is whether this safety distance is sufficient considering the result of this thesis, especially in the local rural areas.

11.2.3 Land use Planning

In the thesis, land use was found to play a significant role in TPI observed in the study area, but with geographically varying influences on the study area. While mosaic grassland/shrubland, broadleaved forest, and shrubland/grassland reduce the probability of TPI occurrences in the logistic GLMs, it was not found to be significant in the Poisson GLMs model. The differences is because the two GLMs models (logistic and Poisson) have differences in modelling assumptions and specifications, relatively producing different effects on the results. On the other hand, there was a statistically significant positive relationship between the mosaic vegetation/cropland and TPI, and a statistically significant negative relationship with water bodies in the Poisson models. This result may be explained by a number of different factors. Agriculture is the dominant economic activity in the study area, and occurs mainly in the mosaic vegetation/cropland land use type. Shifting cultivation is practised, as the people believe their soil to be poor in nutrients. The land under cultivation varied between a minimum of 0.2 per cent in Warri1 North to a maximum of 30.45 per cent in Udu, followed by 25.61 per cent and 25.26 per cent in Patani and Ugheli South respectively. These land use types are seriously protected by the local population against any action that could be detrimental to their farmlands. Therefore, the fear of reprisal attacks can cause vandals to avoid pipelines that traverse these land use type.

Water bodies in the GLMs model were statistically significant. This finding is in agreement with Krone's (1985) findings, which showed mitigating impacts on wetlands and water bodies where pipelines traverse is especially important in preventing TPI. For example, the Royal Dutch/Shell's Russia Sakhalin II 800 kilometres oil pipeline project crosses over 1000 watercourses by trenching. Similar pipeline installations are common in the study area, and such exposures have been marred by unintentional TPI. However, the effect of alternative means of installation, as in the case of Russia's project which utilised horizontal directional drilling, can reduce overall TPI.

The other land use types (e.g. thicket secondary crop land and closed grassland) represents the major land cover patterns available in the study area, for example forestland, swampy land, coastal area and residential land. The general types of lands are the *Iyanomo* land developed on the coastal plain and sand formation. The soils are very deep, well-drained with sandy clay loam sub-soil with low base saturation. The flood plain land type has soils derived from alluvium of the coastal plains on lagoon marshes, brackish and fresh water swamps (Siraj, 2002). It is interesting to note that, in the two GLMs models utilised in this thesis, pipelines laid in these land use types witness more incidence of TPI, and could be concluded to be more vulnerable in the pipeline distribution network.

Although the exclusion of the statistically insignificant land use types did reduce the occurrence of TPI, these results were interpreted with caution. Another possible explanation, in addition to the above, is the presence of soil movement in these land use types. For example, commercial plantation is common practice in the study area, as currently over 4000 hectares of land is under forest plantation, and intertwined with pipelines. These assumptions are consistent with those of other studies; for example, Berman et al. (1994) suggested that soil movement in deltaic regions (e.g. Mississippi and

Atchafalaya river mouths) deposited rapidly during high river flow cause pipeline failure, particularly when pipelines are laid above ground. This explanation is possible considering that human activities in the study area affect the water resources, especially channelisation of streams, creeks and estuaries, through dredging, sand mining, and drainage of adjacent wetland. It can thus be suggested that the significant land use types do not support substantial bank erosion, which will expose buried pipelines.

It has been observed that encroachments into pipeline right-of-ways are more often inadvertently planned, especially in developing countries (Kashi, 2006). In view of these aspects, monitoring of activities in the vicinity of pipelines is of utmost importance (Huebler, 2002). Internationally, these issues have already been discussed and debated, for example the UNECE Safety Guidelines for Pipelines have been adopted by the UNECE countries. The UNECE issued guidelines concerning land use planning (monitoring of settlement and land use) and the recommendations for avoidance of TPI. For example, article 27 of the guideline states: *"UNECE member countries should establish a system of permits and of land use planning procedures with the involvement of the public in order to ensure that pipelines are planned, designed, constructed and operated in a safe way. They should also ensure adequate monitoring and control."* In Germany, safety distances have to be considered when permitting the construction of pipelines. These safety distances, as required in the *"Technical Rule for Pipelines"*, serve primarily to protect the pipeline route against external impacts (Howe, 2009).

The regulatory approach for pipelines in the United Kingdom (UK) reflects the opinion expressed in the questionnaire survey. The methods of mitigating the occurrence of TPI put more emphasis on regulatory approval procedure, risk assessment and safety management. According to Howe (2009), the HSE provides local authorities with information about land use in the proximity of pipelines. These are used for assessment of potentially increased risks using a special dedicated team to consider aspects of land use planning for the entire UK. *"The HSE only has an advisory function in the system of land use planning. It is not authorized to reject approvals by local authorities or requests for permission. It is within the discretion of the competent authority to take decisions and to weigh local needs and advantages against other aspects of planning"* (Howe, 2009).

11.2.4 Pipeline Intrinsic Properties

11.2.4.1 Pipeline Diameter

The result of the GLMs models indicated that there is a positive relationship between pipeline diameter and TPI; the results also indicated that pipeline diameter is statistically significant in the logistic GLMs model. The GLMs models are global models using the average diameter of the pipeline; therefore it is possible that the Poisson GLMs model may hide interesting spatial variation, as was investigated in the GWR models. This is a possible explanation for the statistical insignificant variable (pipeline diameter) in the Poisson GLMs model. Overall, the results of the models substantiate the results of the questionnaire that suggested that increased pipeline diameter increases the occurrence of TPI. For example, from the result of the questionnaire, the overall rating of increasing pipeline wall thickness (high wall thickness corresponds to high pipe diameter) is higher when compared with other measures used in preventing TPI. This thesis produced results which corroborate the findings of many of the previous works about pipeline diameter and TPI. According to Williams et al. (2007), the potential damage caused by a pipeline failure, and the number of consequences, increases as pipeline diameter increases. It has also been suggested that the importance of pipeline diameter, as shown by the EGIG report for pipeline incident data, is solely classified on pinhole, using the diameter of the defect. The EGIG report also identifies that the extent of damage caused by TPI is dependent on pipeline intrinsic properties, such as pipe diameter, depth of cover, and wall thickness (Mather et al., 2001).

Concerning the significance of the pipeline diameter and occurrence of TPI, it has been well established in the literature, as stated above, that TPI increases with increased pipeline diameter. For example, in the study area, large pipelines (>12 inches) account for 60 per cent of the TPI. These results need to be interpreted with caution, as they could be attributed to operating characteristics of the pipeline. However, this thesis has been unable to demonstrate the assumption that larger diameter pipelines are structurally stronger because of thicker walls and thus can withstand more force than smaller diameter pipelines. Nevertheless, useful results were obtained that showed the spatial variation influence of pipeline diameter within the study area. It can therefore be concluded that large pipelines, according to the result of this thesis, experience a larger number of TPI incidents than smaller diameter pipelines. It is interesting to note that large diameter pipelines are located to the shoreline of the study area. Therefore, by focusing attention on these regions, security will be better provided in addition to identifying other possible activities that are responsible for TPI.

11.2.4.2 The Length of Pipeline and Percentage of Oilfields

The Poisson and logistic GLMs models described in this thesis both specify a multiplicative relationship between the occurrence of TPI and the length of pipeline and percentage of oilfields. These two variables are statistically significant in both the Poisson and logistic GLMs models, although the strongest associations were found with the logistic GLMs model. Overall, the results are significant in at least two major respects. Firstly, the length of the pipeline determines the amount of exposure to TPI; secondly, the area of the oil and gas resources of a region determines the probability of occurrence of TPI. On the other hand, these results yielded dissimilar results when compared with results of the questionnaire. It is somewhat surprising that no respondent mentioned or indicated an interest regarding percentage of oilfield being an important factor in understanding the occurrences of TPI. The evidence, albeit statistically significant in the model, suggests that little research has examined systematically the linkages between TPI and the presence of an oilfield in a region. This finding was unexpected and suggests that, although the results of the questionnaire are from the industry experts, this factor is not recognised as being significant in the industry and therefore is not considered in the current TPI mitigation strategies.

The length of pipelines and the area of oilfields are an indirect substitute for each other, and it is hypothesised that regions with large numbers of pipelines might be associated with large percentages of oil and gas. If an oilfield is associated with high numbers of pipelines, according to the above argument, regions with longer pipelines would be expected to experience more TPI. These explanations explaining the influence of these variables are rather plausible; nevertheless, they are satisfactory. Thus, in addition to these explanations, it is recommended that oil and gas pipeline lengths should be short in these vulnerable regions, and proportionally correspond to the socioeconomic and socio-political status.

Another possible explanation is the coexisting activities of intentional and unintentional TPI. For example, it is expected that, in oilfields, supply vessels from 20 to 60 metres long work simultaneously with various drilling activities. According to Berman *et al.* (1994), the activities of the vessels, working closely around drilling rigs, are mostly concentrated in regions with high numbers of pipelines, and hence the high likelihood of TPI. In view of the probable disturbances to pipelines in oilfields, which may be expected, and the detrimental effects of irregular oil spills on the adjacent land, particular attention is required to protect pipelines in the regions.

11.2.4.3 Pipeline Status: Buried or Aboveground

There are similarities between the findings expressed by the result of the GLMs for pipeline status in this thesis and those described by Neville (1981) which state that increasing the depth of cover of pipelines (to about 1.6m) will reduce damage caused by TPI. A longitudinal study by Mather et al. (2001) also reports that 50 per cent of all pipeline damage is concentrated in the 30 per cent of pipelines that have a depth of cover of less than 1.05 metre. However, it was observed in the questionnaire survey that many questions related to pipeline intrinsic properties were unanswered. An implication of this is the possibility of privacy and security concerns regarding a pipeline's geographical location and intrinsic properties, especially after the events of 9/11. For example, in Europe, information that is available to the general public about pipelines is decreasing, because pipelines are classified by the European Union as critical facilities. However, with a small response rate, caution must be applied, as the findings might not be transferable to a security concern.

The result of the Poisson GLMs showed that pipeline status (buried or above ground) is statistically significant, even so, it is imperative to assume that pipeline status influences the occurrence of TPI. However, since the measurement of pipeline status in the thesis is rather ambiguous and several other factors determining why a pipeline is buried or aboveground are not captured by the variable, the result was interpreted with caution. The result was a subjective expectation; nevertheless, the findings do support other previous research, as stated earlier, that aboveground pipelines have higher probability of TPI than buried pipelines. However, in the study area, buried pipelines are relatively not safer. This is because TPI damage to buried pipelines is common, and is attributed to pilfering of oil product and to saboteurs. Other studies have confirmed that other major causes of TPI, especially to buried pipelines, are digging activities (e.g. excavators), construction contractors, and property owners (Sljivic, 1995). These combinations of findings provide some support for the conceptual premise that pipelines, buried and aboveground, are exposed to the same risks of TPI.

11.2.5 Socioeconomic Factors

The low socioeconomic status of local populations in developing countries like Nigeria is one cause, according to the literature (e.g. Nwankqo and Ezeobi, 2008; Hongqing, 2005), that is responsible for pipeline TPI in the study area. The findings from this thesis have shown this is not the case. None of the socioeconomic variables were significant in the GLMs models implemented. On the other hand, only one socio-political variable, namely the percentage of households with pipe-borne water, was significant in the GLMs models. This result is surprising considering the key issues and challenges relating to and affecting TPI in the study area which are interrelated with these factors (Dey, 2004). These results appear to portray TPI, in the study area, as more of a technical rather than a socio-economic problem.

A higher TPI risk may be considered to be related to a poor socioeconomic factor. In regions with a low socioeconomic status, the proportion of potential occurrence of TPI might be high (Okechukwu, 2010). Furthermore, a poor provision of social infrastructure may reflect a poor economic status of the local population, and hence the likelihood of interfering intentionally with a pipeline. For example, the lack of transportation facilities and electricity supply has limited the economic and social development of the study area. In addition, inadequate water supply and unhygienic conditions have led to various health hazards over the years. Therefore, the unemployment due to limited development leads to economic imbalance and severe poverty and thereby vandalism and saboteurs of pipelines throughout the study area. These observations might be related to the higher TPI in the study area, and are characteristic of a socioeconomic factor that can be crucial when measuring the occurrences of pipeline TPI. Surprisingly, this was found to be the reverse in the above model with socioeconomic factors. The key aspects of the results can be listed as follows:

i. The lack of association between socioeconomic variables and the occurrences of pipeline TPI in the study area contradicts previous research that has found a positive relationship between crimes (e.g. intentional pipeline TPI) and socioeconomic factors (Bennett, 1991; Blau and Blau, 1982). According to these researchers, there are a number of factors which contribute to the relationships. Conversely, only a few studies have evaluated the direct association between TPI occurrence and socioeconomic factors (Dey, 2002; DPR, 1997; Okechukwu, 2010). Dey's (2002) study, for example, evaluated this association on a cross-country pipeline rather than on regional spatial units, as used in this thesis. It is important, therefore, to note that it is possible that the above statistical insignificance of the socioeconomic variables in this thesis were due to the generalisation of the data at the individual regional spatial unit level.

ii. Another possible explanation for this result is that the socioeconomic factor of the study area is not exclusively measured by the variables considered in the thesis (Section 5.3). Therefore, it is possible that the variables considered present a less optimistic and realistic relationship with TPI in the study area. Consequently, this might suggest the possibility of ecologic fallacy for the socioeconomic variables used in the study area. This data requirement and limitation is one source of weakness in this thesis which could have affected the measurements of the socioeconomic factor. This could be improved, for example, a primary survey to measure the many households with no access to safe water and electricity. A substantial proportion of the population continues to rely on water from wells, rivers and lakes, which constitutes a serious health hazard to the people (Siraj, 2000).

iii. The socioeconomic and socio-political factors are somehow interconnected and may contribute indirectly to other statistically significant factors in the thesis. For example, low government expenditures may lead to lower quality of social infrastructure, which in turn increases attractiveness to urban areas. Therefore, future research could test further the link between socioeconomic factors and occurrences of TPI, for example by examining other regions in the country and analysing percentage changes in socioeconomic variables over time compared with the frequency of TPI occurrence.

Finally, the major policy lesson is that socioeconomic factors in the study area, despite the assumptions reported in the literature, are not responsible for TPI in the study area, rather accessibility and land use planning are the main causes. It can be concluded that the lack of integrated land-use planning in the study area means that the socioeconomic factors not accurately defined within the study area. However, caution must be applied, as the findings might not be transferable to other area. The result of the questionnaire showed that, in the study area, opinions are divided on the causes of TPI. For example, the majority of the respondents from the oil industry perceived TPI as an act of sabotage; while much literature (e.g. Kash, 2004) blames the government for the low socioeconomic status of the study area. Some literature (e.g. Dey, 2004) presented several views; for example, they identified the continued negligence of the nation's pipeline as the main cause of TPI.

11.2.6 Socio-political Factors

This thesis has successfully examined the socio-political factor as a determinant of pipeline TPI. While previous studies have examined the impact of this factor, there is no study that has systematically examined the relative importance of a socio-political factor, particularly in conjunction with other factors potentially influencing TPI. The results obtained lend support to the hypothesis that, in addition to the standard pipeline intrinsic properties, a socio-political factor is significant in investigating TPI, particularly in the study area. The few studies that focused on the relationship between socio-political factor and TPI have recognised that, in addition to socioeconomic problems in developing countries (e.g. the study area), socio-political failures also increase the occurrence of TPI. Okechukwu (2010), for example, found that political unrest influence the occurrence frequency of TPI. For example, political protests and internal uprisings in the study area involving the local populations where pipeline traverses are detrimental to the integrity and security of these pipelines. Hence, this thesis was able to analyse these variables, and found them to be statistically significant.

The negative association between percentage of households with water and TPI contradicts the hypothesis derived from routine activity theory (Section 5.7), which assumes that TPI will take place most frequently in regions with large numbers of attractive targets (pipelines distribution network). Also, the result of the Poisson GLMs contrast with findings from the logistic GLMs results regarding socio-political factors. However, it should be noted that the socio-political variables in this thesis were based on national disaggregated data and the varying demography of the study area; therefore, the collation format may have resulted in the statistical insignificant results of the logistic GLMs model.

In general, the results of the thesis indicate that socio-political factors are more influential than socioeconomic factors on the occurrence of TPI. Therefore, there are policy recommendations that can be drawn from the result. Socio-political instability and social unrest (ethnic, political unrest and government instability) associated with the study area are significant factors influencing the occurrence of TPI. Therefore, developing countries can recreate policy reforms to take care of these socio-political problems. It may also be more important to improve the quality of the existing infrastructure than to engage in further public investment for new proposed pipeline projects. This recommendation applies internationally because it is not only in the study area that socio-political factors significantly influence occurrence of TPI. For example, the routing of pipelines from the Middle East to the Mediterranean avoided Israel, and the *"new pipelines linking Central Asia with the Mediterranean are being routed in response to the ethnic and religious mosaic of the republics in the Caucasus"* (Markel, 2006).

Finally, a number of important issues need to be considered in understanding the statistical significance of the socio-political factor in the study area. First, the majority of the inhabitants of the region live below the poverty line. There is poor governance and low level of accountability in the use of local and state government resources for development, with attendant poor service delivery and suboptimal deployment of scare resources (Siraj, 2002). The provision of infrastructure is politically derived, teachers are inadequate in terms of quantity and quality, and almost all schools are ill-equipped and dilapidated. The result is that schools have become what has been described in some quarters as 'restive youth factories', whose students cannot compete in order to get good jobs, and are not endowed with skills for farming or other self-employment, thus swelling unemployment ranks and becoming ready recruits for militant groups to vandalise pipelines.

11.2.7 Human Development Indicators

There are contradictory positive and negative relationships in the GLMs models regarding the influence of this factor. For example, the HDI showed a positive relationship with TPI in the LR model, but a negative relationship in the NB model. This is contrary to expectations, and a possible explanation for this result may be the mixed representation in both the GLMs models. The variables were used as a proxy for the human development factor, and were disaggregated from a national scaled data; therefore, representation for a count dependent variable (Poisson distribution) and nominal dependent variable (binomial logistic distribution) will not be true in every region. Therefore, it is important to reiterate that the objective of this study is to understand the relationship between the factors, hence this particular result does not jeopardise the overall objective. Moreover, since this thesis includes a questionnaire survey that has shown that human factors are highly significant in understanding TPI, the performance of the GLMs model may not have been affected adversely by these isolated cases. Therefore, in investigating TPI, it was interesting to introduce human factors for which the relationship aspects have been investigated regarding the occurrence of pipeline TPI and are well understood.

In general, it can be concluded that regions with a low Human Development Index (HDI) have a high propensity and likelihood of experiencing pipeline TPI. This is especially true for most of the local population where a pipeline traverses, but where there is also a lack in social infrastructure, for example access to safe water and electricity. However, caution must be applied, as the findings might not conclude that, for example, poverty reduction and adequate living standards will lead to the improvements of pipeline security. Therefore, the evidence presented in this thesis (Chapter 8) confirms the possibility that the lack of infrastructure needs is a major reason for the high occurrence of TPI.

11.3 Pipeline Failure Databases

Whilst various international pipeline failure databases, reviewed in Chapter 3, are well established and maintained by the individual collating institutions, their research potential is not yet fully exploitable. The review in this thesis has provided a perspective regarding the constraints of their use. This thesis has also highlighted many of the key issues facing the selected pipeline failure databases and the industry today. The following are the key developmental issues:

(i) The findings from the review of various pipeline failure databases, while broad and objective, suggest that the various databases could be subjected to considerable criticism because, until recently, there have been little cross-coordinated understanding of TPI. One of the issues is that many of the databases identified did not use a consistent definition of TPI and therefore database comparison was not possible. This limited the usefulness of these databases for comparative research. This finding is rather disappointing, particularly considering the fact that failure database linkage would allow pipeline failures in a different region, recorded at different times to be collated and merged. These differences are, in part, explained by the classifications procedures of the various organisations involved and individual application of statistical comparison to the data. The need for industry unification is useful; particularly post 9/11, where information relating to oil economics, health risk, terrorism and service delivery is required by regulating and security agencies.

(ii) A systematic comparison of various pipeline failure databases was difficult to accomplish, which suggests that a weak link may exist between various databases. The reason why uniform comparisons are difficult is because of the operating purpose of the pipeline (i.e. gathering, transmission, and distribution) and the criteria for determining an incident as a failure. For example, in 2002, the OPS decided that only pipeline failures resulting in the release of 19 litres or more are to be included in the database (OPS, 2008).

(iii) Lastly, there is a need to produce a uniform nomenclature and homogeneous database for TPI. It is considered that this is a basic requirement for effective management of pipelines, although it is recognised that this will require thorough supervision by the collating agency and external quality control to produce such a database. The advantages of uniform nomenclature and a homogeneous database for use in pipeline failure research cannot be overemphasised. First, such databases will offer high statistical power in predicting and understanding the occurrence of pipeline failure. Rare occurrences in some regions and frequent occurrences in others can therefore be studied more productively. Secondly, collation and categorisation can be done relatively promptly, thereby saving costs on a database's administrative and audit procedure. However, it is imperative that, if a uniform nomenclature is to be adopted, there is continuous quality monitoring, to ensure accuracy and completeness of such a database.

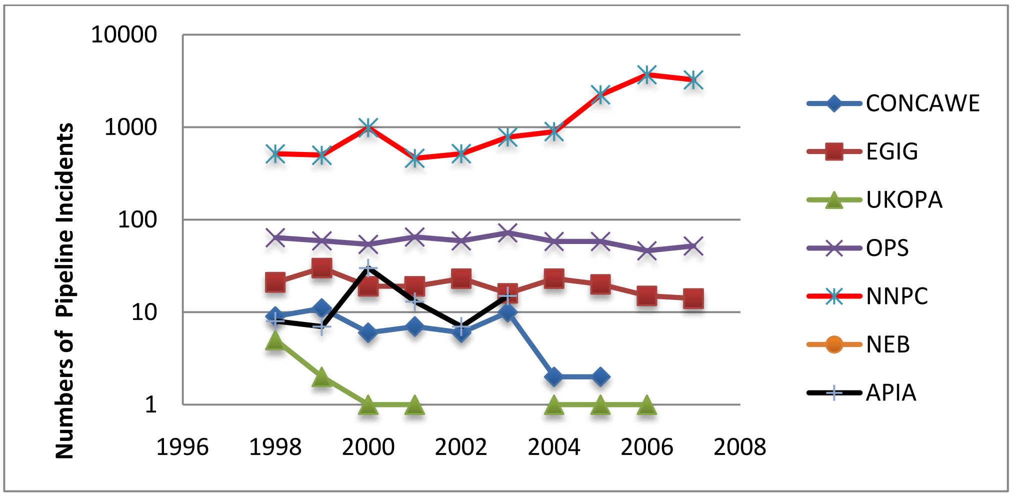

Figure 11-1: Third party damage comparison of pipeline incidents database; the numbers of pipeline incidents are in logarithmic base. This is because the NNPC data are extremes, with numbers of pipeline incidents in thousands, compared to other databases. Hence, the need for the manipulation of the data to enable easy visual characterisation of the database.

The thesis review showed that EGIG, UKOPA and NEB publish periodic reports that would be far more useful and interesting if they had also considered publishing the raw data collected from the original input to their databases. At the present time this cannot be fully enforced because, according to Bolt (2006), data collection can be mandatory or voluntary; either collected and owned by a private company, and managed by regulatory agencies, or jointly managed through cooperation between groups of stakeholders. In the USA, it is a regulatory requirement that companies must publish all related pipeline incident data, and the OPS's database has extensive and numerous publications about general pipeline failures. They have also made the most comprehensive classification of all pipeline failures; for example, while most database reviews have used general terms (e.g. others, unknown) to classify some failures, OPS have been specific. The OPS attempts to publish all relevant raw data on its pipelines, and is available online from the Office of Pipeline Safety website.

The strategy of APIA and CONCAWE in critical assessment, consistencies, and compilation of pipeline incident data has been successful. Figure 11.1 shows the close similarity in trend between APIA and CONCAWE. Restrepo *et al.* (2000), for example, praise CONCAWE's high reliability, especially the setting up of study groups for pipeline failures. In addition, the nomenclature of the EGIG database is very similar to APIA regarding the classification of pipeline failures. However, there is a difference in how pipeline TPI is defined; while APIA specifically identifies pipeline TPI, EGIG generalised the understanding by using the term "external interference".

Finally, returning to the question posed at the beginning of this thesis, it is now possible to state that the thesis, through the examination of an in-depth literature review, has provided a comparative examination of the international pipeline failure databases. It also highlights specific characteristics of the databases in terms of their descriptions of pipeline TPI. In general, a detailed pipeline database review could help the industry maintain failure data consistency, define effective protection measures, enable regulatory bodies to establish safe network, and facilitate application for future design strategies against TPI.

11.4 Protection Methods for TPI

There are various methods for protecting a pipeline against TPI (Chapter 4); however, there are limitations, under certain conditions, that reduce their usefulness. Thus, of all the methods reviewed for protecting pipelines against TPI, the remote sensing application is the most preferred. This method can be used to continuously monitor pipelines against unintentional TPI. There are many reasons for this; firstly, remote sensing (RS) surveillance provides the ability to regularly monitor the pipeline; secondly, it enable the use of change detection analysis and, with stereo forward overlapping satellite imagery, RS enables 3D inspection of potential intrusions. On the other hand, the thesis concludes that the best method for protecting the pipeline against intentional TPI is the use of Fiber-Optic Systems (FOS). This system can continuously monitor pipelines in real-time, covering tens of kilometres. The methodology for detecting vulnerable regions used in this thesis would enable the FOS to be located disjointedly at different locations along vulnerable segments in pipeline network.

Over the last few decades, various forms of protection of pipeline against TPI, and pipeline failure in general, have grown and developed considerably. However, despite these advances, pipeline failure still occurs on a regular basis. Therefore, it appears that, despite various additional researches in protecting pipelines, there is evidence that more research needs to be done, a conclusion drawn from the result of the questionnaire survey. The following can be generally concluded:

i. Emphasises should be placed on redeveloping the existing protection systems to effectively protect particularly vulnerable segments of pipelines using spatial analysis techniques developed in this thesis.

ii. There is need for attention and coordination between different agencies to understand 'indigenous' practices, which will help the industry in general. The practices, for example, are the utilisation of local communities to protect pipelines.

iii. The results of the questionnaire showed that many respondents properly understood the severity of TPI threat. However, there is evidence from the result that suggests that the industry, in terms of protecting pipelines, needs to readjust its strategy to cope with the worsening threat of TPI.

iv. In light of the limitations of the various protection methods, there was the suggestion in the questionnaire that any adapted protection methods should take into account the anticipated probabilistic risk. This should be accompanied by constant re-evaluation and implementation of changes corresponding to the spatial non-stationarity of the occurrence of TPI.

11.5 Questionnaire survey

The survey confirms that TPI is recognised internationally as a leading cause of pipeline damage; but despite this knowledge and various preventative efforts, it still threatens all concerned stakeholders. The accomplishment of a methodology for the prevention of TPI not only requires professional adherence and modification of existing pipeline design standards, but also attention to the realities of an organisation's multiple roles within the pipeline industry and the local community. This result has also demonstrated that the prevalence of TPI in Africa is associated with the socio-political and socioeconomic status. The findings from the survey highlight the need for stakeholders to consider:

- The demonstration of high levels of commitment to the communities through which a pipeline traverses.
- The development of programmes and a support structure to optimise risk mitigation strategies to achieve maximum protection against TPI.
- The benefits of the various modern technologies applicable to the prevention of pipeline third-party interference.

11.6 Recommendations for Further Research

It is believed that an improved understanding of pipeline TPI has been achieved by the work undertaken in this thesis; however, some gaps in the knowledge could not be filled because of the limitations imposed by a combination of data availability and time. These limitations provide an opportunity for future study, especially in the following areas:

- This thesis developed models to better understand and predict the potential for pipeline TPI that included various independent variables. Future researchers should develop other models that will include additional variables, for example the types and modes of pipeline TPI. This will enable the pipeline TPI types to be individually analysed rather than using the collective and total of the number of occurrences for a certain period. In addition, a combination of geological, geophysical and other related crime data may help improve the level of understanding of pipeline TPI if included in future models.

- For future research, it is recommended, within the scope of investigating pipeline failures, that the methodologies used in this thesis be extended to other causes of pipeline failures (e.g. geological, operator error and materials), depending on data and time availability. It will also be valuable if similar analyses of pipeline TPI from other regions of the study area (Nigeria) were performed in order to compare the trends of occurrence and to identify any significant similarities or differences.

- This thesis on TPI has been locally oriented; as such, the possible areas for future research should address the extent of TPI on national and international level. In addition, such research should build on the limitations of this research, and critically evaluate and thoroughly address the issue of litigation and criminology, combining quantitative and qualitative studies.

- Future research could concentrate on the investigation and development of a management and security decision tool. For example, a survival time analysis model, being a predictive model that will estimate the probable time interval to the occurrence of the next TPI. In addition, a forecasting model, such as Artificial Neural Network model (ANN) can be complementary to further research.

- Existing pipeline failure databases, particularly in developing countries, are limited in scope and definition and, as a consequence, may be misleading. In addition, datasets may be unreliable and incomplete. For example, geo-referencing existing datasets with reference to satellite imagery in the study area may reveal inconsistencies in the data collected. These databases do not reflect the priorities of pipeline operator; therefore, future research could exploit the linkage between existing international pipeline failure databases by potentially establishing a comprehensive international nomenclature for databases where the priorities of pipeline operators, security agencies and policy makers are borne in mind.

11.7 General Limitations of the Thesis

This thesis has made significant contributions to literature on TPI; however, there are several limitations that should be recognised. These are:

- Inadequate metadata was available for useful determination of accurate and appropriate datasets for most of the secondary data used in the thesis, although, this is common in developing countries like Nigeria, and does not affect the overall result of the thesis. However, it is believed that the results show what can be achieved in a country with complex political and geographical variations. Therefore, such a thesis as this is needed in the future as it will enable researchers to answer research questions of data collection in similar study areas.

- The data collection for the thesis was not exhaustive. This was because most pipeline incident data are not well collated by the accountable authority in the specific study area, and there is a large amount of missing, potentially useful, observations in the data, for example the exact location of the TPI. However, it was concluded that the data are representative of the selected study area, although the results from the analysis may be less representative in the global context of pipeline TPI.

- It is not possible to account for all the possible factors that influence the relative occurrence of pipeline TPI in a region. The measurements of some factors (e.g. socio-political) in the thesis are limited; however, appropriate proxies (where applicable) are used, and they arguably capture the main situations that are of interest to the thesis objectives. In particular, the use of HDI data is for each of the LGAs and is not directly designed for the basic spatial units. The interpretation of the results was, however, made with caution, because of the possible problem of endogeneity.

- The thesis could not utilise primary surveys, especially to facilitate a more authenticated selection of variables considered. This would have led to a more significant productivity of the statistical techniques and procedures because kidnappings and violence are prevalent in the study area. This is in addition to the presence of cultural and traditional belief systems in the selected study area, for example the presence of fearful shrines and local deities. The sacred groves and shrines are out of bounds to strangers, women and children who are non-initiates of the order. Hence, conducting a primary survey in the study area would be a high risk task for an outside researcher.

12 CONCLUSIONS AND RECOMMENDATIONS

Chapters 7, 8, and 10 presented the results from the thesis and reported the key issues used to examine relationships between land use, socioeconomic and socio-political factors, population density, and pipeline intrinsic properties. This chapter summarises the key conclusions with reference to the research objectives stated in Chapter 1, together with recommendations made for the pipeline industry, with particular reference to the study area. This thesis has extracted analytical approaches from various science and engineering disciplines that are not commonly found in pipeline failure prevention research. An understanding of the physical characteristics of the study area forms an important aspect of the interpretation and evaluation of the various results obtained.

The thesis approach is innovative in the area of TPI research, especially the combination of data collation and manipulation from a variety of disparate sources; the review of major pipeline incident databases; exploratory review of prevention methods; the use of a primary questionnaire survey; and the employment of GIS-based multivariate statistical tests. The thesis has provided a more complete understanding of the complexity of pipeline TPI than any previous studies have accomplished, especially the contribution to the literature from the mixed-methods approaches that have been implemented. The main objective of this thesis has been achieved as set out in Section 1.4. Therefore, this thesis reached important conclusions, which include the following:

i. Pipeline TPI is inevitable and cannot always be prevented. However, this thesis has demonstrated that the ability to identify potential future occurrences can be understood and achieved. A clear repeatable methodology to minimise the occurrence and consequences of TPI, especially as established by standard procedures as formulated in this thesis, has been achieved.

ii. The use of the GIS for spatial statistical analyses and the cartographic capability to model and visualise the spatial distributions of pipeline TPI hotspots has shown that GIS can provide a vital tool for use in the pipeline industry. In the context of this thesis, a GIS has successfully revealed trends and inter-relationships of factors that may be otherwise difficult to identify by simple statistical design or the traditional visual route inspection.

iii. The understanding of future possible occurrences of TPI, let alone their prediction, is a challenge, since it depends on numerous factors as described in Chapter 5. It was concluded that the GWR is the best instrument to model pipeline TPI spatial data when compared with the other models that have been examined. This is because it allows for a critical evaluation of any hidden attributes of a variable in a global context, and enables the investigation of salient relationships between factors in a local context. The thesis provides additional evidence with respect to younger pipelines, in that they are less vulnerable than older pipelines. The thesis suggests that, while younger pipelines had better protection because of the employment of modern protection technology, older pipelines were a lot more accepting to interference than is often thought to be the case.

iv. The use of GLMs methodology in this thesis identified that the total length of pipeline distribution network in a region, the perimeter of oilfields, selected land use types, and pipeline status (buried or aboveground) are the most significant and predictive factors influencing TPI in the study area. Moreover, the evidence in this thesis suggests that some pipeline intrinsic properties (e.g. pipeline diameter) are more important in risk assessment than others, and contribute more significantly to the understanding of TPI than previously thought. This finding is in agreement with existing literature such as Hereth et al. (2007) and Muhlbauer (2004), which showed the importance of pipeline intrinsic properties and pipeline length on failure rates.

v. This thesis has explained the central importance of GIS spatial analysis in predicting the occurrence of pipeline TPI, and the following conclusions can be drawn from the thesis: (i) the probability of pipeline TPI in most cases is proportional to the total length of pipeline distribution network in a region. The LR analysis showed this variable as statistically significant in determining the likelihood of the presence or absence of pipeline TPI; (ii) when holding all other variables constant, the more pipelines installed in the mosaic grassland/forest or scrublands land use type, the less likely the segments of pipeline system will experience TPI.

vi. The findings of the thesis have raised a number of important implications for the categorisations used in pipeline incident databases, and have shown that a harmonisation, in theory, of all the existing pipeline failure databases is possible and urgently needed. The understanding of TPI from these databases needs further identification and reclassification in order for the global scale of the problem to be more accurately determined. This can be achieved through the development of a uniform nomenclature and a unified approach to data collection.

vii. One of the primary goals of this thesis, presented in Chapter 6, was to study the aspects of safety and the effectiveness of various TPI detection and prevention methods. This includes an evaluation of the approaches for minimising pipeline TPI vulnerability, with their corresponding advantages, limitations and disadvantages. When evaluating these methods, the socioeconomic and socio-political status within the monitored geographical region, in addition to population density over time, influenced the implementation of these methods. In conclusion, these findings have a number of important implications for future practice; the effectiveness of methods must be determined in each new application in a manner that will incorporate changes in these influencing factors, especially the significant variables considered in this thesis.

12.1 Recommendations for Industry

The findings of this thesis have a number of important implications for future practice and the industry in general. Therefore, the thesis concludes by making a series of recommendations to the pipeline industry, particularly in the study area. In spite of numerous TPI incidents experienced by the study area, there is no single recognised agency which can be tasked with the responsibility of safeguarding the pipeline infrastructure. The NNPC and the Department of Petroleum Resources (DPR), which oversees and moderates the safety of pipelines in the country, have no capacity to provide effective surveillance for the pipelines. The fundamental problem, based on the responses to the questionnaire survey in this thesis, is the absence of effective patrol teams and sophisticated technologies for monitoring pipelines in the study area. Therefore, the following observations and recommendations are worth serious consideration by all the stakeholders in the study area and in other geographical regions of the world that have a similar problem:

i. The thesis has shown that practical involvement of all stakeholders, especially by the relevant pipeline authority, in campaigns and public education, particularly the nearby local population within the pipeline distribution network, minimises the occurrences of TPI. The pipeline industry should therefore endorse this important route in order to optimise prevention and protection procedure for efficient security of the pipeline distribution network.

ii. It is essential that the industry influences the inadequate legal framework regarding pipeline failures, especially in the study area. It is demonstrated that such legal regulations effectively deal with pipeline TPI, for example as practised in the United Kingdom. The Control of Major Accident Hazards (COMAH) Regulations of 1999 require Local Authorities to prepare and be ready with Off-Site Emergency Plans in order to prevent and respond to major pipeline-related incidents. This arrangement seeks to limit the consequences of any subsequent failure to the environment and to the people, and is enforced by the Health and Safety Executive (HSE) and the Environment Agency (EA) in the United Kingdom.

iii. In order to protect pipeline distribution networks in vulnerable land use types, it is recommended that a potential pipeline operator carry out integrated studies for a better understanding of the local ecosystem, for example cartography, biodiversity, hydrology and socioeconomic status. For the protection of oil and gas pipeline facilities, strategies based on ecological principles of protection, creative approaches, and technical research are recommended. Similarly, in order to protect the local environment from the adverse effects of pipeline failures, a suggestion for control is the organisational setup of local pipeline protection agencies and for the strict implementation of laws for pipeline management.

iv. The existing state of the pipeline infrastructure in the study area needs a complete system overhaul. As acknowledged by the Managing Director of the SHELL Nigeria, Basil Omiyi: *"We do have a substantial backlog of asset integrity work to reduce pipeline spills"* (Ikelegbe, 2001). This lack of maintenance, as required in the industry, does lead to TPI. It is therefore imperative that these pipelines be adequately maintained and, if possible, be buried deeper in the ground. A potential for a 99 per cent reduction in TPI is possible if a depth of 3m is considered for burying pipelines; it is most unlikely that intentional TPI will occur at this depth of cover. This depth of cover should reduce both intentional and unintentional TPI to pipelines (Borysiewicz et al., 2004).

v. The findings from the analysis of open-ended questions utilised in the questionnaire survey highlight the need for stakeholders, globally, to consider: (i) creation of quality practice with high levels of commitment to threat assessment procedures; (ii) development of programs and support to optimise risk mitigation strategies; and (iii) the benefits and understanding of various modern technologies applicable for protecting pipelines against TPI.

vi. The thesis has indicated that TPI will continue to be prevalent in the study area; the government should therefore embrace the growing importance of security investment and a beneficial decision-making process. Specifically, from the results in Chapter 7, it is recommended that more susceptible countries need to intensify prevention efforts and increase investment in prevention schemes, including the following: the implementation of proper standards and procedures; increase the use of awareness campaign by all stakeholders; intensify Research and Development; increase surveillance frequency as determined from risk assessment; discourage, by all means, right-of-way encroachment; encourage adequate communications with all stakeholders; adhere to government and social responsibility to communities; and monitor land use and human activities within the pipeline network.

This thesis has contributed to knowledge about TPI, especially the identification of the key influencing factors. The understanding of these factors could therefore be adopted as the fundamental criteria for assessing and selecting a suitable protection strategy. This shows that the prevention of TPI can only be accomplished through a combined approach of professional adherence and modification of existing pipeline designs, standard, attention to the realities of the identified and significant factors in this thesis; and awareness of an organisation's multiple roles within the pipeline industry and the community where pipelines mostly traverse.

12.2 Summary

This chapter has shown that all the thesis objectives set out in Chapter 1 were met by the research undertaken. Recommendations were then made showing that there is a clear need for the implementation of the conclusion of this thesis, which might enable the pipeline industry to enhance the decision-making process.

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APPENDIX I: OUTPUT OF ANALYSES FROM SPSS

Factor Analysis

```
DATASET ACTIVATE DataSet1. DATASET CLOSE DataSet10. FACTOR
/VARIABLES PcEl PcBW PcLt EXHD ADHI LEI GEM HDI GDP GDI HPI   /MISSING
PAIRWISE   /ANALYSIS PcEl PcBW PcLt EXHD ADHI LEI GEM HDI GDP GDI HPI
/PRINT INITIAL CORRELATION KMO EXTRACTION ROTATION   /FORMAT SORT
BLANK(.3)   /PLOT EIGEN   /CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC   /CRITERIA ITERATE(25) DELTA(0)   /ROTATION OBLIMIN
/METHOD=CORRELATION.
```

Notes

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	N of Rows in Working Data	151
Missing Value Handling	Definition of Missing	MISSING=EXCLUDE: User-defined missing values are treated as missing.
	Cases Used	PAIRWISE: Correlation coefficients for each pair of variables are based on all the cases with valid data for that pair. The factor analysis is based on these correlations.

```
FACTOR
  /VARIABLES PcEl PcBW PcLt EXHD ADHI LEI GEM HDI GDP GDI HPI
  /MISSING PAIRWISE
  /ANALYSIS PcEl PcBW PcLt EXHD ADHI LEI GEM HDI GDP GDI HPI
  /PRINT INITIAL CORRELATION KMO EXTRACTION ROTATION
  /FORMAT SORT BLANK(.3)
  /PLOT EIGEN
  /CRITERIA MINEIGEN(1) ITERATE(25)
  /EXTRACTION PC
  /CRITERIA ITERATE(25) DELTA(0)
  /ROTATION OBLIMIN
  /METHOD=CORRELATION.
```

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	Elapsed Time	0:00:00.328

Notes

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	N of Rows in Working Data	151
Missing Value Handling	Definition of Missing	MISSING=EXCLUDE: User-defined missing values are treated as missing.
	Cases Used	PAIRWISE: Correlation coefficients for each pair of variables are based on all the cases with valid data for that pair. The factor analysis is based on these correlations.

```
FACTOR
  /VARIABLES PcEl PcBW PcLt EXHD ADHI LEI GEM HDI GDP GDI HPI
  /MISSING PAIRWISE
  /ANALYSIS PcEl PcBW PcLt EXHD ADHI LEI GEM HDI GDP GDI HPI
  /PRINT INITIAL CORRELATION KMO EXTRACTION ROTATION
  /FORMAT SORT BLANK(.3)
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  /EXTRACTION PC
  /CRITERIA ITERATE(25) DELTA(0)
  /ROTATION OBLIMIN
  /METHOD=CORRELATION.
```

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	Maximum Memory Required	16004 (15.629K) bytes

```
[DataSet1] H:\Project SPSS Analysis\GLM\FactorAnalysis.sav
```

Correlation Matrix

		PcEl	PcBW	PcLt	EXHD	ADHI	LEI	GEM
Correlation	PcEl	1.000	-.802	.058	-.401	.197	-.192	-.335

PcBW	-.802	1.000	-.305	.647	-.348	.330	.434
PcLt	.058	-.305	1.000	-.433	.127	-.116	-.099
EXHD	-.401	.647	-.433	1.000	-.792	.799	.690
ADHI	.197	-.348	.127	-.792	1.000	-.981	-.866
LEI	-.192	.330	-.116	.799	-.981	1.000	.849
GEM	-.335	.434	-.099	.690	-.866	.849	1.000
HDI	-.178	.336	-.161	.777	-.967	.978	.847
GDP	.070	-.203	.054	-.657	.895	-.901	-.774
GDI	-.268	.411	-.199	.827	-.967	.976	.923
HPI	.213	-.329	.058	-.745	.919	-.920	-.799

Correlation Matrix

		HDI	GDP	GDI	HPI
Correlation	PcEl	-.178	.070	-.268	.213
	PcBW	.336	-.203	.411	-.329
	PcLt	-.161	.054	-.199	.058
	EXHD	.777	-.657	.827	-.745
	ADHI	-.967	.895	-.967	.919
	LEI	.978	-.901	.976	-.920
	GEM	.847	-.774	.923	-.799
	HDI	1.000	-.942	.952	-.884
	GDP	-.942	1.000	-.851	.851
	GDI	.952	-.851	1.000	-.898
	HPI	-.884	.851	-.898	1.000

KMO and Bartlett's Test

	Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	.770
Bartlett's Test of Sphericity	Approx. Chi-Square	3193.377
	df	55
	Sig.	.000

Communalities

	Initial	Extraction
PcEl	1.000	.928
PcBW	1.000	.922
PcLt	1.000	.971
EXHD	1.000	.883
ADHI	1.000	.971
LEI	1.000	.977
GEM	1.000	.829
HDI	1.000	.965
GDP	1.000	.888
GDI	1.000	.969
HPI	1.000	.883

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings	
	Total	% of Variance	Cumulative %	Total	% of Variance
1	7.390	67.184	67.184	7.390	67.184
2	1.772	16.107	83.291	1.772	16.107
3	1.024	9.311	92.602	1.024	9.311
4	.257	2.340	94.942		
5	.180	1.640	96.581		
6	.156	1.422	98.003		
7	.113	1.026	99.029		
8	.072	.650	99.679		
9	.023	.213	99.892		
10	.010	.094	99.986		
11	.002	.014	100.000		

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Extraction Sums of Squared Loadings	Rotation Sums of Squared Loadings[a]
	Cumulative %	Total
1	67.184	7.263
2	83.291	2.708
3	92.602	1.613

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Component Matrix[a]

	Component		
	1	2	3
GDI	.982		
LEI	.972		
ADHI	-.972		
HDI	.966		
HPI	-.922		
GEM	.901		

GDP	-.888	.313	
EXHD	.868		
PcBW	.494	.816	
PcEl	-.333	-.801	-.419
PcLt		-.403	.875

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Pattern Matrix[a]

	Component		
	1	2	3
LEI	.998		
ADHI	-.990		
HDI	.989		
GDP	-.985		
GDI	.952		
HPI	-.947		
GEM	.858		
EXHD	.662		-.354
PcEl		-.997	
PcBW		.881	
PcLt			1.000

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 4 iterations.

Structure Matrix

	Component		
	1	2	3
LEI	.988		
ADHI	-.985		

HDI	.981		
GDI	.981	.352	
HPI	-.937		
GDP	-.926		
GEM	.895	.407	
EXHD	.811	.552	-.540
PcEl		-.951	
PcBW	.367	.941	-.379
PcLt			.983

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Component Correlation Matrix

Component	1	2	3
1	1.000	.294	-.187
2	.294	1.000	-.220
3	-.187	-.220	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Poisson Generalized Linear Models

```
* Generalized Linear Models. GENLIN Freq BY PDia PiSt Geol
(ORDER=ASCENDING) WITH PcBW PcLt HDI EXHD OilF PiLe RvLe RdLe PopD Age
wb esd mvc tsg mbw cgl glf blf     sbl mfc   /MODEL PDia PiSt PcBW
PcLt HDI EXHD OilF PiLe RvLe RdLe PopD Age wb esd mvc tsg mbw cgl glf
blf sbl mfc INTERCEPT=YES  DISTRIBUTION=NEGBIN(1) LINK=LOG   /CRITERIA
METHOD=FISHER(1) SCALE=1 COVB=MODEL MAXITERATIONS=200 MAXSTEPHALVING=5
PCONVERGE=1E-006(ABSOLUTE) SINGULAR=1E-012 ANALYS    ISTYPE=3(WALD)
CILEVEL=95 CITYPE=WALD LIKELIHOOD=FULL   /MISSING CLASSMISSING=INCLUDE
/PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION
(EXPONENTIATED).
```

Notes

	Output Created	29-Jan-2010 19:08:47
	Comments	

Input	Data	H:\Project SPSS Analysis\Logistic Regression\Poission regression-FINAL.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	151
Missing Value Handling	Definition of Missing	User-defined missing values for factor, subject and within-subject variables are treated as valid data. User-defined missing values for any other variables in the model are treated as missing.
	Cases Used	Statistics are based on cases with valid data for all variables in the model.
	Weight Handling	not applicable

Syntax

```
GENLIN Freq BY PDia PiSt Geol
(ORDER=ASCENDING) WITH PcBW PcLt
HDI EXHD OilF PiLe RvLe RdLe PopD Age
wb esd mvc tsg mbw cgl glf blf sbl mfc
  /MODEL PDia PiSt PcBW PcLt HDI EXHD
OilF PiLe RvLe RdLe PopD Age wb esd mvc
tsg mbw cgl glf blf sbl mfc INTERCEPT=YES
 DISTRIBUTION=NEGBIN(1) LINK=LOG
  /CRITERIA METHOD=FISHER(1)
SCALE=1 COVB=MODEL
MAXITERATIONS=200
MAXSTEPHALVING=5 PCONVERGE=1E-
006(ABSOLUTE) SINGULAR=1E-012
ANALYSISTYPE=3(WALD) CILEVEL=95
CITYPE=WALD LIKELIHOOD=FULL
  /MISSING CLASSMISSING=INCLUDE
  /PRINT CPS DESCRIPTIVES MODELINFO
FIT SUMMARY SOLUTION
(EXPONENTIATED).
```

	Elapsed Time	0:00:00.156

```
[DataSet1] H:\Project SPSS Analysis\Logistic Regression\Poission
regression-FINAL.sav
```

Warnings

The maximum number of step-halvings was reached but the log-likelihood value cannot be further improved. Output for the last iteration is displayed.

The GENLIN procedure continues despite the above warning(s). Subsequent results shown are based on the last iteration. Validity of the model fit is uncertain.

Model Information

Dependent Variable	Freq
Probability Distribution	Negative binomial (1)
Link Function	Log

Case Processing Summary

	N	Percent
Included	151	100.0%
Excluded	0	.0%
Total	151	100.0%

Categorical Variable Information

			N	Percent
Factor	PDia	Pipelines less than 8 Inchs	93	61.6%
		9 to 15 Inchs Pipelines	27	17.9%
		Pipelines greater than 16 Inches	31	20.5%
		Total	151	100.0%
	PiSt	Buried Pipeline	18	11.9%
		aboveground pipeline	54	35.8%
		No pipeline	79	52.3%
		Total	151	100.0%
	Geol	Abandoned Beach Ridges	14	9.3%

	Alluvium	5	3.3%
	Coastal Plains Sands	7	4.6%
	Mangrove Swamps	29	19.2%
	Meander Belt,Back Swamps Fresh Water Swamps	24	15.9%
	Sombreiro Deltaic Plain	72	47.7%
	Total	151	100.0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Freq	151	0	64	1.72	5.825
Covariate	PcBW	151	5	68	37.97	21.913
	PcLt	151	44	89	74.49	15.715
	HDI	151	.54645	6.90776	3.6217874	1.10345984
	EXHD	151	-2.46326	6.90776	3.2343395	2.09739794
	OilF	151	.000	8.919	1.97171	1.701956
	PiLe	151	.00	63.98	5.0869	8.07816
	RvLe	151	.001	208.500	22.24364	29.658104
	RdLe	151	.000	11.613	3.88047	2.753099
	PopD	151	45.62	523.48	248.7007	139.77047
	Age	151	.00	16.00	3.6887	5.35934
	wb	151	.001	4.784	.32717	.701594
	esd	151	.320	76.800	18.27378	13.532754
	mvc	151	.001	33.920	1.75629	4.468995
	tsg	151	.001	59.360	11.01145	10.848711
	mbw	151	.001	70.400	3.87230	10.147017
	cgl	151	.001	56.000	3.66422	6.017229
	glf	151	.001	52.320	8.57538	8.815815
	blf	151	.001	35.360	3.99807	6.160491
	sbl	151	.001	67.200	3.85213	9.466219
	mfc	151	.001	1.120	.02850	.147347

Goodness of Fit[b]

	Value	df	Value/df
Deviance	81.636	126	.648
Scaled Deviance	81.636	126	
Pearson Chi-Square	105.623	126	.838
Scaled Pearson Chi-Square	105.623	126	
Log Likelihood[a]	-156.766		
Akaike's Information Criterion (AIC)	363.532		
Finite Sample Corrected AIC (AICC)	373.932		
Bayesian Information Criterion (BIC)	438.964		
Consistent AIC (CAIC)	463.964		

Dependent Variable: Numbers of Pipeline Third-party Interference
Model: (Intercept), PDia, PiSt, PcBW, PcLt, HDI, EXHD, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl, mfc

a. The full log likelihood function is displayed and used in computing information criteria.

b. Information criteria are in small-is-better form.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
226.061	24	.000

Dependent Variable: Numbers of Pipeline Third-party Interference
Model: (Intercept), PDia, PiSt, PcBW, PcLt, HDI, EXHD, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl, mfc

a. Compares the fitted model against the intercept-only model.

Tests of Model Effects

	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	.262	1	.609
PDia	3.916	2	.141
PiSt	6.888	2	.032
PcBW	1.633	1	.201
PcLt	1.347	1	.246
HDI	.278	1	.598
EXHD	.002	1	.964
OilF	6.647	1	.010
PiLe	3.395	1	.065
RvLe	.019	1	.889
RdLe	4.021	1	.045
PopD	.358	1	.549
Age	1.020	1	.312
wb	4.584	1	.032
esd	2.419	1	.120
mvc	6.581	1	.010
tsg	2.327	1	.127
mbw	.759	1	.384
cgl	.219	1	.639
glf	2.674	1	.102
blf	2.554	1	.110
sbl	4.112	1	.043
mfc	3.172	1	.075

Dependent Variable: Numbers of Pipeline Third-party Interference

Model: (Intercept), PDia, PiSt, PcBW, PcLt, HDI, EXHD, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl, mfc

Parameter Estimates

Parameter	95% Wald Confidence Interval

	B	Std. Error	Lower	Upper
(Intercept)	-.434	2.3668	-5.073	4.205
[PDia=1]	.036	.6573	-1.252	1.325
[PDia=2]	1.014	.6570	-.274	2.301
[PDia=3]	0[a]	.	.	.
[PiSt=1]	1.842	.7795	.314	3.370
[PiSt=2]	1.743	.6881	.395	3.092
[PiSt=3]	0[a]	.	.	.
PcBW	-.020	.0160	-.052	.011
PcLt	-.018	.0152	-.047	.012
HDI	-.236	.4472	-1.112	.641
EXHD	-.012	.2679	-.537	.513
OilF	.386	.1496	.092	.679
PiLe	.062	.0334	-.004	.127
RvLe	.003	.0196	-.036	.041
RdLe	.256	.1275	.006	.506
PopD	-.002	.0025	-.006	.003
Age	.050	.0499	-.047	.148
wb	.889	.4154	.075	1.703
esd	.042	.0273	-.011	.096
mvc	-.119	.0464	-.210	-.028
tsg	-.038	.0249	-.087	.011
mbw	-.032	.0372	-.105	.040
cgl	-.027	.0580	-.141	.087
glf	-.048	.0290	-.104	.009
blf	-.063	.0393	-.140	.014
sbl	-.108	.0533	-.213	-.004
mfc	-2.329	1.3075	-4.891	.234
(Scale)	1[b]			
(Negative binomial)	1			

Dependent Variable: Numbers of Pipeline Third-party Interference
Model: (Intercept), PDia, PiSt, PcBW, PcLt, HDI, EXHD, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl, mfc

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Parameter Estimates

	Hypothesis Test				95% Wald Confidence Interval for Exp(B)	
Parameter	Wald Chi-Square	df	Sig.	Exp(B)	Lower	Upper
(Intercept)	.034	1	.855	.648	.006	67.012
[PDia=1]	.003	1	.956	1.037	.286	3.761
[PDia=2]	2.381	1	.123	2.756	.760	9.988
[PDia=3]	.	.	.	1	.	.
[PiSt=1]	5.584	1	.018	6.309	1.369	29.075
[PiSt=2]	6.419	1	.011	5.716	1.484	22.018
[PiSt=3]	.	.	.	1	.	.
PcBW	1.633	1	.201	.980	.949	1.011
PcLt	1.347	1	.246	.983	.954	1.012
HDI	.278	1	.598	.790	.329	1.898
EXHD	.002	1	.964	.988	.584	1.670
OilF	6.647	1	.010	1.471	1.097	1.972
PiLe	3.395	1	.065	1.063	.996	1.135
RvLe	.019	1	.889	1.003	.965	1.042
RdLe	4.021	1	.045	1.291	1.006	1.658
PopD	.358	1	.549	.998	.994	1.003
Age	1.020	1	.312	1.052	.954	1.160
wb	4.584	1	.032	2.433	1.078	5.493
esd	2.419	1	.120	1.043	.989	1.101
mvc	6.581	1	.010	.888	.811	.972
tsg	2.327	1	.127	.963	.917	1.011
mbw	.759	1	.384	.968	.900	1.041
cgl	.219	1	.639	.973	.869	1.090
glf	2.674	1	.102	.954	.901	1.009
blf	2.554	1	.110	.939	.870	1.014
sbl	4.112	1	.043	.898	.808	.996
mfc	3.172	1	.075	.097	.008	1.264

Dependent Variable: Numbers of Pipeline Third-party Interference

Model: (Intercept), PDia, PiSt, PcBW, PcLt, HDI, EXHD, OilF, PiLe, RvLe, RdLe, PopD, Age, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl, mfc

```
LOGISTIC REGRESSION VARIABLES TPI   /METHOD=ENTER PcBW PcLt HDI EXHD
OilF PiLe RvLe RdLe PopD Age PDia PiSt wb esd mvc tsg mbw cgl glf blf
sbl   /CONTRAST (PDia)=Indicator(1)   /CONTRAST (PiSt)=Indicator
/CLASSPLOT   /CASEWISE OUTLIER(2)   /PRINT=GOODFIT CORR ITER(1) CI(95)
/CRITERIA=PIN(0.05) POUT(0.10) ITERATE(100) CUT(0.5).
```

Notes

	Output Created	29-Jan-2010 16:11:22
	Comments	
Input	Data	H:\Project SPSS Analysis\Logistic Regression\logistic regression-FINAL.sav
	Active Dataset	DataSet11
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	151
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing
	Syntax	LOGISTIC REGRESSION VARIABLES TPI /METHOD=ENTER PcBW PcLt HDI EXHD OilF PiLe RvLe RdLe PopD Age PDia PiSt wb esd mvc tsg mbw cgl glf blf sbl /CONTRAST (PDia)=Indicator(1) /CONTRAST (PiSt)=Indicator /CLASSPLOT /CASEWISE OUTLIER(2) /PRINT=GOODFIT CORR ITER(1) CI(95) /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(100) CUT(0.5).
Resources	Processor Time	0:00:00.047
	Elapsed Time	0:00:00.046

```
[DataSet11] H:\Project SPSS Analysis\Logistic Regression\logistic
regression-FINAL.sav
```

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	151	100.0
	Missing Cases	0	.0
	Total	151	100.0
	Unselected Cases	0	.0
	Total	151	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
No Thirdparty Interference	0
Thirdparty Interference	1

Categorical Variables Codings

			Parameter coding	
		Frequency	(1)	(2)
PiSt	Buried Pipeline	18	1.000	.000
	aboveground pipeline	54	.000	1.000
	No pipeline	79	.000	.000
PDia	Pipelines less than 8 Inchs	93	.000	.000
	9 to 15 Inchs Pipelines	27	1.000	.000
	Pipelines greater than 16 Inches	31	.000	1.000

Block 0: Beginning Block

Iteration History[a,b,c]

Iteration		-2 Log likelihood	Coefficients
			Constant
Step 0	1	193.158	-.649
	2	193.138	-.673
	3	193.138	-.673

a. Constant is included in the model.

b. Initial -2 Log Likelihood: 193.138

c. Estimation terminated at iteration number 3 because parameter estimates changed by less than .001.

Classification Table[a,b]

Observed			Predicted: Occurrence of Pipeline Third-party Interference: No Thirdparty Interference	Predicted: Occurrence of Pipeline Third-party Interference: Thirdparty Interference
Step 0	Occurrence of Pipeline Third-party Interference	No Thirdparty Interference	100	0
		Thirdparty Interference	51	0

a. Constant is included in the model.

b. The cut value is .500

Classification Table[a,b]

Observed			Predicted: Percentage Correct
Step 0	Occurrence of Pipeline Third-party Interference	No Thirdparty Interference	100.0
		Thirdparty Interference	.0
		Overall Percentage	66.2

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.673	.172	15.313	1	.000	.510

Variables not in the Equation

	Score	df	Sig.

Step 0	Variables	PcBW	4.239	1	.040
		PcLt	.753	1	.385
		HDI	.147	1	.702
		EXHD	3.497	1	.061
		OilF	15.859	1	.000
		PiLe	51.819	1	.000
		RvLe	1.214	1	.271
		RdLe	10.304	1	.001
		PopD	.975	1	.323
		Age	31.734	1	.000
		PDia	58.508	2	.000
		PDia(1)	28.462	1	.000
		PDia(2)	16.481	1	.000
		PiSt	67.889	2	.000
		PiSt(1)	17.691	1	.000
		PiSt(2)	32.018	1	.000
		wb	.005	1	.943
		esd	.069	1	.794
		mvc	2.375	1	.123
		tsg	3.427	1	.064
		mbw	.019	1	.891
		cgl	.330	1	.566
		glf	.053	1	.818
		blf	.425	1	.515
		sbl	1.041	1	.308
		Overall Statistics	89.325	23	.000

Block 1: Method = Enter

Iteration History[a,b,c,d]

Iteration	Coefficients

		-2 Log likelihood	Constant	PcBW	PcLt	HDI	EXHD	OilF
Step 1	1	100.228	-1.225	-.009	.001	-.025	-.014	.167
	2	81.009	-1.503	-.024	-.003	.047	-.081	.341
	3	73.191	-1.772	-.047	-.013	.331	-.237	.455
	4	70.324	-1.552	-.077	-.021	.594	-.387	.521
	5	69.726	-1.032	-.098	-.024	.696	-.474	.566
	6	69.703	-.909	-.102	-.025	.717	-.499	.581
	7	69.703	-.903	-.103	-.025	.718	-.500	.582
	8	69.703	-.903	-.103	-.025	.718	-.500	.582

a. Method: Enter

b. Constant is included in the model.

c. Initial -2 Log Likelihood: 193.138

d. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Iteration History[a,b,c,d]

		Coefficients						
Iteration		PiLe	RvLe	RdLe	PopD	Age	PDia(1)	PDia(2)
Step 1	1	.090	-.002	.073	-.001	-.029	.998	1.019
	2	.157	.007	.142	-.002	-.037	1.397	1.333
	3	.235	.023	.194	-.001	-.015	1.778	1.290
	4	.312	.034	.191	-.001	.023	2.244	.985
	5	.361	.038	.165	-.002	.050	2.620	.719
	6	.373	.039	.161	-.002	.055	2.717	.678
	7	.373	.039	.160	-.002	.055	2.721	.676
	8	.373	.039	.160	-.002	.055	2.721	.676

a. Method: Enter

b. Constant is included in the model.

c. Initial -2 Log Likelihood: 193.138

d. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Iteration History[a,b,c,d]

		Coefficients						
Iteration		PiSt(1)	PiSt(2)	wb	esd	mvc	tsg	mbw
Step 1	1	1.018	.841	.050	.010	.017	-.011	-.018

	2	1.102	1.210	.259	.024	.013	-.026	-.035
	3	.724	1.388	.755	.047	-.003	-.035	-.053
	4	.220	1.473	1.355	.066	-.019	-.043	-.060
	5	-.155	1.526	1.747	.075	-.029	-.051	-.059
	6	-.237	1.548	1.831	.077	-.031	-.053	-.059
	7	-.240	1.549	1.834	.077	-.031	-.053	-.059
	8	-.240	1.549	1.834	.077	-.031	-.053	-.059

a. Method: Enter

b. Constant is included in the model.

c. Initial -2 Log Likelihood: 193.138

d. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Iteration History[a,b,c,d]

		Coefficients			
Iteration		cgl	glf	blf	sbl
Step 1	1	-.063	-.024	-.014	-.006
	2	-.120	-.052	-.046	-.041
	3	-.135	-.089	-.092	-.097
	4	-.148	-.114	-.127	-.176
	5	-.157	-.124	-.144	-.239
	6	-.160	-.126	-.147	-.253
	7	-.160	-.126	-.147	-.253
	8	-.160	-.126	-.147	-.253

a. Method: Enter

b. Constant is included in the model.

c. Initial -2 Log Likelihood: 193.138

d. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	123.435	23	.000
	Block	123.435	23	.000
	Model	123.435	23	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	69.703[a]	.558	.774

a. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	5.079	8	.749

Contingency Table for Hosmer and Lemeshow Test

		TPI = No Thirdparty Interference		TPI = Thirdparty Interference		
		Observed	Expected	Observed	Expected	Total
Step 1	1	15	15.000	0	.000	15
	2	15	14.989	0	.011	15
	3	15	14.939	0	.061	15
	4	14	14.815	1	.185	15
	5	15	14.376	0	.624	15
	6	13	12.361	2	2.639	15
	7	7	7.686	8	7.314	15
	8	5	4.321	10	10.679	15
	9	1	1.352	14	13.648	15
	10	0	.163	16	15.837	16

Classification Table[a]

	Predicted	
	Occurrence of Pipeline Third-party Interference	
Observed	No Thirdparty Interference	Thirdparty Interference

Step 1	Occurrence of Pipeline Third-party Interference	No Thirdparty Interference	90	10
		Thirdparty Interference	9	42

a. The cut value is .500

Classification Table[a]

Observed			Predicted Percentage Correct
Step 1	Occurrence of Pipeline Third-party Interference	No Thirdparty Interference	90.0
		Thirdparty Interference	82.4
		Overall Percentage	87.4

a. The cut value is .500

Variables	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
PcBW	-0.11	0.043	6.503	1	0.011	0.896	0.823	0.975
PcLt	-0.011	0.033	0.105	1	0.745	0.989	0.927	1.055
HDI	0.014	0.492	0.001	1	0.977	1.014	0.387	2.658
OilF	0.556	0.282	3.891	1	0.049	1.744	1.004	3.029
PiLe	0.378	0.113	11.127	1	0.001	1.459	1.168	1.821
RvLe	0.04	0.041	0.966	1	0.326	1.041	0.961	1.128
RdLe	0.169	0.271	0.389	1	0.533	1.184	0.696	2.014
PopD	-0.003	0.005	0.463	1	0.496	0.997	0.987	1.006
Age	0.034	0.116	0.087	1	0.768	1.035	0.825	1.298
PDia			4.221	2	0.121			
PDia(1)	2.417	1.196	4.082	1	0.043	11.211	1.075	116.931
PDia(2)	0.885	1.409	0.394	1	0.53	2.423	0.153	38.366
PiSt			2.192	2	0.334			
PiSt(1)	1.537	1.272	1.461	1	0.227	4.65	0.385	56.208
PiSt(2)	-0.136	1.815	0.006	1	0.94	0.873	0.025	30.614
wb	1.455	1.015	2.054	1	0.152	4.283	0.586	31.305
esd	0.061	0.047	1.717	1	0.19	1.063	0.97	1.165
mvc	-0.025	0.097	0.069	1	0.793	0.975	0.807	1.178
tsg	-0.046	0.055	0.697	1	0.404	0.955	0.858	1.063
mbw	-0.074	0.068	1.195	1	0.274	0.929	0.813	1.06
cgl	-0.159	0.145	1.198	1	0.274	0.853	0.642	1.134
glf	-0.132	0.061	4.646	1	0.031	0.876	0.777	0.988
blf	-0.171	0.083	4.276	1	0.039	0.842	0.716	0.991
sbl	-0.247	0.122	4.129	1	0.042	0.781	0.615	0.991
Constant	0.262	4.07	0.004	1	0.949	1.3		

a. Variable(s) entered on step 1: PcBW, PcLt, HDI, OilF, PiLe, RvLe, RdLe, PopD, Age, PDia, PiSt, wb, esd, mvc, tsg, mbw, cgl, glf, blf, sbl.

Correlation Matrix

		Constant	PcBW	PcLt	HDI	EXHD	OilF	PiLe
Step 1	Constant	1.000	-.474	-.146	-.548	.313	-.050	.245
	PcBW	-.474	1.000	.028	.141	-.149	-.213	-.682
	PcLt	-.146	.028	1.000	-.509	.493	.084	-.039
	HDI	-.548	.141	-.509	1.000	-.881	.109	.006
	EXHD	.313	-.149	.493	-.881	1.000	-.155	-.016
	OilF	-.050	-.213	.084	.109	-.155	1.000	.175
	PiLe	.245	-.682	-.039	.006	-.016	.175	1.000
	RvLe	-.064	-.258	-.148	.041	.021	.055	.243
	RdLe	-.200	.150	-.108	.017	.019	-.042	-.074
	PopD	-.572	.237	-.459	.542	-.339	-.058	-.146
	Age	-.122	-.137	-.074	.211	-.240	.038	.166
	PDia(1)	.136	-.206	-.282	.177	-.339	.119	.329
	PDia(2)	.080	.202	-.079	-.154	.177	-.086	-.077
	PiSt(1)	-.097	.226	.144	-.164	.262	-.125	-.448
	PiSt(2)	-.078	-.096	.049	-.066	.087	.083	-.209
	wb	-.056	-.421	-.288	.390	-.456	.014	.397
	esd	-.394	.020	-.334	.457	-.418	.018	.121
	mvc	.073	.156	-.176	-.066	.093	-.261	-.067
	tsg	-.126	.226	.104	-.060	.190	-.328	-.109
	mbw	-.028	.120	.085	.151	-.256	-.143	-.136
	cgl	-.058	.027	-.287	.168	-.002	-.127	-.233
	glf	.076	.284	.072	-.096	-.059	-.241	-.340
	blf	-.265	.483	-.070	.302	-.322	-.018	-.465
	sbl	-.411	.727	.173	.022	.105	-.209	-.571

Correlation Matrix

		RvLe	RdLe	PopD	Age	PDia(1)	PDia(2)	PiSt(1)
Step 1	Constant	-.064	-.200	-.572	-.122	.136	.080	-.097
	PcBW	-.258	.150	.237	-.137	-.206	.202	.226
	PcLt	-.148	-.108	-.459	-.074	-.282	-.079	.144
	HDI	.041	.017	.542	.211	.177	-.154	-.164
	EXHD	.021	.019	-.339	-.240	-.339	.177	.262

	OilF	.055	-.042	-.058	.038	.119	-.086	-.125
	PiLe	.243	-.074	-.146	.166	.329	-.077	-.448
	RvLe	1.000	.410	.187	.214	.054	-.282	-.088
	RdLe	.410	1.000	-.064	.080	.123	.029	-.105
	PopD	.187	-.064	1.000	.173	.018	-.063	-.132
	Age	.214	.080	.173	1.000	.465	-.646	-.586
	PDia(1)	.054	.123	.018	.465	1.000	.052	-.653
	PDia(2)	-.282	.029	-.063	-.646	.052	1.000	.217
	PiSt(1)	-.088	-.105	-.132	-.586	-.653	.217	1.000
	PiSt(2)	.198	-.082	-.016	-.346	-.513	-.200	.694
	wb	.471	.171	.203	.371	.350	-.379	-.312
	esd	-.074	.093	.367	.216	.251	-.005	-.161
	mvc	-.124	-.302	.229	-.229	-.040	.284	.098
	tsg	-.377	-.335	.116	-.056	-.150	.154	.068
	mbw	-.587	-.092	-.143	.106	.158	.000	-.131
	cgl	-.386	-.171	.303	-.056	-.083	.097	.047
	glf	-.246	-.350	-.014	-.327	-.199	.140	.276
	blf	-.500	-.122	.141	-.207	-.171	.097	.230
	sbl	-.337	.154	.144	-.422	-.443	.411	.363

Correlation Matrix

		PiSt(2)	wb	esd	mvc	tsg	mbw	cgl
Step 1	Constant	-.078	-.056	-.394	.073	-.126	-.028	-.058
	PcBW	-.096	-.421	.020	.156	.226	.120	.027
	PcLt	.049	-.288	-.334	-.176	.104	.085	-.287
	HDI	-.066	.390	.457	-.066	-.060	.151	.168
	EXHD	.087	-.456	-.418	.093	.190	-.256	-.002
	OilF	.083	.014	.018	-.261	-.328	-.143	-.127
	PiLe	-.209	.397	.121	-.067	-.109	-.136	-.233
	RvLe	.198	.471	-.074	-.124	-.377	-.587	-.386
	RdLe	-.082	.171	.093	-.302	-.335	-.092	-.171
	PopD	-.016	.203	.367	.229	.116	-.143	.303
	Age	-.346	.371	.216	-.229	-.056	.106	-.056

	PDia(1)	-.513	.350	.251	-.040	-.150	.158	-.083
	PDia(2)	-.200	-.379	-.005	.284	.154	.000	.097
	PiSt(1)	.694	-.312	-.161	.098	.068	-.131	.047
	PiSt(2)	1.000	.046	.020	.009	-.242	-.269	-.119
	wb	.046	1.000	.229	-.227	-.313	-.154	-.261
	esd	.020	.229	1.000	-.227	-.122	.079	.043
	mvc	.009	-.227	-.227	1.000	.273	-.114	.137
	tsg	-.242	-.313	-.122	.273	1.000	.144	.452
	mbw	-.269	-.154	.079	-.114	.144	1.000	.086
	cgl	-.119	-.261	.043	.137	.452	.086	1.000
	glf	.225	-.131	-.034	.243	-.239	.186	-.229
	blf	.040	-.209	-.095	.192	.026	.412	.275
	sbl	-.070	-.535	-.166	.224	.354	.101	.167

Correlation Matrix

		glf	blf	sbl
Step 1	Constant	.076	-.265	-.411
	PcBW	.284	.483	.727
	PcLt	.072	-.070	.173
	HDI	-.096	.302	.022
	EXHD	-.059	-.322	.105
	OilF	-.241	-.018	-.209
	PiLe	-.340	-.465	-.571
	RvLe	-.246	-.500	-.337
	RdLe	-.350	-.122	.154
	PopD	-.014	.141	.144
	Age	-.327	-.207	-.422
	PDia(1)	-.199	-.171	-.443
	PDia(2)	.140	.097	.411
	PiSt(1)	.276	.230	.363
	PiSt(2)	.225	.040	-.070
	wb	-.131	-.209	-.535
	esd	-.034	-.095	-.166

mvc	.243	.192	.224
tsg	-.239	.026	.354
mbw	.186	.412	.101
cgl	-.229	.275	.167
glf	1.000	.384	.131
blf	.384	1.000	.374
sbl	.131	.374	1.000

```
             Step number: 1

             Observed Groups and Predicted Probabilities

      80 +
+
         |
|
         |
|
F        |
|
R     60 +
+
E        |
|
Q        |N
|
U        |N
|
E     40 +N
+
N        |N
|
C        |N
|
Y        |N
|
      20 +N
+
         |N
|
         |NT
T|
         |NNNNN  T N
T   TT|
Predicted ---------+---------+---------+---------+---------+---------
+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6
.7        .8        .9        1
  Group:
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNTTTTTTTTTTTTTTTTTTTT
TTTTTTTTTTTTTTTTTTTTTTTTTTTTTT

          Predicted Probability is of Membership for Thirdparty
Interference
```

```
The Cut Value is .50
Symbols: N - No Thirdparty Interference
         T - Thirdparty Interference
Each Symbol Represents 5 Cases.
```

Casewise List[b]

	Observed				Temporary Variable	
Case	Selected Status[a]	TPI	Predicted	Predicted Group	Resid	ZResid
50	S	T**	.298	N	.702	1.535
63	S	T**	.072	N	.928	3.594
73	S	T**	.020	N	.980	7.086
82	S	N**	.833	T	-.833	-2.230
109	S	N**	.815	T	-.815	-2.097

a. S = Selected, U = Unselected cases, and ** = Misclassified cases.

b. Cases with studentized residuals greater than 2.000 are listed.

APPENDIX II: EXTRACTS OF CORRESPONDENCES

Dear <<<<<<>>>>>

Apologies for the cross posting. I got your email address from the <<<<< ...>>>>>. I am a PhD student in Engineering Science in Marine Environment in the faculty of Science and Engineering at Newcastle University, UK under the supervision of Professor Richard Birmingham and Dr. Julia Race. I am writing to solicit for your participation in my research, sponsored by the Petroleum Technology Development Fund (PTDF), Nigeria in form of a questionnaire. The result of this research will help me to investigate the problem of Pipeline Third-Party Interference: to assess and develop a model to predict interferences using multivariate statistical analysis model. The University link below shows the questionnaire that asks a variety of questions, which should take you about 10 minutes to complete.

http://www.students.ncl.ac.uk/rowland.adewumi/

I guarantee that your responses will not be identified with you personally, and promise not to share any information about you with anyone outside my research group. If you have any questions or concerns about completing the questionnaire please do not hesitate to contact me, and if you are not in the best position to contribute to the questionnaire, please kindly forward it to someone you think will be able to help.
Thank you.

Adewumi Rowland (ADRO)
PhD Research Student
School of Marine Science and Technology
Newcastle University Newcastle upon Tyne
NE1 7RU
United Kingdom

APPENDIX III: QUESTIONNAIRE SURVEY

PhD Research Questionnaire on Pipeline Third-party Interference

In all reported pipeline failures worldwide, third-party activities have been recognised as the most dominant failure mechanism in the oil and gas industry, and with limited attention within the research literature. The aim of this research project therefore, is to determine and explore correlations and relationship between land use, population density, pipeline intrinsic properties (e.g. depth, thickness, and size), and environmental, socioeconomic and socio-political factors using hybrid multivariate statistical methods by designing a prediction model with Geographic Information System (GIS) to predict where third party interference will occur in a pipeline alignment. In addition, since September 2001, Al Qaeda's maritime threat has made pipelines naturally vulnerable because of their long distance network. Hence, your participation in this questionnaire will enable us to investigate the problem of Pipeline Third-Party damage. This research is sponsored by the Petroleum Technology Development Fund (PTDF) of Nigeria under the supervision of Professor Richard Birmingham and Dr. Julia Race.

Please complete the questionnaire by checking where appropriate and providing explanation where necessary. Please, If you have any questions about this questionnaire kindly contact Adewumi Rowland, at +44(191) 222-5533, or by email

This survey will not take more than ten minutes to complete. We guarantee that your responses will not be identified with you personally, and not to share any information about you with anyone outside the research group. **Your email address is required in order to send you results of the survey** and to confirm receipt of entry.

Section I: General Information

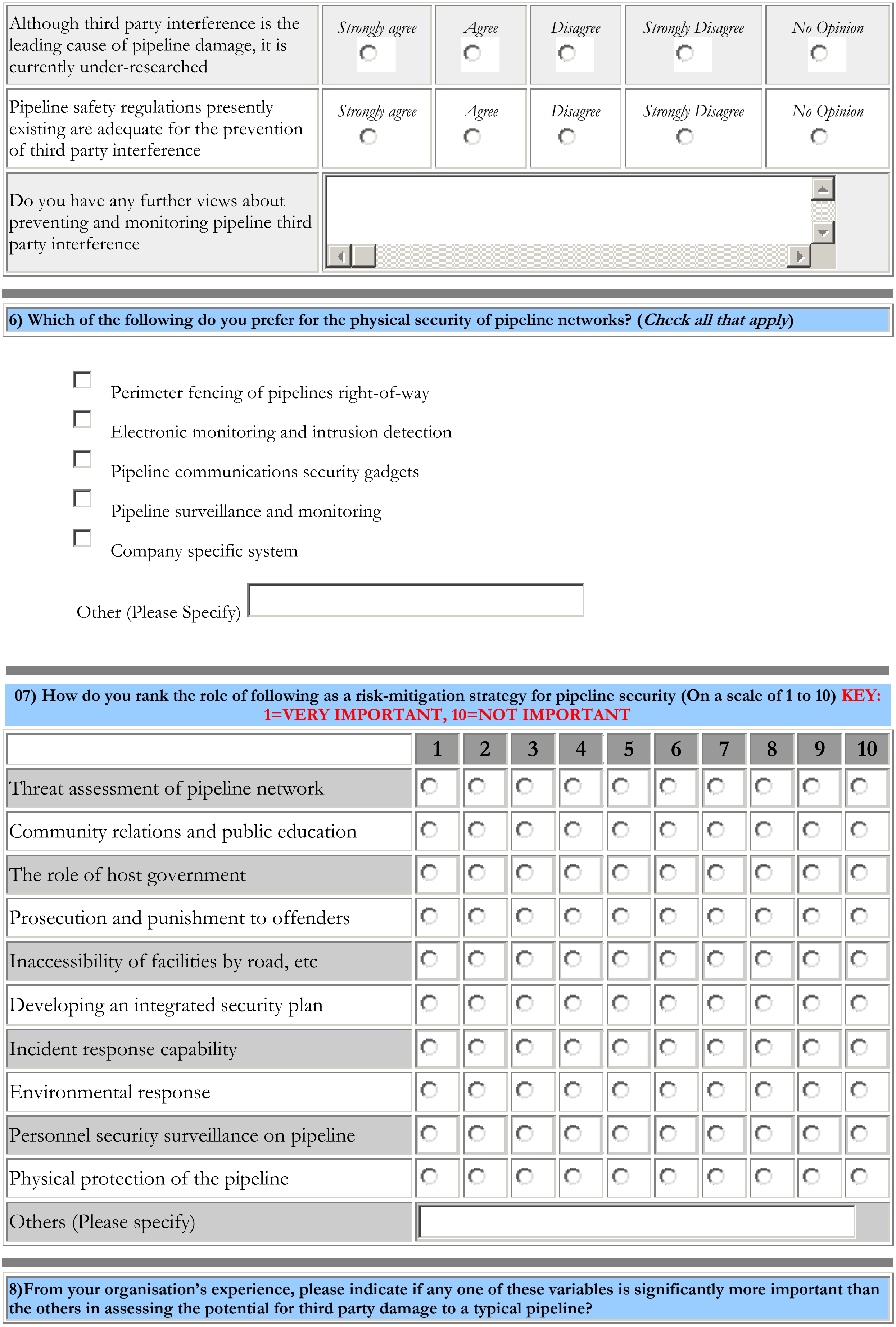
Name*			
email*			
Address		**Country**	United Kingdom ▾
Organisation			

(a) Which of the following best describes your Organisation	**(b) Your Occupation**
○ Government Agency	○ Health and Safety Engineer
○ Academia	○ Piping Technician
○ Private Company	○ Pipeline Project Engineer
○ Professional Body	○ Pipeline Engineer
○ Service Provider	○ Oil and Gas Service Provider
○ Other	○ Pipeline Installer/Inspector

Section II: Unintentional Pipeline Damage

How do you agree with the following general statement about pipeline security?

Pipeline security is a worldwide problem that need a serious attention as any other sector of the economy	*Strongly agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
A pipeline surveillance technology should protect only vulnerable segments of a pipeline network	*Strongly agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○



Although third party interference is the leading cause of pipeline damage, it is currently under-researched	*Strongly agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
Pipeline safety regulations presently existing are adequate for the prevention of third party interference	*Strongly agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
Do you have any further views about preventing and monitoring pipeline third party interference					

6) Which of the following do you prefer for the physical security of pipeline networks? (*Check all that apply*)

☐ Perimeter fencing of pipelines right-of-way
☐ Electronic monitoring and intrusion detection
☐ Pipeline communications security gadgets
☐ Pipeline surveillance and monitoring
☐ Company specific system

Other (Please Specify)

07) How do you rank the role of following as a risk-mitigation strategy for pipeline security (On a scale of 1 to 10) KEY: 1=VERY IMPORTANT, 10=NOT IMPORTANT

	1	2	3	4	5	6	7	8	9	10
Threat assessment of pipeline network	○	○	○	○	○	○	○	○	○	○
Community relations and public education	○	○	○	○	○	○	○	○	○	○
The role of host government	○	○	○	○	○	○	○	○	○	○
Prosecution and punishment to offenders	○	○	○	○	○	○	○	○	○	○
Inaccessibility of facilities by road, etc	○	○	○	○	○	○	○	○	○	○
Developing an integrated security plan	○	○	○	○	○	○	○	○	○	○
Incident response capability	○	○	○	○	○	○	○	○	○	○
Environmental response	○	○	○	○	○	○	○	○	○	○
Personnel security surveillance on pipeline	○	○	○	○	○	○	○	○	○	○
Physical protection of the pipeline	○	○	○	○	○	○	○	○	○	○
Others (Please specify)										

8)From your organisation's experience, please indicate if any one of these variables is significantly more important than the others in assessing the potential for third party damage to a typical pipeline?

(a) Factor Importance for Weighing							*(b) Which is most Important?*
		Very Important	**Quite Important**	**Neither Important nor Unimportant**	**Not very Important**	**Not Important At All**	Please tick only in the column
a.	Minimum depth of Cover	○	○	○	○	○	○
b.	Activity level near the pipeline	○	○	○	○	○	○
c.	Susceptibility of land use activities	○	○	○	○	○	○
d.	Public education program	○	○	○	○	○	○
e.	Accurate line locating & marking	○	○	○	○	○	○

9. How would you describe the following in pipeline damage prevention measures *during* installation

a.	Sleeve as additional protective layer	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
b.	Slabs, Tiles and Plates over pipelines	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
c.	High Tensile Net buried with pipeline	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
d.	Increasing pipeline wall thickness	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
e.	Avoid Pre-identified Vulnerable zone	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
f.	Marker posts along pipeline length	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
g.	Marker Tape buried above pipeline	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
h.	Fibre optics installed at intervals	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
i.	Others (Please specify)					

10. How would you describe the following third-party damage prevention method *post* pipeline installation

a.	Aerial and Helicopter Surveillance	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
b.	Full walking patrol	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
c.	Remote Sensing Satellite Surveillance	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
d.	Global Positioning System (GPS/GIS)	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
e.	Direct Surveillance	○ Excellent	○ Good	○ Average	○ Fair	○ Poor

f.	Electromagnetic Detection/ Acoustic	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
g.	Identify and Monitoring 'Hot Spots'	○ Excellent	○ Good	○ Average	○ Fair	○ Poor
h.	Others (Please specify)					

11. Do you think the issue of third party interference has changed over the past 10 years as a problem?

☐ Problem has been reduced
☐ Problem has been eradicated
☐ Slightly increased as a problem
☐ Problem Increased immensely
☐ Problem has remained the same
☐ Problem still undergoing development
☐ Problem is paid less attention
☐ Technology can't control the problem

Section III: Intentional Pipeline Damage

1. Does your organisation's surveillance of pipeline monitor the following? (Please check all that apply)

a.	Pipeline Vandalism	☐
b.	Theft of product or facilities and criminal activities	☐
c.	Sabotage of any form to pipeline network	☐
d.	Guerrilla attacks	☐
e.	Likelihood of Terrorism against pipeline facilities	☐
f.	Intrusion to above ground facilities	☐
g.	Right-of-Way Encroachment	☐
h.	Cyber attack/potential hijack of network facilities	☐
i.	No opinion	☐

Question 2 to 6: General Information about Intentional Pipeline damage

2.	How would you rate your organisation's ability to identify pipeline terrorism, vandalism, theft, sabotage or criminal activities?	*Very Poor* ○	*Poor* ○	*Very Poor* ○	*Good* ○	*Very Good* ○
3.	How has your organisation sought to identify areas particularly vulnerable to intentional damage?	*Very Poor* ○	*Poor* ○	*Fair* ○	*Good* ○	*Very Good* ○
4.	How has guidance been sought on pipeline security and damage control from: The insurance industry, security agency, and the communities	*Very Poor* ○	*Poor* ○	*Fair* ○	*Good* ○	*Very Good* ○
5.	How well do you work with vendors of monitoring	*Very Poor*	*Poor*	*Fair*	*Good*	*Very Good*

	systems to detect incidents of third party damage on your pipelines?	○	○	○	○	○
6.	What simple methodology would you suggest is most effective for pipeline damage prevention?					

How do you agree with the following as the major factors affecting the occurrence of intentional pipeline damage? We would also welcome more detail/comments.

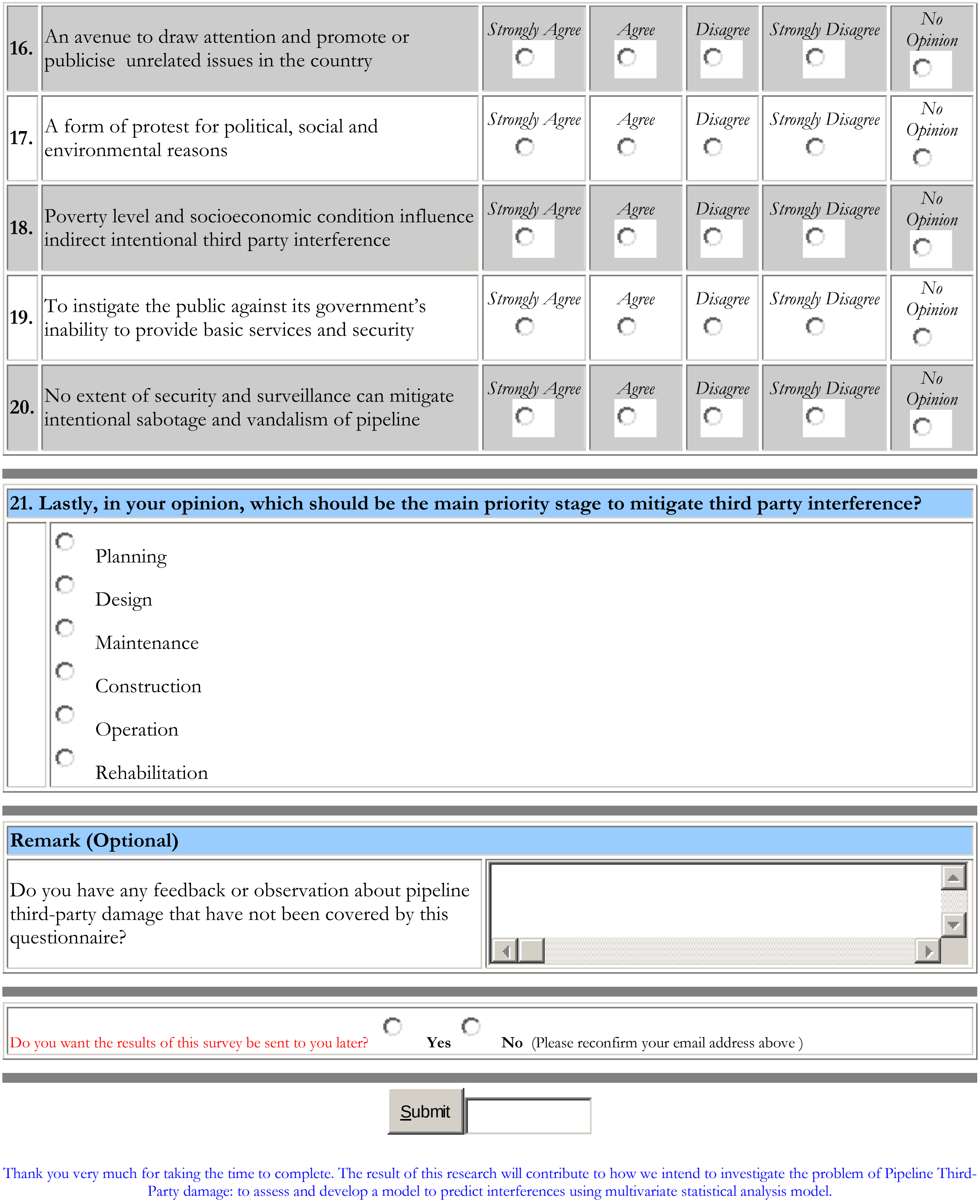
7.	Population distributions (urban growth with people now leaving in close proximity to pipelines)	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
8.	Land use and human activities (e.g. farming, commercial area, industries, and construction activities)	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
9.	The socio-economic conditions of population living near a pipeline (e.g. demography, morbidity, occupations, health, and social infrastructure	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
10.	Accessibility to Pipeline Network (proximity of roads, rivers, streams and rail)	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
11.	Socio-political factors (e.g. literacy rate, employment, political stability violence, revolutions, rebels, coups, and assassinations, etc)	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
12	Depth of Pipeline (exposed pipeline can often provide criminal opportunities)	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○

14: Please could you select the three factors that are most important that could assess the potential for third party damage, and rank them below from 1 to 3 (with <u>1 as the most important</u>)

(a)	Land use and human activities	0 ▼
(b)	Socio-economic conditions of population living near a pipeline	0 ▼
(c)	Accessibility to Pipeline Network (proximity of roads, rivers, streams)	0 ▼
(d)	Socio-political factors (e.g. literacy rate, political stability, and violence	0 ▼
(e)	Depth of Pipeline (exposed pipeline provide criminal opportunities)	0 ▼
(f)	Other factor in your opinion not mentioned	0 ▼
(g)	Unable to Answer	○

How well do you agree with the following motivation for third party interference?

15.	It is an indirect attack on the government and underestimation of it's security	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○



16.	An avenue to draw attention and promote or publicise unrelated issues in the country	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
17.	A form of protest for political, social and environmental reasons	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
18.	Poverty level and socioeconomic condition influence indirect intentional third party interference	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
19.	To instigate the public against its government's inability to provide basic services and security	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○
20.	No extent of security and surveillance can mitigate intentional sabotage and vandalism of pipeline	*Strongly Agree* ○	*Agree* ○	*Disagree* ○	*Strongly Disagree* ○	*No Opinion* ○

21. Lastly, in your opinion, which should be the main priority stage to mitigate third party interference?

○ Planning
○ Design
○ Maintenance
○ Construction
○ Operation
○ Rehabilitation

Remark (Optional)

Do you have any feedback or observation about pipeline third-party damage that have not been covered by this questionnaire?

Do you want the results of this survey be sent to you later? ○ **Yes** ○ **No** (Please reconfirm your email address above)

Thank you very much for taking the time to complete. The result of this research will contribute to how we intend to investigate the problem of Pipeline Third-Party damage: to assess and develop a model to predict interferences using multivariate statistical analysis model.

APPENDIX IV: SELECTED REMARKS FROM THE QUESTIONNAIRE SURVEY

The questionnaire survey asked respondents about any feedback or observation about pipeline third-party interference not covered by the questionnaire, for example, any further views about preventing and monitoring pipeline TPI. These are some selected responses from the open-ended questions collated:

"Industry here held a meeting with various governmental entities to discuss the issue of possible terrorist acts against pipelines, platforms, etc. The lead agency in these discussions was the FBI. FBI recognized that no effective means exists that can prevent a terrorist act. Their desire was that industry set up video surveillance on its facilities with the intent that were such an act to take place that they could retrieve the video for use in investigation of the crime. Industry did not view this favourably in that the approach was tantamount to FBI requesting a "black box" recorder to investigate a disaster after the fact. In other words; FBI accepts the fact that facilities and personnel are in fact helpless to prevent such an attack and as such can only serve to provide possible evidence of the crime after it has been committed. Moreover; even if industry were to set up its own security measures, such measures would not be effective it that no effective counter-response capability exists. Industry representatives even went so far as to suggest that it be allowed the use of firearms to protect it pipeline and associated assets, e.g. offshore platforms. Government did not like this suggestion. Note: it is illegal to possess firearms on such properties. Industry effectively responded that government was powerless to stop industry from arming itself. Government effectively has turned a blind eye to industry's intentions in this regard. As to pipeline yet to be installed; burial, i.e. "hiding" these assets is the most effective means by which to lessen the possibility of their being compromised. Markers are also effective as is membership in a "Dig Alert" organization. Markers however have the disadvantage of advertising placement of pipelines. While your study is very well intentioned and may even provide some positive fruit, it is generally felt here that pipelines are at greatest risk from terrorist activity over which no control or preventative measure is possible. This is not fatalistic viewpoint; it is the reality of the world at this juncture. Joint governmental/industry continued cooperation does exist as regards reacting to reported suspicious activity. However, this is not a pro-active stance. It merely serves the purpose of being able to state that something is being done; no matter how impotent it really is. The recognized truth the matter is the tacit acknowledgement that an attack on a pipeline may be affected with virtual impunity"

"Use of modern technology to track interference, alert impact and determine location will be helpful."

"the government developing rural areas (Villages where the pipeline runs through and Towns where the oil drillings take place) that is places where oil wells and float stations is located. Also the government of oil producing country like Nigeria need to come up with a new regulatory laws that will help the oil producing states most especially the communities where the drilling take place, by providing them with modern amenities and infrastructures such as school, Health Centres or hospitals, community skill acquisition centres and good jobs after graduation from school."

"Greater pipeline awareness and their consequences of damage to be issued to third parties, UKOPA are currently investigating methods. I suggest you contact them for more information that will help."

"Pipeline security initiatives will fail if they remain reactive. It will prove futile to attempt to harden the vast length of critical pipeline infrastructure against attack, as it will always be easier for potential adversaries to improve their ability to disrupt a pipeline than it will be to prevent this. Instead, pipeline security should focus on creating a combination of 1) addressing the root motivations of adversary groups, 2) improving rapid response capabilities, and 3) diversifying, decentralizing, and overlapping pipeline networks

to minimize single points of failure."

"Whilst I would agree with the statement that third party interference is a leading cause of pipeline damage, I am not aware of how much research has been done and cannot comment on the effectiveness of current safety regulations. In terms of research I am aware of the PARLOC initiative which applies to North Sea pipelines and risers. PARLOC provides very useful information on pipeline failures and their causes."

"Better land use planning guidelines. Regulations governing the protection of pipeline from third party are inconsistent from one jurisdiction to the next. Preventing and monitoring pipeline third party interference require more resources than its being put to it"

"Regulator to specify the geodetic parameters for surveying (helps prevent misunderstanding between pipeline operators).Pipeline surveillance could be more intensive in areas of higher risk and less so in other areas. It needs to satisfy cost/benefit criteria which may be difficult for many Australian pipelines which are generally in remote areas."

"Planning of new pipeline system, especially in the third world countries should take into account the current land use, environmental conditions and potential social impacts"

"A remote control network system for monitoring the activities of the third party should be introduced"

"Third Party Damage is the top risk in our Networks Risk Assessment annually as it is outside of the companies' control. All you can do currently is to advertise, make people aware, punish the act and respond asap when it happens."

"What of when these pipe lines vandalism are politically motivated, take for e.g. issues with the 'Niger Delta' in Nigeria, where pipe lines are vandalised for crude oil theft, are there measures to curb excessive and unnecessary crude oil spillages by creating emergency shutdown systems on the pipe lines?"

"Better records are required, particularly on older pipelines. Historical records are very poor, these should always be updated whenever maintenance is carried out."

"There should be legal implications if one damages a third party pipeline. Instant fines and the removal of licence to operate."

"Public Enlightenment to the relevant legal and other regulatory provisions with respect to pipeline protection is needed. Political and economic policies should ensure even spread of development to proactively manage disenchantment within the pipeline host communities."

"The prevention of third party interference is also reliant on the application of standards and procedures by the operating company. In countries where these are regulated it is easier to draw conclusions or state opinions, but in the Middle East for instance, there is a lack of formal regulation and in some cases this can result in a lack of understanding in the need to enforce and ensure the proper preventative measures are taken"

"Effective surveillance is a key means of preventing third party interference (i.e bunkering)"

"Most Pipeline damage is committed by personnel who are not a party to the relevant codes and procedures"

"Certain terrains, political climate have challenged the efficacy of conventional techniques in pipeline surveillance. Thus in developing a workable monitoring/ surveillance strategy specific non-technical

variables need to be addressed"

"Review of existing safety regulations, aware campaigns of damagers associated with pipeline vandalism, enactment of active governmental policies of pipeline policies."

"Third party interference can be 3 types, accidental, sabotage and theft of product. Regulations generally cover accidental damage however the other two cannot be prevented by design or operator only measures and requires government assistance."

"It's not that the pipeline safety (Federal) regulations are adequate, it's the inadequacy of damage prevention state laws, i.e. On-Call systems that needs to be addressed."

"Third party damage may be one of the prevalent threats to pipeline failure, but it is not the prevalent threat in all cases. In our jurisdiction, corrosion issues are by far the prevalent threat to pipeline integrity. Third party damage is relatively infrequent in comparison. This will be different when comparing production pipelines versus clean product transmission pipelines."

"Providing adequate and meaningful legislation to reduce the occurrence of third party damage seems to be a step that the BC Government is reluctant to do. I have been trying for years"

"All jurisdictions must have a system in place for registering buried facilities, ie oil and gas pipeline, fibre optic and other instruments. Within this system a one call needs to exist where the third parties can call free of charge prior to digging. Pipeline locates must be done free of charge to encourage third parties to use the system. A widely distributed public relations campaign needs to be implemented to broadcast the system to all third party, including homeowners."

"There is a great lack of understanding by the public as to who is responsible for protecting pipelines. Right of way encroachment leads to invasion of space by third parties. The public thinks that they can do whatever they want to do on the right of way and the pipeline operator is responsible for fixing anything that goes wrong."

"Mandatory use of one call systems supported by appropriate pipeline safety regulations is highly desirable."

"As a regulator, I strongly endorse the need for industry to develop risk based strategies for third party interference commensurate to the risk of third party interference to the pipeline."

"In New Zealand we have a procedural means of controlling these activities through the Resource Management Act by "Designating" the pipeline Corridor. This enforces all Local Territorial Authorities to delineate the line (with conditions and restrictions imposed and agreed) on the Local District Plan which is the only "Legal" document for all members of the public to utilise when performing works or development of existing land. We have nearly achieved this (by end May this year) after 3 years of Legal lodgement, submissions and appeals."

"There needs to be a distinction between inadvertent third party interference and deliberate wilful damage by 3rd parties. They are different sides of the same problem, and the latter problem may require additional

unconventional solutions."

"In case of Nigeria, Pipeline safety is poor. Existing infrastructure is not just low in technology but it is left unmaintained"

"Regulations to prevent third party damage should not only be focussed on the pipeline industry but certainly also on the construction industry and agricultural industry"

"Statutory protection and financial sanction against unauthorised working over pipelines. Insurance risk for contracting companies to reflect this which would concentrate the efforts of the persons working unheeded."

"Use of a national one call system should be mandatory in the UK"

"Statistics show that the incidents with a major consequence are very rare at all. Also statistic gives evidence that in countries with a frequent surveillance (like in Germany) third party damages are much less than in countries where surveillance is less frequent and dense."

"Pipeline damage in Nigeria is a consequence of socio-economic problem peculiar to that country. What research concludes that third party interference is the leading cause of damage to pipelines. Damage needs to be defined and not just used to satisfy the purpose of this work."

The protection of pipelines is best guaranteed if left in the hands of the community in which the pipelines are situated and the youths are well motivated to stop vandalisation of pipelines"

"Third party interference is more social economic case than technical problem"

"Land use act in Nigeria should be modified. Enforce stricter penalties for 3rd party violators of pipeline system. For example, if a 3rd party fails to utilize the mandated one-call system and then is caught operating near a known system, penalize the violator to the maximum extent."

"Federal Government of Nigeria should ensure further effort in checkmating pipeline vandals and as well giving adequate consequences management to any defaulter or offender.(to act as deterrent to other. not after arresting the offender the next moment or day they are out to continue with their evil activities)The vandals are all humans that can be fished out."

"In addition to pipeline surveillance technology for all the pipeline networks, the host communities should continuously be educated about dangers in pipeline vandalisation and as well engage them for local surveillance."

"Approach to the prevention of third party interference or damage of pipeline must not be viewed narrowly from legalistic perspectives. There are other socio-economic and political factors that underpin third party interference, whether wishfully or unintentionally. And this dimension must be explored."

"All agencies need to work together to reduce in incidence of third party damage. Existing safety regulations are suitable for the prevention of 3rd party interference following construction (i.e. wall thickness, depth of cover, material grade). However regulations for dealing with interference during construction (protesters on site, machines getting vandalised) is unsuitable."

"to preventing third party interference we should use remote sensing technologies and satellite images. And at the beginning the project we should determine the most suitable route. This is most important. Also

geographical information technologies should be used."

"Pipeline safety is only as good as the local government (whether it is state, county or city) enforces whatever laws they have regarding pipelines. If you don't have an enforceable law, you are not accomplishing what really needs to be done; make the people who are excavating near the pipeline be attentive to the situation and the hazards involved."

"We have been working with Fibre optic sensing technology that solves this problem. I'd like to point out that the PHMSA mission does not include a security component. I agree that some safety aspects can double for addressing security ones. Pipeline security in the US is not such a problem as seen across the world. I agree that some sort of protection is warranted only on some systems but much more than just surveillance technology should be part of the plan. For what today's technology can provide (cheaply), i disagree that not enough research has been done. Efforts are well targeting the threats and just need to pan out before we can judge if more research is required. In addition, the problem involves more than just technology. People, process and technology must work hand in hand with a given safety threat. I have no opinion on the adequacy of regulations because the US is now under rulemaking to address damage prevention among other items and the final output may strengthen existing regulations."

"One call systems with real penalties for those that don't use it and working with contractors and the public to raise awareness."

""Regulations and civil penalties should be enhanced; Consider using thicker wall pipe in areas that might be closer to populated sites. Pipeline Aerial survey is still very useful"

"In Canada, communication break-down is a key component of the underlying causes of third-party damage. In my line of work, I function as a Pipeline Accident/incident investigator (for over 30 years). The lack or break-down in communication is a principle and underlying cause that appears to be outside of the ability of Government to regulate."

"Safety regulations should have more guidance on pipeline third party prevention. Hazards vary between nations. In North America, wilful damage is unlikely where as in South America, theft and sabotage are probably a leading cause of pipeline damage."

"A strong enforcement program has showed a decrease in the number of damages to all underground facilities. However, most states or jurisdictional authorities are reluctant to take on this responsibility."

"Local Government Authorities should support Oil and Gas companies in protecting the pipelines. Strong local regulations/laws and enforcement programs are needed to reduce excavation damage to pipelines."

"Pipeline Operators need to work more on prevention programs than only execute what is considered by pipeline safety regulations."

"In our case, we have TPD due to illegal taps and we are working in that way. But the industry should work in how monitoring the pipeline before drilling the pipeline. I think it can be a universal problem."

"There should be much more emphasis on educating the public about damage prevention, particularly contractors involved in excavation. Enforcement of damage prevention laws needs to be improved and fines/civil penalties need to be strengthened. Entities damaging underground facilities, disregarding damage prevention regulations should be penalized."

"TPI is not a worldwide problem, but a serious problem in some parts of the world. Pipeline should be protected along the whole length (against unintended damage. From my point of view issues of Security and those of Safety are too much mixed in your statements)) TPI not under researched, but in practice more possible (and known) measures could and should be taken for protection, as in Germany"

"This is basically a social case that requires the attention of both public and private partnership. The economic situation especially in the third world countries has made vandals to interfere with our pipelines to collect products and sell to make ends meet."

"To prevent Third party Interference it must be increased the awareness of all the contractors excavating or digging in the proximity of pipelines or other buried services. Very often these contractors are completely out of control of the Pipeline operators which cannot do anything to prevent possible damages to their infrastructure."

"We do not perceive there to be a shortage of research related to prevention of pipeline damage. Also, we believe pipeline surveillance technology is not necessary across the pipeline system, rather is potentially appropriate for selection locations only (partially due to risk/reward scenarios)."

"Stronger laws with stronger enforcement, regulation without enforcement are only suggestions"

"In our country there is animal attack (Mouse) .Especially for PE 20 pipe. Until now I don\'t take a measure for this problem. Also other pipe interventions such as Water, Elektricity are a problem. if there are leakage in water that effects Natural gas line in some cases. I experienced that even steel pipe (pin hole) by damaged by small water leakage."

"an highly developed automatic signalling system that will locate and detect any pipeline leakage from fixed station can serve as the best solution"

"Government security involvement to protect the pipelines. Then the Thieves should get severe and capital punishment to deter others. People blame everything on poverty but the power brokers in politics are behind the vandals in Nigeria particularly in the Delta and Riverine area."

"In reference to the Niger-Delta states in Nigeria, the government should eliminate middle men and negotiate directly with host communities where the oil drilling take place without any pre-conditions."

"An integrated approach to security and environmental protection with involvement of specialist organisations."

"Adequate depth burial with protective measures and leak detection equipment from surface. No markers, burial. Effectively hiding the presence of pipelines to maximum feasible extent"

"Public education for those living near the pipeline and related facilities, with a simple, 24 hour means of notifying the operations center of suspicious activities."

"The vast majority of our pipelines cross remote areas and liaison with the landowners is very important to educate them and remind them of our location. We use good market signs and sufficient depth to avoid land use damage. Our Standard requires us to protect against rupture or serious leak in built up areas, we utilise concrete capping for that purpose normally."

"Remote Surveillance is excellent. Also, 1. Avoid vulnerable areas. 2. Work with local communities, make them feel responsible for the pipeline. 3. Ensure government support for asset protection. 4. Physical protection measures and monitoring."

"Intentional damage is very hard to prevent if someone really is intent on damaging a pipeline. Other than deep burial, there is not a lot you can do. Even sophisticated surveillance methods will not help in cases where the pipeline travels through sparsely populated areas as any response to intrusion would come too late to prevent damage."

"Public communication and monitoring programs. The problem posed by pipeline prevention is a hydra headed one and is region-specific and thus requires a customised solution tailored to fit the environment in question. E.g. the use of high tech gadget, while proven to be successful in other countries may not be the same in the Niger Delta region, where the means to power such gadgets are non-existent."

"One call systems, and make it difficult to dig into the right of way. Grasscrete grids at the surface make the area look like a green field, but make it very difficult to dig. This also spreads out the load of a vehicle driven on the right of way. Cost is an issue and gresscrete can only be used on the highest risk areas."

"Good relations with local community promoting awareness of the pipeline location and the potential dangers to safety and environment if damaged."

"Public education about pipelines that run through their neighbourhood; what activity they might normally see on the ROW, what type of equipment they might see, learn to report any suspicious activity to the local authorities."

"Public education and good neighbour policies are often the most effective means of preventing intentional damage. If your neighbours believe that the pipeline and facilities are dangerous, ot a nuisance, or that the operator doesn't care, then they will not be cooperative in reporting potential threats. Burial depth of pipeline can be significant, depending on surrounding activity. For example, in agricultural areas where deep ploughing is practiced or where tile drainage systems are installed, extra depth of burial is warranted."

"In Australia intentional interference is not such an issue, rather unintentional interference brought about by deficiencies in the risk assessment in the first instances failing to identify the threat and relevant controls of such interference. I disagree with the any inference that third parties would intentional seek to damage a pipeline. Unless of course it is in a politically unstable environment e.g. Iraq and Afghanistan."

"New Zeakland is fortunate at present to not experience most of the factors listed for intentional pipeline damage. Others would be vandalism in remote areas and mostly occurs at valve stations and facilities in general (graffiti, theft of fire extinguishers, signage etc."

"Most damage in the US is caused by 3rd party operators not following the pre-scribed process for identifying underground faculties prior to excavation activity. If the penalties were stronger, there would few fewer incidents."

"The reasons for damage can vary by location. e.g. in FSU it is 100% economic (oil theft). In Nigeria it is a mixture of economic and protest. In Colombia it was 100% protest. Protest (terrorism) probably cannot be prevented but should be of limited impact. Economic will remain endemic until the political system has the will to stop it as this does not usually seriously damage the pipeline."

"In Canada we have not seen a large presence of terrorism or other types of activities related to pipeline damage. There have been some pockets of criminal activities within the pipeline community however the greatest threat we face is from within our own ranks. That is a contractor or landowner who performs a ground disturbance without calling for locates and hits a pipeline or other buried infrastructure."

"In a western world country like Australia the risk of third party interference is considered from an unintentional point of view. That is, resulting from poor risk mitigation measures adopted by Pipeline Company such as failing to adequately identify land use and hence put in appropriate and effective controls. People, unless terrorists, don't go round seeking to blow up pipelines!"

Third party damage is typically not an act of sabotage but rather an unintentional interference with the pipeline caused by local activity. The solution is avoidance. Avoidance requires design and construction techniques that identify the pipeline and detection technology on excavating equipment. Where avoidance is not possible then monitoring is required. Solutions must be cost effective"

"The importance of ensuring that Risk assessment is always conducted with the number of increasing events demonstrated the importance of reviewing the pipeline controls for reduction in third party interference. This is normally (in New Zealand)by way of neglect in searching land title for easements coupled with no delineation of the pipeline on District Council Maps. With designation secured the pipeline will be shown on District Council Maps and must be reported to any member of the public seeking a LIM (Land Information Management) Report for development or work."

"You may be aware of the report that was issued by the EU Commission on safety of pipeline transportation systems. The main findings included: Third party damage is the main cause of pipeline incidents and therefore should receive the main focus and the availability of an effective Pipeline Integrity Management system is one of the key elements in controlling the risks. You can search the website of the Commission the find the report within the Transport section."

"Although third party interference is the single main cause for pipeline damage, the cases of major pipeline incidents (on transmission pipelines)is so rare that additional safety measures are not required at all. Major incidents mainly occur on the distribution networks close to the buildings, mainly caused by manipulation of the supply connection directly. e.g., as an attempt of steeling gas, or due to the design for low pressures (plastic pipes)."

"You seem to have overlooked the issue of parochial business interest of some actors, underpinned by corruption. In one of my (field study) interaction with some local people where some Nigeria\'s oil pipelines transverse they argue that some firms or personnel that specialize in repair of pipelines connive with some vandals to puncture these pipes to achieve their mutual interest. The vandals benefit from this through siphoning of the products, while the firms/personnel gain from the award of contracts to effect repairs."

"Intentional damage is not a problem in NA at least not yet. Most damage is due to contractors not using one call or facilities not being properly marked (which could go back to good records of the location of the pipeline). We need to make it very convenient for contractors to use first call and very painful if they don't use it."

"For the past 15 years Virginia government has been involved helping our pipeline industry reduce excavation damage to our pipelines. Our efforts has resulted in reducing these damages by more than 50% while miles of underground pipelines have increased by more than 30%. This has been done by effective public education, use of technology and strong and fair enforcement."