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MINIMUM CONNECTER OF PIPELINES FROM TEMA/TAKORADI TO ALL THE REGIONAL CAPITALS OF GHANA

A THESIS SUMITTED TO THE DEPARTMENT OF MATEMATICS IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE, INSTITUTE OF DISTANCE LEARNING

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DECLARATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material, which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

Natural gas transportation in Ghana is heavily dependent on trucks (tankers). Due to the highly inflammable nature of natural gas, the trucks sometimes catch fire resulting in the death of the truck drivers and causing a big loss to the gas marketing companies.

Gas pipeline transportation is unique in the transportation industry due to its continuous system and time of delivery.

The aim of this thesis is to mathematically model optimally, the minimum connection of gas pipelines from Takoradi/Tema to all the capital towns of Ghana.

Prim's algorithm has been used to achieve this.

DEDICATION

This study is dedicated to the Almighty God, my mother, the Mad. Srumawudu Glago, my wife Ms Dela Sorkpor and my daughter Essela Galley.

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CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND OF THE STUDY

Energy is a basic input that is required to meet many basic human needs, particularly heating, motive power (e.g., water pumps, transport etc.) and light. Business, industry, commerce and public services such as modern healthcare, education, and communication are very dependent on access to energy services. In fact inadequate energy services are directly linked to high infant mortality rates, lowered life expectancy, and illiteracy, among several other poverty indicators. In developing countries, inadequate energy services also directly exacerbate the problem of rural to urban migration (Foss, 2006).

In developing countries, 1.6 billion people lack adequate energy services. Of these, 80% live in the rural areas of South Asia and Sub-Saharan Africa. Increasing energy consumption has long been directly associated with economic growth and improvement in human welfare. Developing countries need more energy to grow their economies at the same rate as developed countries, where through structural changes and increased energy efficiency, energy consumption has been to a great extent decoupled from economic growth. Around half of all people living in developing countries are dependent on fuel wood, dung and crop residues as their main energy source. Modern energy sources like electricity and petroleum-based fuels generally provide a small part of the energy use of the poor, especially in rural areas, because the poor either find these sources too expensive or energy service providers find such areas unattractive. Extensive usage of fuel wood or biomass by the poor has many problems. Efficiency rates of fuel wood and biogas utilisation can be as low as 10%. Collection of wood mainly by women and children wastes valuable time that could otherwise be used for engaging in more productive tasks or education. Fuel wood also exacerbates the problem of deforestation with knock-on effects such as loss of wildlife, soil erosion and increased flooding. Burning of firewood and biomass inside households increases the chances of children contracting acute respiratory disorders by up to four times; this indoor air pollution is proving to be more harmful than outside air pollution.

The World Energy Council (WEC) forecasts that primary energy demand for developing countries will triple from its present state and constitute two thirds of total global requirements by 2050. As these economies develop over the decades, demand for energy is expected to increase considerably. Apart from meeting household needs for adequate energy supply, there is growing energy demand for services such as water supply, sanitation, healthcare, education, for productive activities such as agriculture, and for the development of small and medium enterprises (SMEs).

In Ghana, the pattern of energy demand over the years matches energy patterns for most developing countries, with biomass and petroleum products consumption being the main sources of energy. In 1985, wood fuels, including charcoal, accounted for about 66% of total energy consumption as compared to about 67.3% in 1996. In 1985, petroleum products and electricity accounted for 25.6% and 8.3% respectively while the figures for 1996 were 19.0% and 13.7%. In 2000, a survey conducted by Ghana's Energy Commission established fuel wood consumption at around 60%, petroleum products at 35% and electricity at 10%. These trends are indicative of a high and persistent dependency on wood fuel or biomass.

At the sectoral level, a study conducted for the Energy Commission by Akoena et al,

(2001) revealed that households account for about 60% of total energy demand, the transport sector 28%, industry 9% and services including agriculture 3%. Thus the household and transport sectors alone consumed almost 88% of total energy in 2000.

Upon the completion of the West Africa Gas Pipeline (WAGP), Ghana will start receiving significant amounts of natural gas, primarily to be used in power generation and by industry, which may get more developed due to the availability of natural gas. Eventually, households may be able to benefit from this fuel for cooking, heating water and other uses. Natural gas will be a new source of energy in Ghana's portfolio. As such, it should help the country diversify its energy supply sources and reduce the demand for wood and biomass as well as imported petroleum products. A pipeline infrastructure will be developed gradually to deliver natural gas to users. The investments necessary will be based on the regulatory environment created by the Ghanaian government and its various agencies, including the Ministry of Energy, the Public Utilities Regulatory Commission (PURC) and the Energy Commission (EC).

In this chapter of the thesis, an overview of natural gas in Ghana would be given; a brief description of the problem statement of the thesis is also presented together with the objectives, the methodology, the justification and the organization of the thesis.

The oil and gas industry comprises two parts: "upstream" – the exploration and production sector of the industry: and "downstream" – the sector which deals with refining and processing of crude oil and gas products, their distribution and marketing. Companies operating in the industry may be regarded as fully integrated, (i.e. having both upstream and downstream interests), or may concentrate on a particular sector, such as exploration and production, commonly known as an E&P company or just on refining and marketing (known as an R&M company). Many large companies operate globally and are described as “multinationals”, whilst other smaller companies concentrate on specific areas of the world and are referred to as “independents”. Frequently, a specific country has vested interests in oil and gas in a national company, with its name often reflecting its national parenthood.

In the upstream sector, much reliance is placed upon service and upon contractor companies who provide specialist technical services to the industry, ranging from geophysical surveys, drilling and cementing, to catering and hotel services in support of operations.

This relationship between contractor and oil companies has fostered a close partnership, and increasingly, contractors are fully integrated with the structure and culture of their client.

The oil and gas industry is very important to the socio-economic development of the country. The industry provides energy for almost all the sectors of the economy.

Consequently, the activities of this industry to a large extent determine the rate of economic growth and level of development of the country. The industry also provides revenue for government in the form of taxes and levies incorporated into the petroleum products price build-up.

It has been realised that the industry provides a substantial portion of commercial energy. In the year 2000, about 75% of the commercial energy consumed in the country was from petroleum products. The total amount of petroleum products consumed in the year 2000 was 1.5 million metric tons. This has been increasing at an average annual rate of about 8% over the past few years.

Despite exploration activities since 1896, which have resulted in the drilling of over 66 wells, no commercially sustainable deposits of oil and gas have been discovered.

The country therefore imports 45,000 barrels per day of crude oil from Nigeria on a government-to-government contract, which is just about 70% of petroleum needs.

The balance is obtained in the form of petroleum product obtained from the international market by competitive bidding.

It has been estimated that the country spends as much as 20-30% of its export earnings on crude oil and petroleum products importation depending on the world market prices of these products. An amount of US$ 528 million, about 27% of the country's total export earnings were spent on the importation of about 1.1 million metric tons of crude oil and 0.8 million metric tons of petroleum products in the year. Consumption of products in 2002 was about 1.64 million metric tons. It was projected in 2002 that demand for petroleum products would increase by 28% from 2003 to 2008 from 1.9 million metric tons to 2.43 million metric tons. Product supply from the Tema Oil Refinery (TOR) during the same projected period would range from 1.4 million metric tons to 1.8 million metric tons. This gives a projected product shortfall per annum of between 0.2 million metric tons to 0.8 million metric tons (Foss, 2006).

Exploration for oil and gas in Ghana can be divided into three phases. The first phase was between the years 1896 and 1967 when exploration was concentrated in the offshore Tano, Keta and Voltaian basins (see figure 10). During this period, a total of 16 wells were drilled around known oil seepages, mostly without relying on any form of seismic data. The second phase was between the years 1967 and 1981. During this period, 24 concessions offshore were licensed to private foreign companies for exploration.

More than 31 wells were drilled during this period. These activities led to the discovery of three oil and gas accumulations, which are the oil and gas at the Saltpond Field in the year 1970, natural gas accumulation at Cape Three Points in the year 1974 and the oil and gas accumulation in the North and South Tano Fields in the years 1978 and 1981. The Saltpond Field was developed and put into operation with a production rate of about 4,800 barrels per day by Agri-Petco of the USA. This however declined to about 680 barrels per day by the mid 1980s when it was shutdown in 1985. The third phase of the exploration activities has been between the years 1981 and 2006. This phase began with seismic data retrieval and gathering in the shallow water areas. In the year 1982, the government initiated a restructuring of the whole energy sector. A comprehensive plan to accelerate the pace of petroleum exploration and development was established with the enactment of three laws 2, 3 and 4 for details), namely:

• The Ghana National Petroleum Corporation Law (PNDC Law 64) in 1983

• The Petroleum Exploration and Production Law (PNDC Law 84) in 1984, and

• The Petroleum Income Tax Law (PNDC Law 188) in 1987.

It is important to note that until this phase, oil and gas exploration in Ghana was episodic, until the inception of the Ghana National Petroleum Corporation (GNPC) in 1983-84.

Crude oil and petroleum product imports still constitute the single highest consumers of the country's foreign exchange. In the early 80s almost half of the nation's foreign exchange earnings went into petroleum imports. Currently over 20% of foreign exchange earnings are spent on importing petroleum. In recent times, even though Ghana's foreign exchange earnings have increased, there has been a concomitant increase in the world market price of crude oil. The crude oil price increases of the 1970s and early 1980s had a major impact on Ghana's economy as they did to other oil importing developing countries, particularly because at the time inappropriate pricing of foreign exchange under a fixed exchange rate regime led to massive subsidies on petroleum products.

While world oil prices by 1980 were more than five times 1972 levels, in real terms the prices of petroleum products in Ghana in 1980 were below their 1972 levels.

Smuggling to neighbouring countries flourished under these circumstances. The petroleum sector thus contributed in no small measure to the distortions in the Ghanaian economy. These same phenomena can be observed in the country today as world market prices for crude began to increase in 2000 and remain stubbornly high by historic standards. The country now spends in excess of US$ 1 billion per annum in the importation of petroleum products. Local production therefore, of even a third of Ghana's crude oil requirements would easily save about US$ 350 million annually, resources which could then be made available to other areas of the national economy.

The availability of natural gas could afford the country the following benefits amongst others:

• displace liquid fuels in power generation and industry in Ghana.

• contribute towards the reduction of emissions of greenhouse gases in the country.

• lead to value added processing of minerals.

Surface seepages of oil have been known in Ghana for a long time. Not far from the border with La Côte d'Ivoire, onshore prospecting for hydrocarbons by the international industry began as far back as the last decade of the 19th century near some of these seepages. Many of these onshore wells drilled, then and over the following three decades, flowed small amounts of crude oil, and some production is reported during the Second World War. It was also in this onshore area that in the 1950s four very deep wells were drilled along the coastline by Gulf Oil. In 1965, the Romanian government provided technical assistance to the Ghana Geological Survey Department in undertaking exploratory drilling on the coastal area to the Southwest; wells were drilled at Anloga and Atiavi. Hydro-geological investigations in the Voltaian basin in the 1960s also encountered bituminous material, but only one deep well was ever drilled in this huge basin by Shell in the southern part in 1978. From 1966 onwards exploratory work extended offshore, as concessions were granted to a number of international companies offshore, among them Amoco, Chevron, Mobil, Occidental, and Signal Union Carbide.

A consortium of US companies, with Mesa Petroleum as operator, also drilled a well at Dzita in the same onshore Keta Basin in the early 1970s. In 1970, the Saltpond field was discovered by the AMOCO/SIGNAL Consortium. This was a small field with less than 50 million barrels of light low sulphur crude oil in place. With low crude oil prices at the time, the consortium relinquished it as not commercial. In 1974 another consortium of companies (Phillips, Zapata, Oxoco, Agip), with Phillips Petroleum as operator, made the first discovery of natural gas in Ghana in the Cape Three Points sub-basin. That discovery was never appraised, as gas was not of interest to the companies due to a lack of local markets for natural gas.

Currently, exploration activities involve acquisition, processing and reprocessing and interpretation of seismic data. Up to 3,000m bathymeters (water depth) covering an area of 50,000 sq km and 29,000 sq km are either licensed or subject to negotiations. About 21,000 sq km are open and 3,000 sq km of coastal onshore sedimentary basins are available. The Voltaian Basin of 103,000 sq km has only one well drilled and 230 km 2-D seismic data despite its potential for oil generation and accumulation.

The offshore sedimentary basins up to 3,000m bathymeters cover an area of about 50,000 sq km. Also available are about 3,000 sq km of coastal onshore sedimentary basins. One of these is the Onshore Tano Basin where we have the oil seepages. There is also the interior Voltaian Basin, which is about 103,000 sq km in area. This basin has seen very little exploration despite the fact that it has a good potential for oil generation and accumulation. For example, only one exploration well has been drilled and 230 kilometers of 2-D seismic data shot in this basin. Water wells drilled in parts of this basin have encountered dead oil stains. There are currently three companies with substantive licenses for exploration in Ghana and there is another company undertaking the redevelopment of the Saltpond fields. Some companies have submitted applications that are being reviewed and still others have expressed an interest in obtaining licenses to operate in the open acreages.

The potential for commercial oil and gas discovery in the remaining open acreage is high. In all about 48 exploration wells have been drilled in Ghana's sedimentary basins, which is about 150,000 sq km. 75% of these wells have encountered oil or gas shows and seven of them have been discoveries. The Ghana National Petroleum

Corporation (GNPC) with previous and present operators has identified over 70 undrilled prospects and leads with high potential for hydrocarbon accumulation.

From 1996 to date companies awarded blocks have in conjunction with GNPC, acquired, processed and interpreted over 3,500 sq km of 3-D seismic data out of which 2,400 sq km are in deepwater. 8,000 km of 2-D seismic data has also been acquired in addition to the reprocessing of over 21,000 km of 2D seismic data.

Given the prospecting ability of our basins, there is the urgent need to at least maintain the momentum of the current exploration and promotion activities. The State Oil and Gas Company, GNPC with assistance and support from Government, is therefore currently engaged in activities aimed at:

1. Sustaining the current levels of exploration, by assisting the various operators in their farm-in drives;

2. Attracting new companies to the open acreage.

GNPC will continue to re-evaluate the existing data and integrate the results of drilling and other exploration activities as they become available, and also continue with its aggressive promotional campaign. Under exceptional circumstances, new data will be acquired either on speculative or under special delayed payment arrangements with service companies, especially in the deepwater and virgin areas like the Voltaian Basin. This will be done in close collaboration with industry in a manner that will not saddle the Corporation with long-term debts.

Since 1996/97 when these companies were awarded their blocks, they, in conjunction with GNPC, have acquired, processed and interpreted about 3,500 sq km of 3-D seismic data out of which 2,400 sq km are in deepwater. About 8,000 km of 2-D seismic data have also been acquired in addition to the reprocessing of another 21,000 km of 2-D seismic data. For the GNPC to play its role effectively under the current Petroleum Agreements, GNPC Law, (PNDC Law 64) and Exploration and Production Law (PNDC Law 84), it is important that the Corporation is retooled with modern computers (workstations) in tune with current industry demands. Until recently, the Corporation was able to promote the country's petroleum potential with its pencil and paper maps. It is becoming increasingly difficult to continue with this antiquated medium because the multinationals cannot use our data and we cannot use theirs, because of the vast differences in media and formats.

To achieve government's policy objectives in the petroleum upstream sector, the following are being pursued:

• Undertaking effective programmes for institution building;

• Accelerating petroleum exploration activities in association with international oil companies to achieve commercial production; and

• Appraising existing oil and gas discoveries with the view to developing and producing these where feasible and economically viable, having particular regard to national requirements. A comprehensive plan to accelerate the pace of petroleum exploration and development was established with the enactment of three laws to govern petroleum upstream operations.

• The Ghana National Petroleum Corporation Law (PNDC Law 64) in 1983. This law established GNPC as the sole government agency to promote the exploration and orderly and planned development of petroleum resources in the country.

• The Petroleum Exploration and Production Law (PNDC Law 84) in 1984. This law sets out the legal and regulatory framework for petroleum exploration and production in Ghana. It also sets out the fiscal regimes under which such exploration and production is to be undertaken and describes the role of all institutional participants.

• The Petroleum Income Tax Law (PNDC Law 188) in 1987. This law spells out the tax policy of the government for companies engaged in petroleum operations. A model agreement has been synthesized and formulated from the three laws as a basic negotiating document. The model agreement is based on the following:

• Acreage Exploration Period: first phase – 3 years, a second extension of 2 years and a third extension of 2 years

• Work programme

• Relinquishment clause

• Royalties of 10-25 % for oil and gas

• Corporate tax.

In addition to the above, GNPC has Carried Interest of 10% and also charges for surface rental, training allowance and capital allowance.

Natural gas has been recognised for a long time as an environmentally attractive fuel by those close to the gas industry but in recent years environmental issues have generated discussion about the relative merits of fuels among a much wider range of experts. Natural gas appears to be gaining an increased share of the market because of its availability, environmental advantages and efficiency in use. Studies conducted reveal that industrial gas demand from small and medium-size consumers can only materialize if a gas distribution company is put in place. Gas for power generation is judged to be by far the major consumer of gas and indeed gas usage for power generation at the Aboadze Power Station underpins the whole of the WAGP Project. Other possible uses of gas from the WAGP are limited as it is free of heavy hydrocarbons, liquids and water and is therefore ideally suited only as fuel for power plants and industrial applications.

Purvin and Gertz (2001) adopted an essentially macro-economic approach making use of probabilistic methods in developing projections of the market, having regard to exogenous economic variables such as the expected progression of economic growth, likely evolution of national trading patterns. A scenario approach was adopted with respect to Ghana, Togo and Benin. The broad picture that emerges from the Purvin and Gertz report is that Ghana will be the principal consumer of gas. Ghana's share of the three countries' demand is estimated at about 85%, with the electricity generation sector accounting for the bulk of national consumption. Some industrial projects are identified in the Purvin and Gertz report that could require the use of natural gas. They are:

• Iron and steel manufacture, Takoradi

• Manganese ore processing, Tarkwa

• Bauxite processing, Nyinahin

• Limestone clinkerisation, Buipe

• Salt recovery and allied processes, Tema

• Poly Vinyl Chloride (PVC) manufacture, Tema

The report however emphasizes the fact that each of these projects would use gas only if the gas price is competitive with the fuel oil price.

1.1 PROBLEM STATEMENT

The specific form of problem that this thesis seeks to solve is to mathematically find, the minimum connection of natural gas pipelines from Takoradi/Tema to all the capital towns in Ghana.

1.2 OBJECTIVES

Liquefied natural gas is transported by means of trucks or ship. Due to its high cost of production and being highly inflammable, it must be shipped at a very low temperature. This makes shipping mode of transportation prohibitively expensive. Thus the most efficient and effective movement of large quantities of natural gas from producing regions to consumption regions is through pipeline transportation system especially for long distance transportation cited (Wikipedia, 2008). Gas pipeline transportation is unique in the transportation industry due to its mode captivity, continuous transport system, time of transport and as a commodity (Dott, 1997).

The goal of this research is to mathematically model optimally, the minimum connection of natural gas pipelines from Takoradi/Tema to all the capital towns in Ghana.

1.3 METHODOLOGY

In our methodology, we shall propose the minimum spanning tree algorithms in solving our problem. First, the algorithm would be presented along with relevant examples. A real life computational study would be performed to evaluate the algorithms.

1.4 JUSTIFICATION

In Ghana, the pattern of energy demand over the years matches energy patterns for most developing countries, with biomass and petroleum products consumption being the main sources of energy. In 1985, wood fuels, including charcoal, accounted for about 66% of total energy consumption as compared to about 67.3% in 1996. In 1985, petroleum products and electricity accounted for 25.6% and 8.3% respectively while the figures for 1996 were 19.0% and 13.7%. In 2000, a survey conducted by Ghana's Energy Commission established fuel wood consumption at around 60%, petroleum products at 35% and electricity at 10%. These trends are indicative of a high and persistent dependency on wood fuel or biomass which is a major cause of environmental degradation. Using natural gas as a substitute of the above could help to address the above problem drastically. Meanwhile the only means of transport of natural in Ghana currently is by road with gas tankers which poses danger to the drivers in times of accident and also delays the delivery time to the consumers hence the reason for solving the proposed problem.

1.5 ORGANIZATION OF THE THESIS

In chapter one, we presented a background study of natural gas situation in Ghana.

In chapter two, related work in minimum spanning tree problems and natural gas would be discussed.

Chapter three presents the minimum spanning tree algorithms for solving minimum spanning tree problems.

Chapter four will provide a computational study of the algorithm applied to data collected.

The final chapter is devoted to the conclusion and recommendations of the study.

1.6 LIMITATIONS OF THE STUDY

The study has been limited by inadequate funds. Unstable internet connectivity has also been a limitation to the study.

1.7 SUMMARY

In this chapter, we looked at the background of the study, problem statement, objectives, justification, methodology, organization of the study and the limitations of the study. In the next chapter, we shall review relevant literature.

CHAPTER TWO

LITERATURE REVIEW

Minimum Spanning Tree (MST) is one of the well known classical graph problems. It has many applications in wireless communication and various other fields. Rohit et al., (2005) presented a new parallel Prim's algorithm targeting SMP with shared address space. The authors used the cut property of graphs to grow trees simultaneously in multiple threads and a merging mechanism when threads collide. The authors also presented two new heuristics and a simple load balancing scheme to improve the performance of the algorithm.

The Generalized Minimum Spanning Tree (GMST) problem occurs in telecommunications network planning, where a network of node clusters needs to be connected via a tree architecture using exactly one node per cluster. Bruce et al., (2003) presented two heuristic search approaches for the GMST problem: local search and a genetic algorithm. Our computational experiments show that these heuristics rapidly provide high-quality solutions for the GMST and outperform some previously suggested heuristics for the problem. In their computational tests on 211 test problems, their local-search heuristic found the optimal solution in 179 instances and our genetic-algorithm procedure found the optimal solution in 185 instances (out of the 211 instances, the optimal solution is known in 187 instances). Further, on each of the 19 unsolved instances, both our local-search heuristic and genetic-algorithm procedure improved upon the best previously known solution.

Joannis et al., (2003) considered the Multilevel Capacitated Minimum Spanning Tree (MLCMST) problem, a generalization of the well-known Capacitated Minimum Spanning Tree (CMST) problem that allows for multiple facility types in the design of the network. The authors developed two flow-based mixed integer programming formulations that can be used to find tight lower bounds for MLCMST problems with up to 150 nodes. We also develop several heuristic procedures for the MLCMST problem. First, the authors presented a savings-based heuristic. Next, we develop local search algorithms that use exponential size, node-based, cyclic and path exchange neighbourhoods. Finally, the authors developed a hybrid genetic algorithm for the MLCMST. Extensive computational results on a large set of test problems indicating that the genetic algorithm is robust and, among the heuristics, generates the best solutions. They are typically 6.09% from the lower bound and 0.25% from the optimal solution value.

Ghana and three other West African countries including Benin, Togo and Nigeria have installed pipelines to establish the flow of natural gas. Donkoh et al., (2010) combined Prim's and Steiner Tree algorithms with factor rating method to solve the single source shortest path offshore/onshore pipeline problem.

Data on the West African Gas Pipeline (WAGP) project was collected and analyzed. We used Prim's algorithm to find the minimum spanning tree of length 712.30 km. This is a reduction over the original 788.90 km WAGP project design. Factor rating method was then used to find an alternative path of length 723.29 km. Steiner Tree algorithm and geometry were used to obtain an optimal pipeline length of 707.75 km. This is 10.3% reduction of the WAGP length. Our solution is shown to be topologically equivalent to the WAGP network and hence optimal in pipeline distance and project cost.

Liquefied natural gas can be transported by means of truck or ship. Due to its high cost of production and being highly inflammable, it must be shipped at a very low temperature. This makes shipping mode of transportation prohibitively expensive. Thus the most efficient and effective movement of large quantities of natural gas from producing regions to consumption regions is through pipeline transportation system especially for long distance transportation (Wikipedia, 2008). Gas pipeline transportation is unique in the transportation industry due to its mode captivity, continuous transport system, time of transport and as a commodity (Dott, 1997). Lurie (2008) reviewed the mathematical models of fluid and gas flow in the interior of a pipeline and discussed issues of non-stationary gas flow in a pipeline and non-isothermal gas flow in gas-pipelines.

Hochbaum and Segev (1989) observed that sending flow along a pipeline segment involves fixed cost for using the segment and variable cost for a unit of flow. The authors recommended the use of Lagrange multiplier method in finding the minimum cost of pipeline segments along which flow will be directed in a network.

Li *et al*. (2008) established a topology optimization technology for flow networks that finds the least cost network topology while the seismic reliability between the sources and each terminal satisfies prescribed reliability constraints. The model is applied to a large city in China and the solution is based on genetic algorithm.

The Minimum Spanning Tree (MST) problem is one of the most typical and well known problems in combinatorial optimization. Borçvka (1926) (cited in Graham and Hell, 1985), used Euclidean MST to find the most economical construction of an electricity network in Moravia. The author’s MST is applied to a network with distinct edge distances (Wikipedia, 2010). Schrijver (1996) cited Borůvka as the first to consider the MST. The MST algorithms that are commonly used are the Prim’s (1957) and Kruskal’s (1956) algorithms (cited in Jayawant and Glavin, 2009). However, Kruskal algorithm finds the minimum spanning forest if the network is not connected (Agarwal, 2010).

Zachariasen (1998) noted that all known exact algorithms for the Euclidean Steiner tree problem require exponential time. The general consensus is to use heuristics and approximation algorithms. However, one of the first and easiest methods involves the use of minimal spanning trees as approximation to the Steiner tree algorithm. The Euclidean Steiner tree problem has its roots in Fermat problem whereby one finds in the plane a point, the sum of whose distances from three given points is minimal (Ivanov and Tuzhilin, 1994). The Steiner ratio compares the solution of the Steiner Minimum Tree (SMT) problem to that of the MST. Moore in (Gilbert and Pollack, 1968) put the lower bound of the Steiner ratio to be 0.5 while Gilbert and Pollack (1968) conjectured the upper bound to be 0.866. This means that the SMT can be shorter than the MST by at most 13.4% (Bern and Graham, 1989).

Dott (1997) reduced the 952 km Palliser pipeline network to 832 km using the haMSTer program, which is based on Prim algorithm. This was a 13% reduction over the original length. The author conjectured that if the SMT is used in addition to the haMSTer then 721 km will be realized.

Brimberg *et al;* (2003) presented the optimal design of an oil pipeline network for the South Gabon oil field. The original design covered thirty-three (33) nodes with hundred and twenty-nine (129) possible arcs having total distance of 191.1 km. Using a variation of Prim's algorithm, this reduced the connection to 121.6 km, which was a reduction of 36.4% of the total distance to be covered.

Dott (1997) obtained an Optimal Design of Natural Gas Pipeline of Amoco East Crossfield Gas pipeline project, (Alberta, Canada). The pipeline, which covers a distance of 66 km was reduced to 48.9 km with the use of the haMSTer program software. Steiner tree algorithm was later used to reduce the MST created by the hamster to 48.84 km. This was 1% reduction over the MST.

Arogundade and Akinwale (2009) used Prim's algorithm to find the shortest distance between 88 villages connected by 96 roads of Odeda local government map, Nigeria, and arrived at an MST of 388,270 m.

Nie et al. (2000) combined an algorithm of rectilinear Steiner tree and the constraints and connectivity reliability of road network to obtain a new method of rural road network layout designing in a county area. The method is applied to the rural road network layout designing of Shayang County, China.

Natural gas is fast becoming a major primary source of fuel in Nigeria and is normally piped to the end users. The flow rate is measured with the orifice meter. The current practice is to manually read the sales line pressure and temperature, differential pressure and static pressure. These data are then used to compute manually the flow rates using necessary conversion factors. Ayoade and Uzoma (2008) developed a Microsoft Excel 2000 template for computing the flow rates of natural gas in pipelines. The data collected from one of the gas stations in the Niger Delta Area for a period of six months in 1999 were used to validate the template. The computed flow rates are then compared with the manually calculated flow rates. It is found that the ratio of the computed to calculated flow rates is 1.00 ± 0.02 for most of the days; the range was 0.80 - 1.10. The lowest values occurred after the gas supply was disrupted for two days.

In China, there are lots of gas pipeline network needed to be designed and constructed nowadays. Nie (2006) applied the Hopfield Neural Network optimal method to optimize the layout of natural gas pipeline network. According to the models of natural gas network total cost optimal layout and equivalent length optimal layout, the energy function model of optimal layout of natural gas network based on Hopfield Neural network was established. The dynamic equation of state of neural was induced. When iterative time increases, the energy function decreased to a stability value, the smallest namely. The network state gradually tends to stability appearance. The minimum energy function is responded to the optimal layout which to be wanted. The results express that adopting the length shortest layout match the actual project. The satisfied result could be gotten through applying Hopfield Neural Network method in gas network optimal layout.

Gas transmission network layout is an aspect of network optimization. In the proceedings of the 20th world gas conference, the C3 report indicated that the gas pipeline network optimal is the new problem cited (1998).The problem how to connect the all node-points to make the layout of gas transmission system reasonable should be solved after the basic data are obtained for design in the gas industry. When the pipeline route goes through many cities, the route's terrain is irregular and complicated, and several programs can be selected for the route, only the program that is optimized should be used.

The normal method to solve network layout include minimum spanning tree and min cost circulation and dynamic programming etc. The minimum spanning tree consider gas network as undirected graph. The efficient method is Dijkstra algorithm. The minimum spanning tree is efficient for branch pipeline layout but not so efficient for circle pipeline layout (Hu, 1998).The minimum cost circulation method is a network algorithm used to solve the linear programming problem (Federgruen et al., 1986).Dynamic programming selects solutions according time or phase. The operation amount increases index with the increased variables. There is the dimension obstacle. It’s difficult to solve multi-variables optimal problem using dynamic programming.

The natural gas transmission network layout problem similes the shortest path problem. The shortest path problem is the basic problem of combination optimization- NP problem. The intelligent optimal method recently developed can solve this kind of problem efficiently (Nirwan, 1999, and Wang, 1998). Pedrycz et al., (1992) adopted Annual Neural Network (ANN) modeling objective and parameter to design natural gas pipeline (Pedrycz et al., 1992, and Davidson and Goulter, 1991). Neural network can express the correlation clearly. This method is used for existing solutions not for detailed parameters determination.

In 1980s, Hopfield (1982) and Tank (1985) have used Annual Neural Network (ANN) to solve TSP and gotten success. Neural network method gets attention increasingly for its strong self-search ability. And it has been applied in transportation and electric and communication etc. In oil and gas field the method begin to be applied in oil field collection and transport system layout. The main technique is adopting right energy function according to the objective function of problem to determine the weights between the neural. With the change of network state the energy decreases to the minimum and the state get balance. It converges to a local optimal solution. Since the Hopfield neural network (HNN) can solve optimal problem such as TSP (Traveling Salesman Problem). The gas transmission optimal layout problem was similar to TSP. The Hopfield neural network was proposed to solve the gas transmission system optimal layout.

The exploitation of offshore natural gas reserves involves several phases, including production from reservoirs, separation of by products, and transportation to markets. The gas, which may originate as far as 100 miles from land, must be transported through pipelines to onshore delivery points. Rothfarb et al., (2007) developed techniques for solving the following problems: (1) selection of pipe diameters in a specified pipeline network to minimize the sum of investment and operation costs; (2) selection of minimum-cost network structures, given gas-field location and flow requirements; (3) optimal expansion of existing pipeline networks to include newly discovered gas fields. The techniques incorporate procedures for globally optimizing pipeline diameters for fixed tree structures and heuristic procedures for generating low-cost structures.

Chebouba et al., (2007) presented an Ant Colony Optimization Algorithm (ACO) for operations of steady flow gas pipeline. The system was composed of compressing stations linked by pipe legs. The decisions variables are chosen to be the operating turbo compressor number and the discharge pressure for each compressing station. The objective function is the power consumed in the system by these stations. Until now, essentially Gradient based procedures and dynamic programming has been applied for solving this no convex problem. The main original contribution proposed, in this paper, is that we use an ant colony optimization algorithm for this problem. This method was applied to real life situation. The results are compared with those obtained by employing dynamic programming method. The authors obtained that compared with those obtained by employing dynamic method. The authors obtained that the ACO is an interesting way for the gas pipeline operation optimization.

Nadejda and Grigoriev (2007) addressed the valve location problem, one of the basic problems in design of long oil pipelines. Whenever a pipeline is depressurized, the shutoff valves block the oil flow and seal the damaged part of the pipeline. Thus, the quantity of oil possibly contaminating the area around the pipeline is determined by the volume of the damaged section of the pipeline between two consecutive valves. Then, ecologic damage can be quantified by the amount of leaked oil and the environmental characteristics of the accident area. Given a pipe network together with environmental characteristics of the area, and given a number of valves to be installed, the task is to find a valve location minimizing the maxi- mal possible environmental damage. The authors presented a complete framework for fast computing of an optimal valve location.

In the classical maximal flow problem, the objective is to maximize the supply to a single sink in a capacitated network. In this paper we consider general capacitated networks with multiple sinks: the objective is to optimize a general “concave” preference relation on the set of feasible supply vectors. Awi and Henry (1986) showed that an optimal solution can be obtained by a marginal allocation procedure. An efficient implementation results in an adaptation of the augmenting path algorithm. The authors also discussed an application of the procedure for an investment company that deals in oil and gas ventures.

The Troll natural gas field (Phase I), the largest offshore gas field in Europe, is located some 60 km from the Norwegian west coast. Gas will be produced from 1st October 1996 onwards and will be transported to an onshore processing plant via two 36 inches carbon steel wet gas pipelines. The design life of the pipelines is 50 years and the minimum operational life has been set at 30 years, in line with the current gas sales contracts. The wet gas pipelines are designed such that a limited amount of internal corrosion is acceptable and an active corrosion management system is required. Knox and Guthrie (1967) presented the various interlocking elements of the corrosion management system, including the corrosion control method selected for the pipelines-injection of monoethylene glycol to reduce corrosivity such that the available corrosion allowance is sufficient for the planned life. A comprehensive corrosion monitoring system, based on the use of several complementary techniques, is an integral part of the corrosion management system. The key component of it, namely, on-line wall thickness measurement and the use of ultrasonic-based intelligent pigs, are highlighted. Details are given regarding two fall-back options, gas cooling and inhibition/PH modification, which can be implemented in the event that measured corrosion rates are higher than anticipated.

Most of the gas pipeline design codes utilize a class location system, where the design safety factor and the hydrostatic test factor are determined according to the population density in the vicinities of the pipeline route. Consequently, if an operator is requested or desires to maintain an existing gas pipeline in compliance with its design code, it will reduce the operational pressure or replace pipe sections to increase the wall thickness whenever a change in location class takes place. Cunha et al., (2009) presented an alternative methodology to deal with changes in location classes of gas pipelines.

Neshati et al., (2004) presented the acid- gas pipelines of a gas refinery were simulated in laboratory. Acid gas is normally the feed of sulfur recovery plant (SRP) in a gas refinery. For studying corrosion kinetic and related mechanisms the impedance spectroscopy was used. Impedance diagrams were simulated by Boukamp1988 software. It was found that the simulated systems can be equated to a circuit with two time constants. For studying corrosion rate changes a type of inhibitor was utilized. The inhibitor used in this work was an imidazoline, an appropriate based inhibitor formulated with the commercial grade imidazoline and dimmer - trimmer acid. It was shown that impedance spectroscopy technique can be used for corrosion monitoring of acid gas pipelines in gas refineries. The impedance spectroscopy will be tried in due course as a suitable technique in field for corrosion control of acid-gas pipelines.

Behbahani-Nejad and Baghen (2010) presented an efficient transient flow simulation for gas pipelines and networks. The proposed transient flow simulation is based on the transfer function models and MATLAB-Simulink. The equivalent transfer functions of the nonlinear governing equations are derived for different boundary conditions types. Next, a MATLAB-Simulink library is developed and proposed considering any boundary condition. To verify the accuracy and the computational efficiency of the proposed simulation, the results obtained are compared with those of the conventional finite difference schemes (such as total variation diminishing algorithms, method of lines, and other finite difference implicit and explicit schemes). The effect of the flow inertia is incorporated in this simulation.

Gas transmission pipelines are susceptible to both internal (gas side) and external (soil side) corrosion attack. Internal corrosion is caused by the presence of salt laden moisture, Mokhatab et al., (2003) presented a model with the main objective being the development of a relatively simple analytical algorithm for predicting flow temperature and pressure profiles along the two-phase, gas/gas-condensate transmission pipeline. Results demonstrate the ability of the method to predict reasonably accurate pressure gradient and temperature gradient profiles under operating conditions.

India began gas imports since 2004 through liquefied natural gas (LNG) route. Imports through trans-country gas pipelines could help in bringing gas directly into the densely populated Northern part of India, which are far from domestic gas resources as well as coastal LNG terminals. Yu et al., (2009) studied on the scenarios, which quantify the impacts for India of regional cooperation to materialize trans-country pipelines. The analysis covers time period from 2005 to 2030.

Gastner and Newman (2004) studied spatial networks that are designed to distribute or collect a commodity, such as gas pipelines or train tracks. The authors focused on the cost of a network, as represented by the total length of all its edges, and its efficiency in terms of the directness of routes from point to point. Using data for several real-world examples, we find that distribution networks appear remarkably close to optimal where both these properties are concerned. The authors proposed two models of network growth that offer explanations of how this situation might arise.

Volz et al., (2009) investigated the problem of designing a minimum cost flow network interconnecting n sources and a single sink, each with known locations and flows. The network may contain other unprescribed nodes, known as Steiner points. For concave increasing cost functions, a minimum cost network of this sort has a tree topology, and hence can be called a

Minimum Gilbert Arborescence (MGA). We characterize the local topological structure of Steiner points in MGAs for linear cost functions. This problem has applications to the design of drains, gas pipelines and underground mine access.

Carvalho et al., (2009) studied the load and vulnerability backbones of the Trans-European gas pipeline network. Combining topological data with information on inter-country flows, we estimate the global load of the network and its vulnerability to failures. To do this, the authors applied two complementary methods generalized from the betweenness centrality and the maximum flow. The authors found that the gas pipeline network has grown to satisfy a dual-purpose: on one hand, the major pipelines were crossed by a large number of shortest paths thereby increasing the efficiency of the network; on the other hand, a non-operational pipeline causes only a minimal impact on network capacity, implying that the network is error-tolerant. These findings suggest that the Trans-European gas pipeline network is robust, i.e. error-tolerant to failures of high load links.

Oil Sector plays a crucial role in the development of a country and provides the required balance and stability to the economy. Though traditionally coal has had the largest share in the energy basket in India, oil and gas as a source of energy have gradually gained importance and it is expected that oil and gas will continue to command a significant share in the years to come. Transportation of oil and gas by pipelines, which are recognized worldwide as the most reliable and cost effective mode for transportation is a developing business in India. With the increasing demand for oil and gas, a necessity has arisen for according priority attention to develop a well-spread out pipeline network throughout the country so as to facilitate efficient transportation to various consumption centres. Jha et al., (2008) studied a model to address the above.

Saudi Aramco pipelines network transports hydrocarbons to export terminals, processing plants and domestic users. This network faced several safety and operational-related challenges that require having a more effective Pipelines Integrity Management System (PIMS). Saad (2009) developed PIMS for Saudi Aramco on the basis of geographical information system (GIS) support through different phases, i.e., establishing the integrity management framework, risk calculation approach, conducting a gap analysis toward the envisioned PIMS, establishing the required scope of work, screening the PIMS applications market, and selecting suitable tools that satisfy expected deliverables, and implement PIMS applications. Saudi Aramco expects great benefits from implementing PIMS, e.g., enhancing safety, enhancing pipeline network robustness, optimizing inspection and maintenance expenditures, and facilitating pipeline management and the decision-making process. Saudi Aramco and Apos's new experience in adopting PIMS includes many challenges and lessons-learned associated with all of the PIMS development phases. These challenges include performing the gap analysis, conducting QA/QC sensitivity analysis for the acquired data, establishing the scope of work, selecting the appropriate applications and implementing PIMS.

The capacitated minimum spanning tree problem is to find a minimum spanning tree with an additional cardinality constraint on the number of nodes in any sub tree off a given root node. Luis and Pedro (2005) presented two improvements on a previous cutting-plane method proposed by Gouveia and Martins (Networks 35(1) (2000) 1)) namely, a new set of inequalities that can be seen as hop-indexed generalization of the well known generalized sub tour elimination (GSE) constraints and an improved separation heuristic for the original set of GSE constraints. Computational results show that the inclusion of the new separation routine and the inclusion of the new inequalities in Gouveia and Martins' iterative method (see (Networks 35(1)

(2000) 1)) produce improvements on previously reported lower bounds. Furthermore, with the improved method, several of previous unsolved instances have been solved to optimality.

The diameter-constrained minimum spanning tree problem consists in finding a minimum spanning tree of a given graph, subject to the constraint that the maximum number of edges between any two vertices in the tree is bounded from above by a given constant. This problem typically models network design applications where all vertices communicate with each other at a minimum cost, subject to a given quality requirement. Thiago et al., (2010) presented alternative formulations using constraint programming that circumvent weak lower bounds yielded by most mixed-integer programming formulations. Computational results show that the proposed formulation, combined with an appropriate search procedure, solves larger instances and is faster than other approaches in the literature.

Cuneyt (2006) presented a thesis which addressed two classes of well-known network optimisation problems; those of finding minimum cost multi-commodity flow networks and those of finding centralised tree-like networks. Five specific problems falling into these broad categories have been solved. The first two problems are closely related versions of the minimum concave-cost multi-commodity network design. In a telecommunications context, the networks are undirected and large numbers of commodities may be involved. A modification of an existing greedy heuristic is proposed leading to better quality solutions. For directed networks, the problem can take the form of non-linear cost transshipment. Following an improvement over an existing method, it is solved using the recently developed Tabu search metaheuristic. The second part of the thesis studies three selected graph problems on centralized networks and their solutions with special emphasis on practical performance. The problems investigated include the ordinary incapacitated minimum spanning tree, the minimum spanning tree verification and the capacitated minimum spanning tree. There have been remarkable achievements over the last two decades in inventing faster and faster minimum spanning tree algorithms. A comprehensive survey and an empirical comparative study are carried out on both the classical and modern methods for solving the ordinary incapacitated case. The linear-time solution of the verification problem is important since it arises as a sub problem in a recently developed linear-time minimum spanning tree algorithm. A linear-time implementation of an existing verification approach, which until recently was thought not to be possible, is proposed. It simplifies the previous techniques significantly. Finally, a study of the capacitated minimum spanning tree problem, which is devoted mainly to investigating the Lagrangean relaxation based lower bounding schemes and developing a branch and bound strategy using a directed formulation, is presented.

Franz (2005) presented an experimental investigation into the properties of the optimal communication spanning tree (OCST) problem. The OCST problem seeks a spanning tree that connects all the nodes and satisfies their communication requirements at a minimum total cost. The paper compares the properties of random trees to the properties of the best solutions for the OCST problem that are found using an evolutionary algorithm. The results show, on average, that the optimal solution and the minimum spanning tree (MST) share a higher number of links than the optimal solution and a random tree. Furthermore, optimal solutions for OCST problems with randomly chosen distance weights share a higher number of links with an MST than OCST problems with Euclidean distance weights. This intuitive similarity between optimal solutions and MSTs suggests that some heuristic optimization methods for OCST problems might be improved by starting with an MST. Using an MST as a starting solution for a greedy search in the tested cases either improves median running time up to a factor of 10 while finding solutions of the same quality, or increases solution quality up to a factor of 100 while using the same number of search steps in comparison to starting the greedy search from a random tree. Starting a local search a simulated annealing approach and a genetic algorithm from an MST increases solution quality up to a factor of three in comparison to starting from a random solution.

Xiong (2005) presented a dissertation research which involved combinatorial optimization. This is a key area in operations research and computer science. It includes lots of problems that have a wide variety of real-world applications. In addition, most of these problems are inherently difficult to solve. My specific dissertation topic is the Minimum Labeling Spanning Tree (MLST) problem and some variants, including the Label-Constrained Minimum Spanning Tree (LC-MST) problem and the Colorful Traveling Salesman Problem (CTSP). All of the three problems are NP-hard. The MLST problem tries to find a spanning tree of a graph with the smallest number of labels. The LC-MST problem tries to find the minimum-cost spanning tree of a graph with no more than K labels. The CTSP tries to find a Hamiltonian cycle of a graph with the smallest number of labels. For each of the problems, we use both heuristic and genetic algorithms to solve them. From the computational results, the genetic algorithm can always obtain a better trade-off between the solution quality and the running time. My dissertation research shows that the genetic algorithm can be successfully applied to solve many NP-hard problems.

Aili and Daming (2006) devised a Deoxyribonucleic Acid (DNA) encoding method and a corresponding DNA algorithm for the minimum spanning tree problem, an instance of optimization problems on weighted graphs. In order to find out the minimum spanning trees of a weighted graph G= (V, E, W) by means of molecular biology techniques, the authors encoded each vertex $v_i$isinV using one recognition code of length l, l= max {[$\log_4 n$], 6}; they encode each edge e_{ij}isinE using two DNA strands of length 2p=2max {w_{ij}, l}; for any two adjacent edges $e_{ij}e_{jk}$ we add one DNA strand s_{aijk} of length w_{ij} +W_{jk} as an additional code. They also presented a DNA algorithm for the minimum spanning tree problem based on the proposed DNA encoding method, in which we firstly obtain the Euler cycle corresponding to the minimum spanning tree by means of the molecular biology techniques, and then the Euler cycle is converted to the minimum spanning tree. Their work provides further evidence for the ability of DNA computing to solve numerical optimization problems.

Minimum Spanning Trees (MST) problem is a classical problem in operation research and network design problem is an important application of it. Minimum Spanning Tree (MST) problem can be solved efficiently, but its Bi-objective versions are NP hard. Sanger and Agawal (2010) compared three tree encoding schemes using Bi-objective evolutionary algorithm. Three different tree encoding methods in the evolutionary algorithms are being used to solve three different instances of Bi-objective Minimum Spanning Tree problem; comparative study of the tree encoding schemes used is done on the basis of Pareto optimal front obtained. Our approach involves Bi-objective Minimum Spanning Tree problem using Non-dominated Sorting Genetic Algorithm II (NSGAII). We compare Edge Set encoding, Pru

A processor array with a reconfigurable bus system is a parallel computation model that consists of a processor array and a reconfigurable bus system. Pan and Lin (2001), a constant-time algorithm is proposed on this model for finding the cycles in an undirected graph. We can use this algorithm to decide whether a specified edge belongs to the minimum spanning tree of the graph or not. This cycle-finding algorithm is designed on a two-dimensional $n\times n$ processor array with a reconfigurable bus system, where n is the number of vertices in the graph. Based on this cycle-finding algorithm, the minimum spanning tree problem and the spanning tree problem can be solved in O(1) time by using fewer processors than before, O($n\times m\times n$) and O(n^3) processors respectively. This is a substantial improvement over previous known results. Moreover, we also propose two constant-time algorithms for solving the minimum spanning tree verification problem and spanning tree verification problem by using O(n^3) and O(n^2) processors, respectively.

There are several parallel implementations of Prim's algorithm. Kumar et. al., (2003) pointed out that the main outer while loop of serial Prim is very difficult to run in parallel. But one can find nearest outside node in parallel by Min-Reduction and also the update-keys step can be done in parallel. The adjacency matrix is partitioned in a 1-D block fashion. (Each processor has $n \times n/P$ of the adjacency matrix and n/p of the Key Array). Each processor finds the locally nearest node, a global min reduction is done and main thread adds the nearest node to the tree and the row entry of this node in adjacency matrix is broadcast to all processors.

Gonina et al., (2007) follows a very similar algorithm but instead of adding one node to the current tree, their algorithm tries to add more nodes to the tree in every pass by doing some extra computation. The algorithm finds locally K nearest outside nodes and global Min-Reduction is done to obtain globally closest K nodes. The algorithm then iterates through the list to find out whether they are valid or not.

Bader et al., (2006) came up with a nondeterministic shared memory algorithm which uses a hybrid approach of Borůvka and Prim algorithm. Each processor chooses a root node and grows tree in similar fashion of serial Prim approach and when the tree finds a nearest node that doesn't belong to any other tree it can add the node, whereas if the node belongs to another tree then it must stop growing and start with a new root. In the end, we get different connected components (which are trees) and some isolated vertices. No two trees share a vertex because merging was avoided. Now Find-Min step of Borůvka Algorithm is used to shrink each of the components into a super node.

Tiago et al., (2005) studied the minimum spanning tree problem with fuzzy parameters and an Exact Algorithm was proposed to solve it. However, as this problem conveys the need of large number of comparisons, a Genetic Algorithm with special characteristics is proposed to try to avoid the complexity issue. These algorithms use Possibility Theory (Holland, 1975), searching for the solution set.

The route of transcontinental natural gas pipelines is characterized by complexity, compared to national and cross-border pipelines, since their large magnitude results in the examination of parameters that do not exist or are considered negligible for pipelines of smaller scale and that require management of more information. Fotios (2006) presented a dissertation with the aim of is the development of a route selection method, able to deal with the aforementioned complexity of transcontinental pipelines. The developed algorithm examines the validity of the conditions for economic viability of the pipeline, defines the alternative routes, selects the weights of criteria that affect the pipeline design and compares the routes, taking into consideration the available data, the experience and knowledge of the decision maker. The consistency and sensitivity of the results is examined. The method is applied in the case of a transcontinental pipeline transporting gas from the broader Caspian Region to Western Europe. Different scenarios of criteria weights are used and discussed at the results of the application. The software tool Gas-PRS, allows quick application of the method and facilitates the decision maker in examining the consequences of different choices.

Minimum spanning tree (MST) computation on a general graph is an irregular algorithm. Regular, data-parallel algorithms map well to the SIMD architecture of cell BE. Irregular algorithms on discrete structures like graphs are harder to map to them. Obtaining efficient parallel implementations for irregular graph problems always remains a challenge. Mittal et al., (2009) presented a parallel implementation of MST on multi-core Cell Broadband Engine Architecture by utilizing the cell architecture potentials including DNA transfer, double buffering, mailboxes and at the same time considering the architecture limitations including memory constrains and thread synchronization. The implementation achieves up to 7 times speedup over sequential implementation.

The Euclidean Minimum Spanning Tree problem has applications in a wide range of fields, and many efficient algorithms have been developed to solve it. March et al., (2009) presented a new, fast, general EMST algorithm, motivated by the clustering and analysis of astronomical data. Large-scale astronomical surveys, including the Sloan Digital Sky Survey, and large simulations of the early universe, such as the Millennium Simulation, can contain millions of points and fill terabytes of storage. Traditional EMST methods scale quadratically, and more advanced methods lack rigorous runtime guarantees. We present a new dual-tree algorithm for efficiently computing the EMST, use adaptive algorithm analysis to prove the tightest (and possibly optimal) runtime bound for the EMST problem to-date, and demonstrate the scalability of our method on astronomical data sets.

The Multi period Minimal Spanning Tree (MMST) problem consists of scheduling the installation of links in a network so as to connect a set of terminal nodes to a central node with minimal present value of expenditures. Some of the terminal nodes are available in the network at the beginning of the planning horizon while others are added over time. Kawatra (2006) formulated this problem as an integer programming problem. The author suggested a Lagrangean based heuristic to solve the integer programming formulation of the network topology problem. Lower bounds found as a by product of the solution procedure are used to estimate the quality of the solution given by the heuristic. Experimental results over a wide range of problem structures show that the Lagrangean based heuristic method yields verifiably good solutions to this hard problem.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

This chapter provides discussions of the methods for solving minimum spanning tree problems. In order to understand the methods for solving the minimum spanning tree problems, it is necessary to have a good understanding of some of the background graph theory for combinatorial optimization problems.

Suppose we are given a connected, undirected, weighted graph. This is a graph

G = (V, E) together with a function w: E

3.1 GRAPH THEORY.

DEFINITION: A graph theory is the study of points and lines. In particular, it involves the ways in which set of points, called vertices, can be connected by lines or edges, called edges. Graphs in this context differ from the more familiar coordinate plots that portray mathematical relations and functions.

DEFINITION: UNDIRECTED GRAPHS

An undirected graph is a graph in which the nodes are connected by undirected arcs. An undirected arc is an edge that has no arrow. Both ends of an undirected arc are equivalent--there is no head or tail. Therefore, we represent an edge in an undirected graph as a set rather than an ordered pair:

An undirected graph is an ordered pair G = (V, E) with the following properties:

(i)The first component, V, is a finite, non-empty set. The elements of V are called the vertices of *G*.

(ii)The second component, E, is a finite set of sets. Each element of E is a set that is comprised of exactly two (distinct) vertices. The elements of E are called the edges of *G*.

DEFINITION: A path is a simple graph whose vertices can be ordered so that two vertices are adjacent if and only if they are consecutive in the list.

DEFINITION: DIRECTED, DIGRAPH

Directed or digraph is a graph in which each edge symbolizes an ordered, non-transitive relationship between two nodes. Such edges are rendered with an arrowhead at one end of a line or arc.

DEFINITION: DEGREE

Degree is the number of edges which connect a node.

In Degree is the number of edges pointing to a node.

Out Degree is the number of edges going out of a node.

DEFINITION: WEIGHTED GRAPHS

A weighted graph is a graph in which each edge has a weight (some real numbers). The weight of a graph is the sum of all the weights of all edges.

DEFINITION: CONNECTED GRAPHS

A graph is called connected if given any two vertices V_i, V_j, there is a path from V_i to V_j.

THEOREM: Every connected graph has a spanning tree.

DEFINITION: SPANNING TREES

A sub graph T of an undirected graph G = (V, V) is a spanning tree of G if it is a tree and contains every vertex of G.

3.1.1 MINIMUM SPANNING TREE

Given a connected undirected graph $G = (V,E)$ with real edge costs $c : E \rightarrow$R+. A minimum spanning tree (MST) of G is defined by a set T

Minimum spanning trees are perhaps the simplest variant of an important family of problems known as network design problems. Because MSTs are such a simple concept, they also show up in many seemingly unrelated problems such as clustering, finding paths that minimize the maximum edge cost used, and finding approximations for harder problems.

3.1.2 CUT AND CYCLE PROPERTIES

Two simple Lemmas allow one to add edges to an MST and to exclude edges from consideration for an MST. To do this we need the concept of a cut in a graph. A cut in a connected graph is a subset E' of edges such that $G \setminus E'$ is not connected. Here, $G \setminus E'$ is an abbreviation for $(V, E \setminus E')$. If S is a set of nodes with

Proof: Consider any MST T of G. Suppose T contains $e = (u,v)$. Edge e splits T into two sub trees T_u and T_v. There must be another edge $e' = (u',v')$ from C such that u′

halts, F consists of a single n-node tree, which must be the minimum spanning tree. Obviously, we have to be careful about which edges we add to the evolving forest, since not every edge is in the minimum spanning tree.

The intermediate spanning forest F induces two special types of edges. An edge is useless if it is not an edge of *F*, but both its endpoints are in the same component of F. For each component of F, we associate a safe edge—the minimum-weight edge with exactly one endpoint in that component. Different components might or might not have different safe edges. Some edges are neither safe nor useless—we call these edges undecided.

All minimum spanning tree algorithms are based on two simple observations.

Lemma 3.3. The minimum spanning tree contains every safe edge and no useless edges.

Proof: Let *T* be the minimum spanning tree. Suppose *F* has a 'bad' component whose safe edge $e = (u, v)$ is not in *T*. Since *T* is connected, it contains a unique path from *u* to *v*, and at least one edge *e*` on this path has exactly one endpoint in the bad component. Removing *e*` from the minimum spanning tree and adding *e* gives us a new spanning tree. Since *e* is the bad component's safe edge, we have $w(e`) > w(e)$, so the the new spanning tree has smaller total weight than *T*. But this is impossible—*T* is the minimum spanning tree. So *T* must contain every safe edge.

Adding any useless edge to *F* would introduce a cycle. So our generic minimum spanning tree algorithm repeatedly adds one or more safe edges to the evolving forest *F*. Whenever we add new edges to *F*, some undecided edges become safe, and others become useless. To specify a particular algorithm, we must decide which safe edges to add, and how to identify new safe and new useless edges, at each iteration of our generic template.

3.2.1 Boruvka’s Algorithm

The oldest and arguably simplest minimum spanning tree algorithm was discovered by Boruvka in 1926, long before computers even existed, and practically before the invention of graph theory. The algorithm was rediscovered by Choquet in 1938; again by Florek et al.,1951; and again by Sollin some time in the early 1960s. Because Sollin was the only Western computer scientist in this list—Choquet was a civil engineer; Florek and his co-authors were anthropologists—this is often called ‘Sollin’s algorithm’, especially in the parallel computing literature.

The Bor˙uvka/Choquet/Florek/Łukaziewicz/Perkal/Stienhaus/Zubrzycki/Sollin algorithm can be summarized in one line:

BOR˙UVKA: Add all the safe edges and recurse.

At the beginning of each phase of the Boruvka algorithm, each component elects an arbitrary ‘leader’ node. The simplest way to hold these elections is a depth-first search of F; the first node we visit in any component is that component’s leader. Once the leaders are elected, we find the safe edges for each component, essentially by brute force. Finally, we add these safe edges to F.

The Algorithm

BORU VKA(V, E):

F = (V, ∅)

while F has more than one component

choose leaders using DFS

FINDSAFEEDGES(V, E)

for each leader

finally by Dijkstra in 1958. Prim, Loberman, Weinberger, and Dijkstra all (eventually) knew of and even cited Kruskal's paper, but since Kruskal also described two other minimum-spanning-tree algorithms in the same paper, this algorithm is usually called 'Prim's algorithm', or sometimes even 'the Prim/Dijkstra algorithm', even though by 1958 Dijkstra already had another algorithm (inappropriately) named after him. In Jarník's algorithm, the forest F contains only one nontrivial component T; all the other components are isolated vertices. Initially, T consists of an arbitrary vertex of the graph. The algorithm repeats the following step until T spans the whole graph:

JARNÍK: Find T's safe edge and add it to T.

To implement Jarník's algorithm, we keep all the edges adjacent to T in a heap. When we pull the minimum-weight edge off the heap, we first check whether both of its endpoints are in T. If not, we add the edge to T and then add the new neighbouring edges to the heap. In other words, Jarník's algorithm is just another instance of the generic graph traversal algorithm we saw last time, using a heap as the 'bag'! If we implement the algorithm this way, its running time is $O(E \log E) = O(E \log V)$.

However, we can speed up the implementation by observing that the graph traversal algorithm visits each vertex only once. Rather than keeping edges in the heap, we can keep a heap of vertices, where the key of each vertex v is the length of the minimum-weight edge between v and T (or 1 if there is no such edge). Each time we add a new edge to T, we may need to decrease the key of some neighbouring vertices.

To make the description easier, we break the algorithm into two parts. JARNÍKINIT initializes the vertex heap. JARNÍKLOOP is the main algorithm. The input consists of the vertices and edges of the graph, plus the start vertex *s*.

JARNÍK(*V*, *E*, *s*):

JARNÍKINIT(*V*, *E*, *s*)

JARNÍKLOOP(*V*, *E*, *s*)

JARNÍKINIT(*V*, *E*, *s*):

for each vertex v

for each edge (u, v)
add v and edge(v) to T
← EXTRACTMIN

v

Since we examine the edges in order from lightest to heaviest, any edge we examine is safe if and only if its endpoints are in different components of the forest *F*. To prove this, suppose the edge *e* joins two components *A* and *B* but is not safe. Then there would be a lighter edge *e*0 with exactly one endpoint in *A*. But this is impossible, because (inductively) any previously examined edge has both endpoints in the same component of *F*. Just as in Boruvka's algorithm, each component of *F* has a 'leader' node. An edge joins two components of *F* if and only if the two endpoints have different leaders. But unlike Boruvka's algorithm, we do not recompute leaders from scratch every time we add an edge. Instead, when two components are joined, the two leaders duke it out in a nationally-televised no-holds-barred steel-cage grudge match. One of the two emerges victorious as the leader of the new larger component. More formally, we will use our earlier algorithms for the UNION-FIND problem, where the vertices are the elements and the components of *F* are the sets. Here's a more formal description of the algorithm:

KRUSKAL(*V*, *E*):

sort *E* by weight

F

UNION (u, v)

add (u, v) to F

return F

THE STEINER TREE PROBLEM

We are given a non-negatively weighted undirected graph G = (V, E) and a set S of nodes. The goal is to find a minimum-cost subset T of the edges that connects the nodes in S. Such a T is called a minimum Steiner tree. It is a tree connecting a set U with S

Euclidean space and thus infinite. Usually the metric is given by the Euclidean Distance (L^2-norm). That is, for two points with coordinates (x_1; y_1) and (x_2; y_2), the distance is

Add sub paths from u to p_i and from p_j to v to T.

Output T.

CHAPTER FOUR

DATA COLLECTION AND ANALYSIS

4.0 INTRODUCTION

In this chapter, the Prim's algorithm shall be used to solve a minimum connector problem.

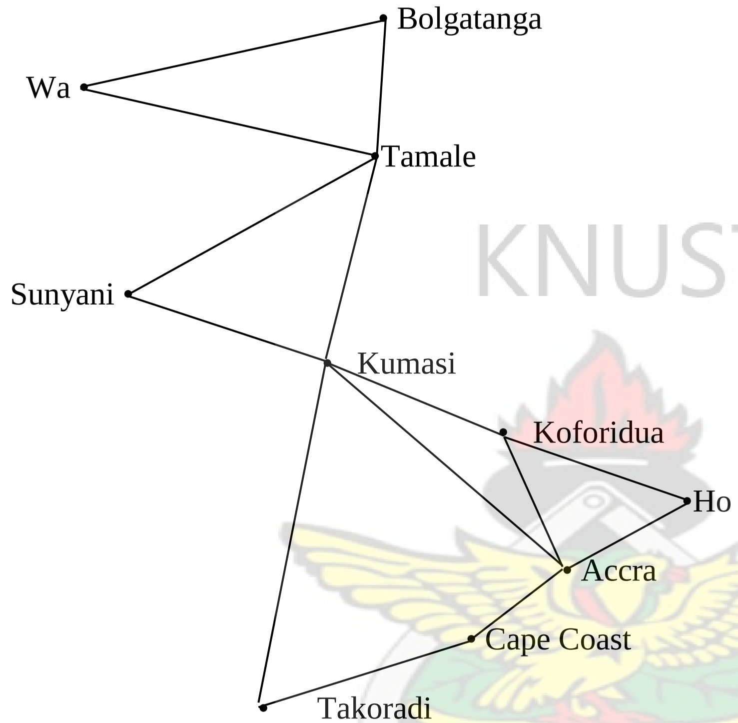
The minimum connector problem is a real practical problem in the gas pipeline construction industry.

The aim is to determine the minimum distance linking all the regional capitals of Ghana from Tema/Takoradi so as to reduce cost and delivery time of gas through the pipelines to all these points.

The gas distribution industry in Ghana today is heavily dependent on gas tankers. This creates a lot of problem at the loading bay as tankers wait in long queues to be filled. The delivery time is also delayed as tankers have to travel long distances to get to the gas filling stations where consumers buy their gas. Drivers also lose their lives in times of accident. All these are manifested in the popular “NO GAS” sign boards at the gas filling stations in Ghana.

4.1 DATA COLLECTION AND ANALYSIS

The network below shows the distances in kilometers connecting all the regional capitals of Ghana.



The distances between the various regional capitals of Ghana are presented in table 4.0.2. Where there is no direct connection, the distance is represented with ∞. Determine the shortest distance connecting Tema (Accra)/Takoradi to all the regional capitals.

Table 4.0.2 Distances between the Capital Towns in Ghana. Courtesy: Ghana Highways Authority

	Acc	K’si	K’dua	T’di	S’nyani	T’male	C.Coast	Wa	Ho	Bolg
ACCRA	∞	270	85	∞	∞	∞	144	∞	165	∞
KUMASI	270	∞	194	242	130	388	∞	∞	∞	∞
KOFORIDUA	85	194	∞	∞	∞	∞	∞	∞	162	∞

TAKORADI	∞	242	∞	∞	∞	∞	74	∞	∞	∞
SUNYANI	∞	130	∞	∞	∞	300	∞	∞	∞	∞
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170
C. COAST	144	211	∞	∞	∞	∞	∞	∞	∞	∞
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
HO	165	∞	162	∞	∞	∞	∞	∞	∞	∞
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞

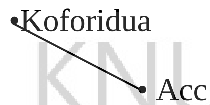
Choose a starting vertex say Accra (Tema). Delete the row Accra. Look for the smallest entry in column Acc.

1

	Acc	**K'si**	**K'dua**	**T'di**	**S'nyani**	**T'male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
~~**ACCRA**~~	~~∞~~	~~270~~	~~85~~	~~∞~~	~~∞~~	~~∞~~	~~144~~	~~∞~~	~~165~~	~~∞~~
KUMASI	270	∞	194	242	130	388	∞	∞	∞	∞
KOFORIDUA	85	194	∞	∞	∞	∞	∞	∞	162	∞
TAKORADI	∞	242	∞	∞	∞	∞	74	∞	∞	∞
SUNYANI	∞	130	∞	∞	∞	300	∞	∞	∞	∞

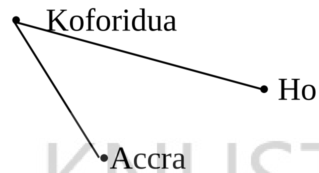
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170
C. COAST	144	211	∞	∞	∞	∞	∞	∞	∞	∞
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
HO	165	∞	162	∞	∞	∞	∞	∞	∞	∞
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞

Accra Koforidua is the smallest edge joining Accra to other vertices. Put edge Accra Koforidua in to the solution. Delete row Koforidua. Look for the smallest entry in column Acc and K'dua.



	1 ⇩		2 ⇩							
	Acc	**K'si**	**K'dua**	T'di	**S'nyani**	**T'male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
KUMASI	270	∞	194	242	130	388	∞	∞	∞	∞
~~**KOFORIDUA**~~	85	194	∞	∞	∞	∞	∞	∞	162	∞
TAKORADI	∞	242	∞	∞	∞	∞	74	∞	∞	∞
SUNYANI	∞	130	∞	∞	∞	300	∞	∞	∞	∞
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170

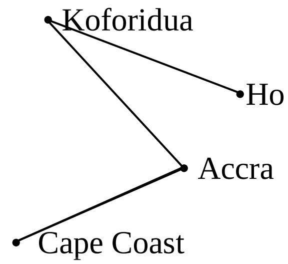
C. COAST	144	211	∞	∞	∞	∞	∞	∞	∞	∞
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
HO	165	∞	162	∞	∞	∞	∞	∞	∞	∞
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞



Koforidua Ho is the smallest edge joining Accra Koforidua to other vertices. Put Koforidua Ho in to the solution. Delete row Ho. Look for the smallest entry in columns Accra, Koforidua and Ho.

	1 ⇩		2 ⇩						3 ⇩	
	Acc	**K'si**	**K'dua**	**T'di**	**S'nyani**	**T'male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
KUMASI	270	∞	194	242	130	388	∞	∞	∞	∞
TAKORADI	∞	242	∞	∞	∞	∞	74	∞	∞	∞
SUNYANI	∞	130	∞	∞	∞	300	∞	∞	∞	∞
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170
C. COAST	144	211	∞	∞	∞	∞	∞	∞	∞	∞
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368

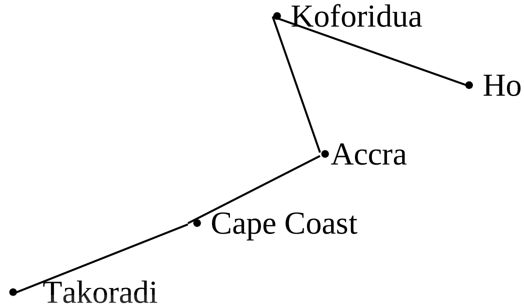
~~**HO**~~	~~165~~	~~∞~~	~~162~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞



Accra Cape Coast is the smallest edge joining Koforidua Ho to other vertices. Put edge Accra Cape Coast in to the solution. Delete row C. Coast. Look for the smallest entry in columns Acc, K'dua, Ho and C. Coast.

	1 ⇩		2 ⇩				4 ⇩	3 ⇩		
	Acc	**K'si**	**K'dua**	**T'di**	**S'nyani**	**T'male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
KUMASI	270	∞	194	242	130	388	∞	∞	∞	∞
TAKORADI	∞	242	∞	∞	∞	∞	74	∞	∞	∞
SUNYANI	∞	130	∞	∞	∞	300	∞	∞	∞	∞
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170
~~**C. COAST**~~	~~144~~	~~211~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~

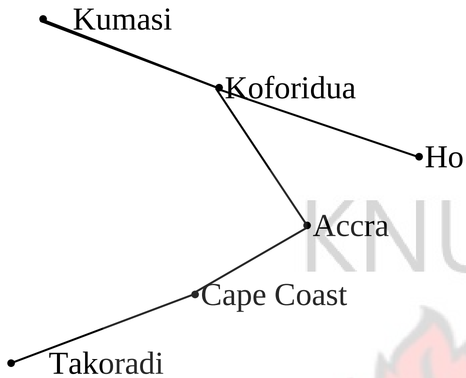
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞



Cape Coast Takoradi is the smallest edge joining Accra Koforidua Ho and Cape Coast to other vertices. Put edge Cape Coast Takoradi in to the solution. Delete row Takoradi. Look for the smallest entry in columns Acc, K'dua, Ho, C. Coast and Takoradi.

	1 ⇩		2 ⇩	5 ⇩			4 ⇩		5 ⇩	
	Acc	**K'si**	**K'dua**	**T'di**	**S'nyani**	**T'male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
KUMASI	270	∞	194	242	130	388	∞	∞	∞	∞
~~**TAKORADI**~~	~~∞~~	~~242~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~74~~	~~∞~~	~~∞~~	~~∞~~
SUNYANI	∞	130	∞	∞	∞	300	∞	∞	∞	∞

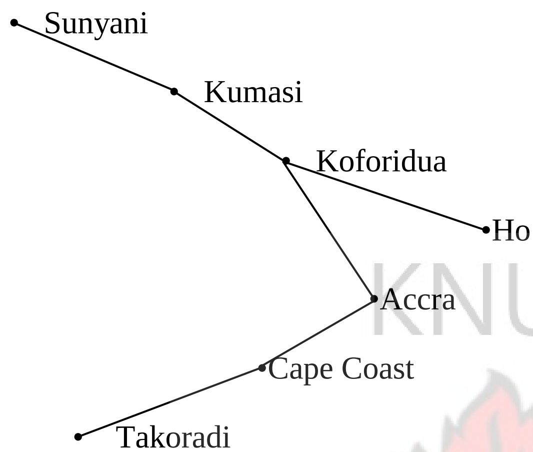
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞



Koforidua Kumasi is the smallest edge joining Accra, Koforidua, Ho, Cape Coast and Takoradi. Put the edge Koforidua Kumasi in to the solution. Delete row Kumasi. Look for the smallest entry in columns Acc, K’dua, Ho, C. Coast, Takoradi and K’si.

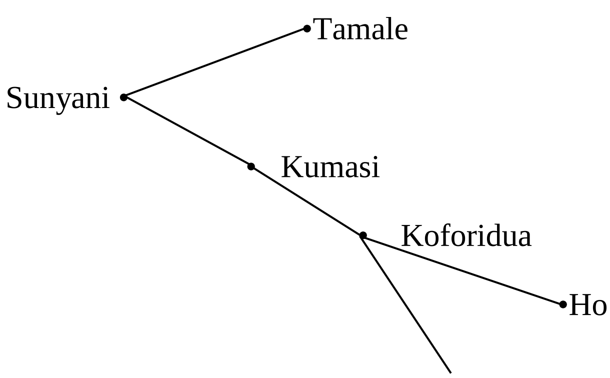
	1 ⇩	6 ⇩	2 ⇩	5 ⇩			4 ⇩		3 ⇩	
	Acc	**K’si**	**K’dua**	**T’di**	**S’nyani**	**T’male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
~~**KUMASI**~~	~~270~~	~~∞~~	~~194~~	~~242~~	~~130~~	~~388~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~
SUNYANI	∞	130	∞	∞	∞	300	∞	∞	∞	∞
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170

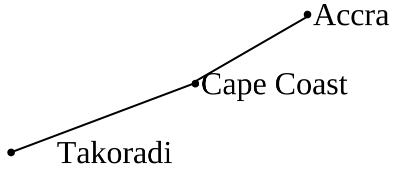
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞



Kumasi Sunyani is the smallest edge joining Accra, Koforidua, Ho, Cape Coast, Takoradi and Kumasi. Put edge Kumasi Sunyani in to the solution. Delete row S'nyani. Look for the smallest entry in the columns Acc, K'dua, Ho, C. Coast, Takoradi, K'si and S'nyani.

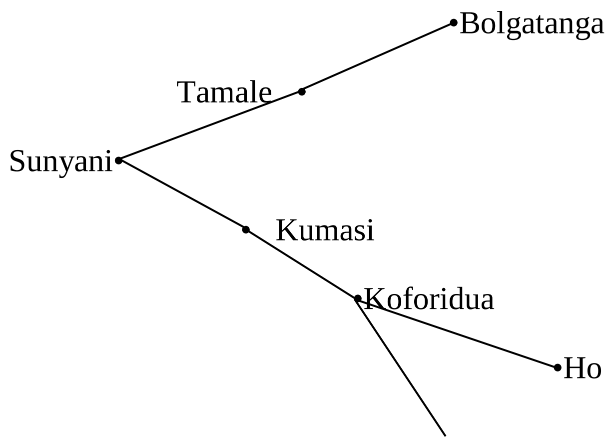
	1 ⇩	6 ⇩	2 ⇩	5 ⇩	7 ⇩	8 ⇩	4 ⇩		3 ⇩	
	Acc	**K'si**	**K'dua**	**T'di**	**S'nyani**	**T'male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
~~**SUNYANI**~~	~~∞~~	~~130~~	~~∞~~	~~∞~~	~~∞~~	~~300~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~
TAMALE	∞	388	∞	∞	300	∞	∞	314	∞	170
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞

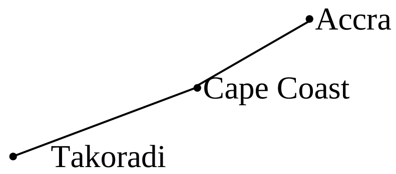




Sunyani Tamale is the smallest edge joining Accra, Koforidua, Ho, Cape Coast, Takoradi, K’si and Sunyani. Put edge Sunyani Tamale in to the solution. Delete row T’male. Look for the smallest entry in the columns Acc, K’dua, Ho, C. Coast, Takoradi, K’si and S’nyani and T’male.

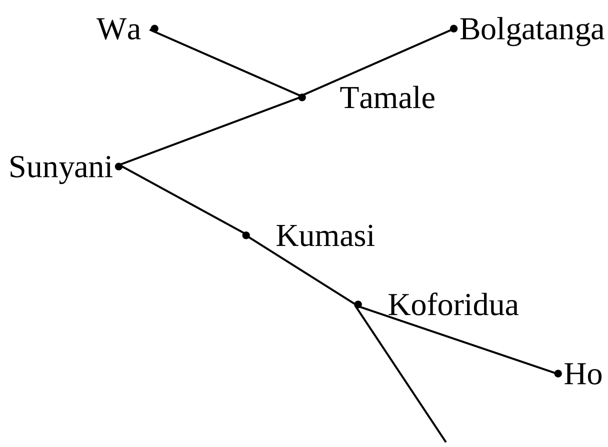
	1 ⇩	6 ⇩	2 ⇩	5 ⇩	7 ⇩	8 ⇩	4 ⇩		3 ⇩	
	Acc	**K’si**	**K’dua**	**T’di**	**S’nyani**	**T’male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
~~**TAMALE**~~	~~∞~~	~~388~~	~~∞~~	~~∞~~	~~300~~	~~∞~~	~~∞~~	~~314~~	~~∞~~	~~170~~
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
BOLGA	∞	∞	∞	∞	∞	170	∞	360	∞	∞

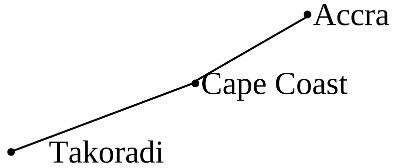




Tamale Bolgatanga is the smallest edge joining Accra, Koforidua, Ho, Cape Coast, Takoradi, K’si and Sunyani and Tamale to the other vertices. Put edge Tamale Bolgatanga in to the solution. Delete row Bolga. Look for the smallest entry in the columns Accra, Koforidua, Ho, Cape Coast, Takoradi, K’si, S’nyani, T’male and Bolga.

	1 ⇩	6 ⇩	2 ⇩	5 ⇩	7 ⇩	8 ⇩	4 ⇩		3 ⇩	9 ⇩
	Acc	**K’si**	**K’dua**	**T’di**	**S’nyani**	**T’male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
WA	∞	∞	∞	∞	∞	314	∞	∞	∞	368
~~**BOLGA**~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~170~~	~~∞~~	~~360~~	~~∞~~	~~∞~~





T’male Wa is the smallest edge joining Accra, Koforidua, Ho, Cape Coast, Takoradi, K’si, S’nyani, T’male and Bolga to the other vertices. Put T’male Wa in to the solution.

	Acc	**K’si**	**K’dua**	**T’di**	**S’nyani**	**T’male**	**C.Coast**	**Wa**	**Ho**	**Bolg**
~~**WA**~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~314~~	~~∞~~	~~∞~~	~~∞~~	~~368~~

We have now connected all the vertices (capital towns) in to the spanning tree.

Length=85+162+144+74+242+130+300+170+314=1621km.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.0.1 INTRODUTION

The main aim of this chapter is to present an overall summary of the main concepts covered in this thesis, the use of Prim’s algorithm for finding the minimum connector of pipelines from Tema / Takoradi to all the regional capitals in Ghana.

5.0.1 FINDINGS AND CONCLUSIONS

Prim’s algorithm for minimum spanning tree solution of the pipeline from Tema/Takoradi to all the regional capitals in Ghana resulted in a pipeline distance of 1621 km. The Minimum Spanning Tree (MST) length obtained is from the segment addition result of Acc K’dua + K’dua Ho + Acc C. Coast + C. Coast T’di + T’di K’si + K’si S’nyani +S’nyani T’male +T’male Bolga + T’male Wa.

5.0.2 RECOMMENDATIONS

Prim’s algorithm gives a good reduction in distance over other Minimum Spanning Tree methods. We therefore recommend it to the contractors in the gas pipeline construction industry as it would help reduce cost and time involved in the construction of the pipelines. We recommend the findings above to the Ghana Gas Company in the construction of pipelines that will link all the capital towns of Ghana.

We also recommend that gas pipelines be constructed to all district capitals and eventually to all small towns and villages so that transportation of natural gas by gas tankers would become a thing of the past.

Like electricity, we recommend that gas pipelines be extended to individual households to encourage the people to use gas for domestic purpose. This would help the nation reduce the use of charcoal and firewood to the barest minimum and help save the environment from desertification.

Furthermore, we recommend that massive education on bush fires be conducted in all the communities where the pipeline would pass to safeguard lifespan of the pipeline and also save lives and properties of the people in these communities.

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