MINIMUM CONNECTION OF GAS PIPELINES FROM TAKORADI TO ALL THE REGIONAL CAPITAL TOWNS IN GHANA

By

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Institute of Distance Learning

CERTIFICATION

I hereby declare that this submission is my own work towards the M.Sc. 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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DEDICATION

To the King Eternal without whom I can do nothing

To my mother, my wife: Saviour Adzimani and all my siblings for their support.

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The completion of this research represents the realization of a long awaited dream.

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ABSTRACT

The demand for the use of natural gas is on the increase as an energy source. Natural gas transportation requires a continuous pipeline network from the source of gas across long distance to the various destinations. The main objective involves extending gas pipelines from Takoradi to all the regional capital towns in Ghana by developing a straight forward method of locating pipeline facilities and designing pipeline networks to minimize cost and distance covered. The problem is formulated as a network of distances and the solution is presented based on Prim's Algorithm for minimum connections. Data on distances are obtained from the Ghana Highways Authority. In comparison, the total distance in the original network was reduced drastically by 68.79% to the new network. Solutions are provided for the environmental damages revealed by the gas pipeline network.

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CHAPTER 1

1.0 INTRODUCTION

Natural Gas is an essential source of energy all over the world. Ghana is one of the developing countries in Africa whose dependants are increasingly depending on the use of Natural Gas. The West Africa Gas Pipelines Project from Nigeria down to Ghana-Takoradi was developed to facilitate the free flow of the Gas. The recent oil find in the west region of Ghana has contributed to the production of the Natural Gas. This Gas has to be made available at a cheaper cost to all consumers. This can only be done when the Gas is transmitted from the source to the consumers via pipelines at a minimum cost. The pipelines are connected in network form to enable the free flow of the natural gas from one place to another. There are several ways networks are used: Telephone networks, Manufacturing and Distribution networks, and Computer networks. The networking must be done efficiently to provide the consumers good service. To minimize these network connections constitute the domain of shortest path problems.

The shortest path problems are the most fundamental and commonly encountered problems in the study of transportation and communication network. All the networks are made up of nodes (vertices) and arcs. One can move from one node along some edges to some other node. Since all edges have length a shortest path is the one that has the smallest number of edges among all paths. Similarly, a longest path is the one for which that sum is maximum. In some applications, one requires not only the shortest path but also the second and the third shortest paths. The research seeks to determine the shortest distances (and paths) from node to every other node in the network.

Pipelines networks are not typically designed by transportation engineers. Perhaps, it is not surprising then that the subject of pipelines has not received the required attention from transportation researchers. Optimization of pipeline operation has traditionally been approached from inside the pipeline. Understanding flow in pipes is a common example of this focus. This thesis cast a different light on the gas pipeline optimization problem by looking at it from the perspective of an operation researcher and an industrial mathematician: How can the design of the gas pipeline network layout made efficiently? (Donkoh, 2010)

Natural gas pipelines demand optimal design and layout since natural gas is one of the most important energy sources used in the world. Normally, natural gas is supplied to users through natural gas pipeline system .Many pipeline systems are built throughout the world , from the gas reservoir to the end users in order to support the highly increasing demand for natural gas. In America alone, from 1996 to 1998, at least 78 pipeline construction projects were completed adding approximately 11.7 billion cubic feet per day of capacity (Energy Information Administration, USA-1998). Meanwhile in Malaysia, as of January 2004, network of gas pipeline covering a total of 831.7 kilometers had been completed, and this is constantly being expanded to reach a larger population (Hwee, 2007).

Ghana is located in West Africa of which Togo, Burkina Faso and Cote d'Ivoire form the eastern, northern and western boundaries respectively. The south of it is the Gulf of Guinea. Geographically, Ghana is divided into ten regions with their capital towns. The region and their capital towns to which the gas pipelines are to be connected from the Western Region -Takoradi are: Upper West-Wa, Upper East-Bolgatanga, Northern –Tamale, Brong -Ahafo -Sunyani, Ashanti-Kumasi, Eastern-Koforidua, Volta-Ho, Greater Accra-Accra and Central- Cape Coast.

The existing roads linking the regional capital towns will be used to provide access to the construction of the pipelines connection. In addition to standard pipeline construction methods special connection techniques are used when warranted by site-specific conditions such as when constructing across paved roads, highways, railroads, steep terrain, water bodies and wet lands, and when blasting through rock. All these are done so as to ensure safety and minimize cost and distance covered.

1.1 BACKGROUND OF THE STUDY

The proposed connection of Gas Pipelines from Takoradi to other nine regional capitals is being designed to make natural gas from the West African Gas Pipeline (WAGP) and the Jubilee Oil Field abundantly (JOF) and cheaply to the Ghanaian consumers.

Ghanaians are increasing depending on natural gas for its energy needs. In 2010 alone, the nation consumed 124.1 billion cubic metres with demand of 165.2 billion cubic metres of natural gas, forecast for 2015, Business Monitor International (BMI). Large portions of the gas consumed are transported from Tema and Takoradi to the rest of the regions.

Ghana is yet to have a major natural gas production basins and the pipeline network of the gas is not fully developed to other regional capitals. Most of the natural gas consumed are imported and few supply from the West African Gas pipeline (WAGP). Of the natural gas consumed in Ghana, 0% is produced locally. There is no transmission of pipeline system connecting the West African Gas Pipeline from Takoradi to other nine regional capitals. The primary function of the transmission pipeline is to move huge amounts of natural gas hundreds of miles from the producing region to the local natural gas utility delivery points. This delivery points, called “city gates stations” are usually owned by distributions companies, although some are owned by transmission companies. Compressor stations at required distances boost the pressure that is lost through friction as the gas moves through the steel pipes (EPA 2000).

The Takoradi Thermal Power Station (TTPS) is located at Aboadze, 17 kilometres east of Sekondi-Takoradi in the Western Region of Ghana. The Power Station which started operation in 1997 was initiated by the Volta River Authority to complement the existing Hydro Plant at Akosombo and Kpong. TTPS is therefore a facility of strategic importance for meeting Ghana's energy needs.

The current installed capacity of the Takoradi Power Plant is 550MW and is to be upgraded to 660MW by the CMS/VRA joint Venture. The wholly owned VRA portion of 330MW combined cycle Plant with a 2x2x1 configuration meaning two (2) 110MW GE Frame 9E combustion gas turbines, with two (2) HRSGs feeding one (1) 110MW Steam Turbine Generator. The voltage output of the Generators which is 13.8kV is stepped up by Power Transformers to the national grid system voltage of 161kV.

With the objective of being an electrical supplier of choice for customers in Ghana and West Africa, the Plant operates on two modes, namely Simple Cycle and Combined Cycle. The primary fuel used for power generation is Light Crude Oil (LCO) which is normally received from ocean tankers via a Single Point Mooring (SPM), connected to the plant by approximately 4.5km undersea pipeline and stored in four (4) 29,500m 3 capacity storage tanks. The secondary fuel on site - Distillate Fuel Oil (DFO) is normally used for start-up and shutdown as it is less volatile. On the average, a Gas Turbine at base load (110MW) can generate 2.5GW of electricity using about 890m 3 of LCO a day.

The Plant has dual firing capacity and is being converted to run on natural gas. The West African Gas pipelines company has also laid pipelines from the Niger Delta to the thermal plant to process and supply Natural gas to the nation.

The transmission segment of the gas industry is responsible for transporting natural gas from the producer to the market areas via pipelines. The transmission segment is composed of pipelines, compressor stations, city gate stations, and storage facilities. The energy sector of Ghana is faced with urban and rural areas, transport sector, and industries total dependence of natural gas. This gas is either not readily available or transportation is very high hence high cost of the gas. The connection of gas pipelines from Takoradi to the other regional capitals seek to solve the transportation problem. The installation of these pipelines across these regional capitals is expensive and disruptive to the natural environment. Thus, this thesis seeks to find the shortest-path these pipelines should be installed so as to reduce the cost of installation, minimize the number of pipelines needed and hence a reduction on the environmental problems.

1.2 STATEMENT OF THE PROBLEM

The demand for natural gas in Ghana has increased significantly as it has been a cheaper alternative fuel used in our homes, industries, and mining and transportation sectors within the country.

In view of this, the research is being conducted to connect the gas from Takoradi to the regional capital towns to meet the growing demands of its citizenry. The study is therefore conducted to design a minimum connection of gas pipelines that interconnects all the regional capital towns.

1.3 OBJECTIVES

From the problem statement above, the researcher seeks to:

(i) Develop a straightforward method of locating pipeline facilities;

(ii) Extend gas pipelines from Takoradi to the regional capital towns in Ghana;

(iii) Design pipeline networks to minimize cost and distance covered;

(iv) Develop a method of incorporating environmental considerations in pipeline network design.

1.4 SIGNIFICANCE OF THE STUDY

Individuals, companies or organizations are required to monitor and adapt to the continuous changes in the political, economic, social and technological environment. Consequently, it can be said that a proper path and distances are crucial for the overall production and supply of natural gas from the source to different destinations.

It is anticipated that the findings from the study will pave way for the Ghana National Petroleum Corporation (GNPC) together with transportation engineers a clear picture of how to design a network flow so as to minimize cost and distance covered. The study will also serve as a guide for further research in other areas such as network design in transportation (rail lines, water pipelines roads, etc), telecommunication (fibre-optic networks, computer networks etc) and rural and urban electrification in a township or country. The result of the study will help the people along the pipelines on environmental issues. Finally, the study serves as a partial fulfillment of the requirement for the master degree in Industrial Mathematics.

1.5 JUSTIFICATION

The rampant shortage of natural gas has been a problem to the consumers. The transport sector has been affected most in this regard because of their increasing use of the gas. It takes several days for the gas to be transported to the various regional capitals even if the gas is imported into the country. This makes the system unfair to those who are far from the delivery point. This situation calls for the connection of the gas pipelines from Takoradi to the other regional towns to ensure even distribution of the gas when available.

1.6 SCOPE OF THE STUDY

This research is limited to all the ten regional capital towns in Ghana. The respondents will cover some employees at the Gas industry, GPRTU, Ministry of Energy and Ministry of Roads and Highways. The area covered was the map of road network from Takoradi to other regional capital towns in Ghana. Findings of this study apply to the regional capital town which was selected for the study. However, the findings could be adapted to other areas with similar characteristics.

1.7 METHODOLOGY

Since the study is on minimum connection of gas pipelines from Takoradi to the regional capital towns in Ghana, the researcher deployed the use of shortest path method. The shortest path method include; Dijkstra's algorithm, Floyds-Warshall algorithm, Prism's algorithm etc. For the purpose of this study, the researcher used Prism's algorithm to minimize the pipeline network systems of the regional capital towns.

The research used a map provided by the Ghana Highway Authority. The map was the road network system of the regional capital towns and the distance they cover within the region.

1.8 LIMITATION OF THE STUDY

The following are the limitation encountered when conducting the study;

(i) Financial constraints; as the researcher has to travel frequently to all the regional capital towns.

(ii) Getting the appropriate correspondents to answer the questionnaires.

(iii)Time constraint was a major setback in the conduct of the study since enough time was not available for the researcher to sample a larger population.

1.9 ORGANIZATION OF THE STUDY

The content of this thesis is arranged as follows. Chapter 1 establishes the introduction to the network and pipeline optimization problem, background to the study, statement of the problem, objective, significance of the study ,justification, scope of the study, methodology, limitation of the study, physical and network analysis and introduces important gas pipeline basics . Chapter 2 presents relevant related research ideas which have been published and shows their significance for the current research. Chapter 3 introduces, develops and illustrates the general algorithms of the method of solutions of the problem. Chapter 4 analyzes optimal layout of the Gas Pipeline Project focusing on Prim's algorithm for MST. Also in this chapter, the environmental damages revealed by the pipeline network design were looked at. A summary, recommendations and conclusions derived from this research are presented in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

The review of literature summarizes a number of works in the field of networks, which have application to pipelines. This chapter begins by reviewing publications related specially to developments in the pipeline industry. The study of networks, however, encompasses more than just pipelines. Hence, the following sections contain a summary of published literature related to transportation network optimization. They include developments in each of the analytical, exact computational and heuristic solution approaches.

2.1 GAS PIPELINE RESEARCH

Accelerated growth in pipeline construction is expected due to recent industry deregulation in the United States, West Africa etc. the growing presence of Mexico in the North America market is analyzed in George and Mortenson (1995). They anticipate private investment in Mexico's upstream sector followed by full integration with the continental natural gas market, in which Mexico is expected to be a net gas importer in the long term.

These developments indicate potential exists to improve the efficiency of gas pipelines systems in North America at all levels from gathering systems through distribution. Wearmouth (1994) found that, in 1993, 13 percent of Alberta's gas processing facilities or gas plants contained over two thirds of the raw gas processing capacity in the providence. Additionally, over 50% of Alberta's gas processing plants were designed to process less than ten percent (10%) of the total gas processing requirements. These findings alone indicate room for improvement in gas gathering network design.

Bolkan (1991) developed a dynamic programming model to optimize design and operation of an oil pipeline. Only physical elements of the pipeline designed were considered (pipeline diameter, pumping stations, and suction and discharge pressures). The pipeline route was not included in the optimizations parameters. Bolkan found little published research on optimal pipeline design and determined that the common industry practice for design involves a trial-and-error approach using cost benefit analysis for comparison of alternatives. Her findings are consistent with those of the author in that little published research is available on pipeline optimization and little of that relates to route design. There are few cases of published pipeline route optimization attempts and those that exist utilize the trial-and-error.

The North American Regional Gas Supply-Demand Model was commissioned by the Gas Research Institute (GRI) in 1984 and is essentially a large-scale dynamic economic equilibrium model (Nesbitt, 1988). The model incorporates all supply and demand regions in a network, the links of which represent pipeline corridors. These corridors include a number separates pipelines connecting similar regions. The simplified representation combined with the many difficulties associated with the economy make the model subject to large errors. Its main value is in sensitivity analysis and comparison of alternatives. The model is used extensively by government and regulatory agencies for guidance in broad-range policy making, but has limited value for regional application. It is not a suitable model for determining the efficiency of the existing pipeline network.

The above publications touch the fringes of the problem of interest in this work that being the spatially optimal design of pipeline networks. However, pipeline industries publications appear to b e lacking I the specific area of interest. The previous chapter made an analogy between the pipeline and electricity transportation systems. The latter of these systems were not of the focus of the literature review as such may contain published research of some value to the pipeline problem being studied.

2.2 PIPELINE SELECTION AND ROUTING CRITERIA

The factors influencing pipeline route selection are technical and engineering requirements, environmental consideration and population density. However, these factors are chosen to balance engineering and construction cost against environmental cost and future liability. The engineering and technical considerations merge partly with some environmental considerations used in this research include pipeline length, topography, surface geology, river and wetland crossings, road and rail road crossings and the proximity to large proportion centers.

The literature shows that the route selection is the first and the most effective means of preventing pipeline impacts from the outset. The literature is rich, diverse, detailed and helpful, Environmental assessments of pipelines are neither new nor obscure nor precedent setting. The environmental assessment of pipeline impacts on vulnerable ethnic minorities, biodiversity, conservations units and spill risks is standard in other projects by now. Of course, each pipeline is different, but the methodologies and the types of impacts to be aware of have long since become standard (Dott, 1997)

2.3 OPTIMAL NETWORKS

Network optimization techniques have been studied extensively and applied in transportation, manufacturing, communication and circuit board design industries to name a few. The problem is usually this nature; how can a set of points be connected together with a system of links for the least cost? In the case of pipeline networks, the points are supply and demand locations and the links are pipelines. The similarities and differences between this problem and others which utilize network optimization techniques are discussed. The overview highlights and development which have significance to pipelines.

Arogundade and Akinwale (2009) successfully used Prim's algorithm at a profit-oriented transportation systems in rural areas of Nigeria. The authors used Odeda Local Government map which has 88 villages connected by 96 roads. The project requires 388,270 meters to be covered. Their findings shows that given the cost of fuel for travelling over 8000 meters to be 70.00 Naira a transport company will make more profit with the implementation and use of Prim's algorithm; taking into an account the cost of travelling over 8000 meters by an averagely good Toyota 14 sector bus. The solution obtained was reported and compared with the result obtained before they apply Prim's algorithm on the existing network in both Table 2.2 and Table 2.3. For example, the value of objectives function from Oguntoke to Olajugun was 544 Naira as shown in table 2.3 without using Prim's algorithm is applied. The same situation is to travel from Obantoko to Nitoji with objective function of 507 Naira as against 186 Naira without using the algorithm. They reported that the value of the objective function in Table 2.3 of column *h* is very low compared to that of table 2.2 where Prim's algorithm is used. This, they affirm that the company will make more profit with the implementation of the algorithm taking into account the cost of travelling over 8000 meters is estimated. In the course of their work, they discovered that the algorithm is very effective in providing shortest distances between two set of villages. In addition, Arogundade and Akinwale found that in one way it reduces the cost of fuel and time for transportation of passengers from one town to another which normally determines prices in Nigerian transportation.

Table 2.1: Results of Objectives Function using Prim's Algorithm

A	b	c	D	e	F=*e*/8000*70.00	*g*=axb	*h*=*g*-*f*
14	80.00	Oguntoko	Olajogun	46,730	40888	1120	711
14	50.00	Obantoko	Nitoji	21,960	192.15	700	507
14	130.00	Kangudu	Lokoji	60,270	527.36	1820	1292
14	130.00	Oguntoke	Alatibaba	64,710	566.21	1820	1253
14	80.00	Odeda	Akitoye	43,270	378.61	1120	741
14	60.00	Asawo	Mosafeyo	22,170	193.98	840	746

Table 2.2: Results of Objectives Function without using Prim's Algorithm

A	b	c	D	e	F=*e*/8000*70.00	*g*=axb	*h*=*g*-*f*
14	80.00	Oguntoko	Olajogun	64,690	566	1120	554
14	50.00	Obantoko	Nitoji	58,730	513.8	700	186
14	130.00	Kangudu	Lokoji	71,530	625.8	1820	1194
14	130.00	Oguntoke	Alatibaba	85,670	749.6	1820	1070
14	80.00	Odeda	Akitoye	47,710	417.4	1120	702
14	60.00	Asawo	Mosafeyo	46,920	410.55	840	429

a= number of passengers b= cost of travelling per head c= starting village

d= destination village e= total distance generated in meters f= total edge cost

g= total profit h= value of objective function.

Dott (1997), in his study of Optimal Design of Natural Gas Pipeline of Amoco East Crisfield Gas Pipeline project, (Alberta in Canada) containing 22 wells and connected by a gathering system of approximately 66km pipeline uses Prim's and Steiner tree algorithm design a MST that covered a 38km and less than 13.4% respectively of the original length of the pipeline. A similar study by Bolkan (1991) in the same year of the Palliser Natural Gas Pipeline Project Canada which was planned to connect 68 gas processing plant and compressor stations from Southeastern Alberta to Empress/McNeil export location on the Alberta Saskatchewan border via downstream TransCanada pipeline and Foothills pipelines to consumers all over North America. The project requires 709km laterals to a mainline approximately 243km in length for a total of 952km of installed pipe and a cost of $365 million. The minimum spanning tree created by Prim's algorithm for the Palliser Pipeline design length of 952km, for a 13% total length reduction. The construction cost which corresponds to this 13% reduction may be approximated as 13% of $365 million or $46 million. The MST does not represent the shortest responsible network and up to a further 13.4% reduction may be achieved with a Steiner tree. It is also important to note that the Palliser Pipeline designers were probably unaware of or disinterested in any techniques which could achieve this global or local minimum and thus the MST length is probably the more appropriate measure.

Brimberg et al., (2003) studies the optimal design of an oil pipeline network for the South Gabon oil field. This oil field has 33 nodes representing onshore platforms, onshore wells, several connection points and one port (Gamba) with 129 possible arcs having total distance of 188.2 miles. Their finding in concert with Prim's algorithm reduces the connection to 156.2 miles which is a reduction of 17% of the total distance to be covered. They reported that the government saved a substantial amount of money from the number of pipelines used, labour quantity, time and even minimize environmental destruction of the earth's topography.

The most recently published work in the field of network design promotes use of genetic algorithm to find optimal or near-optimal solutions. Genetic algorithms use Darwin's theory of evolution as a basis for their structure. Essentially, individuals seek out the fittest mate in order to procreate and give their likewise fit offspring a greater chance of survival.

Genetic algorithm solves problems by representing potential problem solutions as individuals. Each individual or solution has a unique genetic descriptor or chromosome. In this case, a chromosome is a string of characters or genes each of which represents one element of the solution it represents. An optimal or near-optimal solution is found through successive "crossovers" or mating of the chromosomes. Sometimes mutation occurs which can reduce or improve fitness of the offspring. Fitness of each solution is measured by a fitness function. Each generation of solutions is usually of the same size as the previous generation with the less fit solutions being replaced by more fit. The fit solution is always carried through until it is replaced or is found to be the best solution.

The genetic algorithm is superior to other heuristic algorithm because the crossing over and the mutation chromosomes enable the offspring which can be very different from either parent. Since a locally optimal tree network is likely to have a drastically different structure from the global optimum, this aspect of the genetic algorithm is valuable.

The history of the Steiner tree problem presented here indicates that determining spatially optimal networks is a complicated and imperfect science. In addition, the pipeline industry does not prescribe too many of the solution principles, even simple ones for design. In real route-design problems it is usually true that the finite number of routes is viable for consideration.

In computer science, Prim's algorithm is an algorithm that finds a minimum spanning tree for a connected weighted undirected graph. This means it finds a subset of the edges that forms a tree that includes every vertex, where the total weight of all the edges in the tree is minimized. Prim's algorithm is an example of greedy algorithm. The algorithm was developed in the 1930 by Czech mathematician Vojtĕch Jarnik and later independently by computer scientist Robert C Prim in 1957 and rediscovered by Edsger Dijkstra in 1959. Therefore it is also sometimes called the DJP algorithm, the Jarnik algorithm, or the Prim-Jarnik algorithm.

Gonnia et al., (2007) describe parallel implementation of Prim's algorithm for finding a minimum spanning tree of a dense graph using MPI. Our algorithm uses a novel extension of adding multiple vertices per iteration to achieve significant performance improvements on large problems (up to 200,000 vertices). We describe several experimental results on large graphs illustrating the advantages of our approach on over a thousand processors.

Gloor et al., (1993) described a system of visualizing correctness proofs of graph algorithms. The system has been demonstrated for a greedy algorithm, Prim's algorithm for finding a minimum spanning tree of undirected, weighted graph. We believe that our system is particularly appropriate for greedy algorithms, though much of what we discuss can guide visualization of proofs in other contexts. While an example is not a proof, our system provides concrete examples to illustrate the operation of the algorithm. These examples can be referred to by the user interactively and alternatively with the visualization of the proof where the general case is portrayed abstractly.

McCarthy et al., (2009) presented the application of two well known graph algorithms, Edmonds' algorithm and Prim's algorithm, to the problem of optimizing distributed SPARQL queries. In the context of this paper, resolved by contacting any number of remote SPARQL endpoints. Two optimization approaches are described. In the first approach, a static query plan is computed in advance of query executions, using one of two standard graph algorithms for finding minimum spanning trees (Edmonds' and Prim's algorithm). In the second approach, the planning and the execution of the query are interleaved, so that as each potential solution is expanded it is permitted to an independent query plan. Our optimization approach requires basic statistic regarding RDF predicates which must be obtained prior to the user's query, through automated querying of the remote SPARQL endpoints.

Martel et al., (2002) studied the expected performance of Prim's minimum spanning tree (MST) algorithm implemented using ordinary heaps. We show that this implementation runs in linear or almost linear expected time on a wide range of graphs. This helps to explain why Prim's algorithm often beats MST algorithms which have better worst-case run times. Specially, we show that if we start with any n node edge graph and randomly permute its edge weights, then Prim's algorithm runs in expected O (m + nlogn log (2m/n)) time. Note that O (m + nlogn log (2m/n)) = O (m) when m = Ω (n log n log n). We extend this result to show that the same expected run times apply even when an adversary can select the weights of m/logn edges and the responsible weights of the remaining edges (which are then randomly assigned).

Chang et al., (2008) described the reason why it is beneficial to combine with graph theory and board game. Forbye, it also descants three graph theories: Dijkstra's, Prim's, and Kruskal's minimum spanning tree. Then it would describe the information about the game we choose and how to combine the game with before-mentioned three graph theories. At all times, we could account for the advantage of combining with these three graph theories and the game specifically.

Dijkstra's algorithm conceived by Dutch computer scientist Edsger Djikstra in 1959 is a graph search algorithm that solves the single-source shortest path problem for a path with nonnegative edge path costs, producing a shortest path tree. This algorithm is often used in routing. An equivalent algorithm was developed by Moore in 1957.

For a given source vertex (node) in the graph, the algorithm finds the path with lowest cost (i.e. the shortest path) between that vertex and any other vertex. It can also be used for finding cost paths from a single to a single destination vertex by stopping the algorithm once the shortest path to the destination vertex has been determined. For example, if the vertices of the graph represents cities and edge path cost represent driving distance between pairs of cities connected together by a direct road, Dijkstra's algorithm can be used to find the shortest route between one city and all other cities. As a result, the shortest path first is widely used in network routing protocols, most notably IS-SI and OSPF (Open Shortest Path First).

The literature makes it abundantly clear that the procedure commonly known today as Dijkstra's Algorithm was discovered in the late 1950s, apparently independently, by a number of analysts. There are strong indications that the algorithm was known in certain circles before the publication of Dijkstra's famous paper. It is therefore somewhat surprising that this fact is not manifested today in the "official" title of the algorithm.

Dijkstra, (1959) submitted his shorter paper for publication in Numerische Mathematik June 1959. In November 1959, Pollack and Wiebenson [1960] submitted a paper entitled Solutions of the shortest route problem- a review to the journal Operations Research. This review briefly discusses and compares seven methods for solving the shortest path problem.

However, the review presents a 'highly efficient' method, attributed- as a dateless private communication- to Minty. The procedure is defined as follows (Pollack and Wiebenson [1960, p. 225]: the objective is to find the shortest path from city A to city B.):

Sneidovich, (2006) described Dijkstra's Algorithm as one of the most popular algorithms in computer science it is also popular in operations research. It is generally viewed and presented as a greedy algorithm. In this paper we attempt to change this perception by providing a dynamic programming perspective on the algorithm. In particularly, we reminded that this famous algorithm is strongly inspired by Bellman's Principle of Optimality and that both conceptually and technically it constitutes a dynamic programming successive approximation procedure par excellence. One of the immediate implications of the perspective is that this popular algorithm can be incorporated in the dynamic programming syllabus and in turn dynamic programming should be (at least) alluded to in a proper exposition/teaching of the algorithm.

Goldberg et al., (2006) proposed shortest path algorithms that use a search in combination with a new graph-theoretic lower bounding technique based on landmarks and triangle inequality.

Our algorithms compute optimal shortest paths and work on any directed graph. We give experimental results showing that the most efficient of our new algorithms outperforms previous algorithms, in particular A□ search with Euclidean bounds, by a wide margin on road networks and on some synthetic problem families.

Pangilinan et al., (2007) presented an overview of the multi-objective shortest path problem (MSPP) and a view essential and resent issue regarding the methods to its solution. The paper further explored a multi-objective evolutionary algorithm as applied to the MSPP and describes its behavior in terms of diversity of solutions, computational complexity and optimally of solutions. Results show that the evolutionary algorithm can find diverse solutions to the MSPP in polynomial time (based on several networks instances) and can be an alternative when other methods are trapped by the tractability problem.

As in the case of single –objective shortest path problem, the multi-objective shortest path problem has been studied extensively by various researchers in the fields of optimizations, route planning for traffic, transport design, information and communication networks design. The MSPP is an extension of the traditional shortest path problem and it is concerned with finding a set of efficient paths with two or more objectives that are usually in conflict. For example the problem of finding optimal routes in communication networks involve minimizing delay while maximizing throughput or finding efficient routes in transportation planning that simultaneously minimize travel cost, path length and travel time. The concept of optimization in the MSPP or in a multi-objective problem in general is different from the single-objective optimization problem wherein the task is not to find a solution that optimizes a single objective function. The task in a multi-objective problem is not to find an optimal solution for each objective function but to find an optimal solution that simultaneously optimizes .all objectives. And in most case, no single optimal solution exists, only a set of efficient and non- dominated solutions.

A variety of algorithms and methods as dynamic programming, label selecting, label correcting, interactive methods and approximation algorithms have been implemented and investigated with respect to the MSPP. The problem is known to be NP-complete. It has been shown that a set of problems exist wherein the number of Pareto-optimal solutions is exponential which implies that any deterministic algorithm that attempts to solve it is also exponential in terms of runtime complexity at least in the worst case. But some labels algorithm studies, disputes this exponential behavior. They show that the number of efficient paths not exponential in practice. Other authors avoid the complexity problem by developing new methods that run in polynomial time. For instance, Hansen and Warburton separately develop Fully Polynomial Time Approximation Schemes (FPTAS) for finding paths that are approximately Pareto-optimal. Interactive procedures similarly avoid the problem of generating the complete set of efficient paths by providing a user-interface that assists the decision maker to focus only on promising paths and identifying solutions accordance to preferences.

Given the wealth of literature in multi-objective algorithms for the MSPP, there still seems to be a lack of reported review in Evolutionary Algorithm (EA) application in relation to the MSPP. Several of the most recent alternative methods focus mostly on execution comparisons speed of different MSPP algorithms but analysis of the salient issues in multi-objective performance analysis such as runtime complexity, diversity, and optimally of non- dominated solutions are almost omitted.

In other to dominate a clearer picture of the advantages and disadvantages of EAs in optimization, this paper attempts to investigate a multi=objective evolutionary algorithm as applied to the MSPP.

Divoky, (1990) presented a framework for solving the shortest-path, cost-flow problem with positive edge weights can be implemented by itself or as a subordinate process in a solution procedure for a bigger problems. The efficiency of such shortest-path frameworks depend on the technique employed to use the structure of the network from the solution of the bigger problem, as well as on the efficiency of the frameworks. The topology of the networks is characterized by arcs with positive weights and of sub-networks called zero-weight components. The techniques for using topology include; identifying the zero-weight edges and adding them to the graph; identifying and adding the basic sub-trees to the shortest-path tree; and interrupting the shortest-path frameworks scanning or fixing the labels of all the nodes in the sub-tree.

Pettie et al., (2002) evaluated the practical efficiency of a new shortest path algorithm for undirected graphs which was developed by the two authors. This algorithm works on the fundamental comparison-addition model. Theoretically, this new algorithm out-performs Dijkstra’s algorithm on sparse graphs for the all-pairs shortest path-problem, and more generally, for the problem of computing single –source shortest path from different sources. Our extensive experimental analysis demonstrated that this is also the case in practice. The authors presented results which showed the new algorithm to run faster than Dijkstra’s on a variety of sparse graphs when the number of vertices ranges from a few thousand to a few million, and when computing single-source shortest paths from a few as three different sources.

Wang et al., (2005) said multiple pairs of shortest path problem (MPSP) arise in many applications where the shortest paths and distances between only some specific pairs of origin-destination (OD) nodes in a network are desired. The traditional repeated single-source shortest path (SSSP) and all pair's shortest paths (APSP) algorithms often do unnecessary computation to solve the MPSP problem. Our method is especially suitable for applications with fixed network topology but changeable arc lengths and desired OD pairs. Preliminary computational experiments demonstrate our algorithms superiority on airline network problems over other APSP and SSSP algorithms.

Chang, (2009) described the shortest distance between two points as a straight line. But in the real world, if those two points are located at opposite ends of the country, or even in different neighborhood, it is unlikely you will find a route that enables you to travel from origin to destination via one straight road. You might pull out a map to determine the fastest way to drive somewhere, but these days, you are just as likely to use a Web-based service or a handheld device to help with driving directions. The popularity of mapping applications for mainstream consumer use once again has brought new challenges to the research problem known as "shortest-path problem."

The shortest path problem, one of the fundamental quandaries in computing and graph theory, is intuitive to understand and simple to describe. In mapping terms, it is the problem of finding the quickest way to get one location to another. Expressed more formally, in a graph in which vertices are joined by edges and in which each edge has a value, or cost, it is the problem of finding the lowest-cost path between two vertices. There are already several graph-search algorithms that solve this basic challenge and its variations, so why is shortest-path perennially fascinating to computer scientist?

Goldberg, (2001) principal researcher at Microsoft Research Silicon Valley, said there are many reasons why researchers keep studying the shortest-path problem.

"Shortest path in an optimization problem that's relevant to a wide range of applications, such as network routing, gaming, circuit design, mapping," Goldberg says. "The industry comes up with new applications all the time, creating different parameters for the problem. Technology with more speed and capacity, allows us to solve bigger problems, so the scope of the shortest-path problem itself has become more ambitious. And now there are Web-based services, where computing time must be minimized so that we can respond to queries in real time."

Venkataraman et al., (2003) proposed a block version of Floyd's all-pairs shortest-paths algorithm. The blocked algorithm makes utilization of cache than does Floyd's original algorithm. Experiments indicate that the blocked algorithm delivers a speedup (relative to the unlocked Floyd's algorithm) between 1.6 and 1.9 on a Sun Ultra Enterprise 4000/5000 for graphs that have between 240 and 1200 vertices is between 1.6 and 2.0.

Arulselvan et al., (2008) considered the problem of maximizing the total connectivity for a set o wireless agents in a mobile ad hoc network. That is, given a set of wireless units having a start point and a destination point, our goal is to determine a set of routes for the units which maximize the overall connection time between them. Known as the COOPORATIVE COMMUNICATION PROBLEM IN MOBILE AD HOC NETWORKS (CCPM), this problem has several military applications including coordination of rescue groups, path planning for unmanned air vehicles, geographical exploration and target recognition. The CCPM is NP-hard; therefore heuristic development has been the major focus of research. In this work, we survey the CCPM examining first some early combinatorial formulations and solution techniques. Then we introduce new continuous formulations and compare the results of several case studies. By removing the underlying graph structure, we are able to create a more realistic model of problem as supported by the numeric evidence.

Razzaque et al., (2009) said a fast algorithm is proposed to calculate k^{th} power of an n × n Boolean matrix that requires addition operations were p is the probability that an entry of the matrix is 1. The algorithm generates a single set of inference rules at the beginning. It then select entries (specified by the same inference rule) from any matrix (Ak-1) and adds them up for calculating corresponding entries for A k. No multiplication operation is required. A modification of the proposed algorithm 1 can compute the diameter of any graph and for massive random graph, it requires only $O(n2(1-p)E[q])$ operations, where q is the number of attempts required to find the first occurrence of 1 in a column in a linear search. The performance comparisons say that the proposed algorithms outperform the existing ones.

The Floyd-Warshall algorithm, also variously known as Floyd's algorithm, the Roy-Floyd algorithm, the Roy-Warshall algorithm, or the WFI algorithm, is an algorithm for efficiency and simultaneously finding the shortest paths, (i.e., graph geodesics) between every pair of vertices

The Floyd algorithm is essentially equivalent to the transitive closure algorithm independently discovered by Roy (1959) and Warshall (1962) (Pemmaraju and Skiena 2003), which is the

Hougardy, (2010) the Floyd Warshall algorithm is a simple and widely used algorithm to compute shortest paths between all pairs of vertices in an edge weighted directed graph. It can also be used to detect the presence of negative cycles. Hougardy, (2010) show that for this task, many existing for the implementation of the Floyd- Warshall algorithm will fail because exponentially large numbers can appear during its execution.

Chen et al., (2007) focused on the optimization problems about complicated network, this paper present an algorithm KSPA to solve the K-shortest paths problem complicated networks based on algorithm, in which the time cost is taken as target function and the establishment of the target function model is given. Experimental results show that the proposed KSPA maintains an excellent efficiency on certain public traffic data. It can be used to solve the K-shortest paths problems in multi-graph.

Lysgaard, (2000) presented a new algorithm for finding the shortest path from a source to a single sink in a network, in which the location in the plane of each node is known. The algorithm consists of two phases. In the first phase a heuristic solution is to the shortest path problem is found. In the second phase the upper bound provided by the heuristic solution is utilized in a modification of a standard shortest path algorithm. Estimates based on computational test show that on average the computation time of the presented algorithm is on the order of 40-60% of the computation time is required if the information on node locations is not utilized.

Rabbani et al., (2008) presented a distribution network design problem in a multi-product supply chain system that involves the locating production plants and distribution warehouse as well as determining the best strategy for distributing the product from plants to warehouse and from warehouse to customers. The goal is to select the optimum numbers, locations and capacities of plant and warehouses to open, so that all customers demand of all product types are satisfied at minimum total costs of the distributing network. Unlike most of the previous researches, our study considered a multi-product supply chain system. We develop a mixed-integer mathematical programming model for designing a supply chain distribution network. Finally, this paper represents a real-case study to investigate designing a pharmaceutical supply chain distribution network. A possible extension is offered in the conclusion.

Multi pairs shortest path problem (MPSP) that arises in many applications where the shortest paths and distances between only some specific pairs of origin destination (OD) nodes in a network are desired. The traditional repeated single-source shortest path (SSSP) and all pairs shortest path (APSP) algorithm often do unnecessary computation to solve the MPSP problem. Sololá et al., (2005) proposed a new shortest path algorithm to save computational work when solving the MPSP problem. Our method is especially suitable for applications with fixed network topology but changeable arc length and desired OD pairs. Preliminary computational experiments demonstrate our algorithm superiority on airline network problems over other APSP and SSSP algorithm.

Hseih et al., (2004) designed shortest path routing algorithms is in general more difficult than designing simple routing algorithms. In this paper we derived a shortest path routing algorithm for pyramid networks. The proposed algorithm takes O (1) time to determine the shortest path between any two nodes in a pyramid network. We also designed a distributed routing algorithm such that an intermediate node takes O (1) time to confirm the next node along the shortest path without any centralized controller.

Algorithms for finding the shortest path from one point to another have been researched for years. Applications abound, but let's keeping things simple by saying we want to find the shortest path from one point A to point B in a city with just a few streets and interactions. There are quite a few algorithms that have been developed to solve such problems, all with different C; C^N becomes astronomical when N gets even moderately large.

One of the fastest algorithms for solving this problem has a runtime of $O\left(E * V * Log(V)\right)$, where E is the number of segments, and V is the number of intersections. To put this in perspective, the algorithm will take about 2 seconds to find the shortest path in a city with 10000 intersections and 20,000 road segments (there are usually about 2 road segments per intersection). The algorithm, known as Dijkstra's Algorithm, is fairly complex, and requires the use of the data structure known as a priority queue. In some applications, however, even this runtime is too slow (consider finding the shortest path from New York City to San Francisco- there are millions of intersections in the US), and programmer try to do better by using what are known as heuristics. A heuristic is an approximation of something that is relevant to the problem, and is often computed by an algorithm of its own. In the shortest path problem, for example, it is useful to know approximately how far a point is from the destination. Knowing this allows for the development of faster algorithm (such as A*, an algorithm that can sometimes run significantly faster than Dijkstra's algorithm) and so programmers come up with heuristics to approximate this value. Doing so does not always improve the runtime of the algorithm in the worst case, but it does make the algorithm faster in most real world applications.

Traffic information systems are among the most prominent real-world applications of Dijkstra's algorithm for shortest paths. Schulz et al, (2000) considered the scenario of a central information server in the realm of public railroad transport on wide area networks. Such a system has to process a large number of on-line queries for optimal travel connections in real time. In practice, this problem is usually solved by heuristic variations of Dijkstra's algorithm, which do not guarantee an optimal result. We report results from a pilot study, in which we focused on the travel time as the only optimization criterion. In this study, various speed-up techniques for Dijkstra's algorithm were analyzed empirically. This analysis was based on the timetable data of all German train and on a "snapshot" of half a million customer queries.

In graph theory, the shortest path problem is the problem of finding a path between two vertices (nodes) such that the sum of the weights of its constituent edges is minimized. An example is finding the quickest way to get from one location to another on a road map; in this case, the vertices represents the location and the edges represents the segments of road and are weighted by the time needed to travel that segment.

Formally, given a weighted graph (that is, a set *V* of vertices, a set E of edges, and a real-valued weight function $f:(E \to R)$, and one element of *v of V*, find a path P from v to a v' of V so that

$$\sum_{p \in P} f(p)$$

it is minimal along all paths connecting v to v'.

The problem is also sometimes called the single-pair shortest path problem, to distinguish it from the following generalizations:

- The single-source shortest path problem, in which we have to find shortest paths from a source vertex v to all their vertices in the graph.
- The single-destination shortest path problem, in which we have to find shortest paths from all vertices in the graph to a single destination vertex v. this can be reduced to the single-source shortest path problem by reversing the edges in the graph.
- The all-pairs shortest path problem, in which we find shortest paths between every pair of vertices v, v' in the graph.

These generalizations have significantly more efficient algorithms than the simplistic approach of running a single-pair shortest path algorithm on all relevant pairs of vertices.

2.4 SUMMARY

In this chapter, we reviewed publications related specifically to developments in the pipeline industry. They include developments in each of the analytical, computational and heuristic solution approaches. In the next chapter, we shall introduce, develop and illustrate the general algorithms for the method of solutions of the problem.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 INTRODUCTION

This chapter focuses on the method and algorithms for solving the problem of designing gas pipeline network. The techniques employ here are useful for getting several alternative systems of near-optimal arrangements which can be compared using economic and qualitative analysis mostly used in industry to determine the most efficient network route.

Network design methods are not well recorded and applied in practice. The practical example consider in this chapter will provide guidelines for effective pipeline network design for industries that uses network in its operations. Include is the environmental factors in the network design algorithm is also elaborated.

Shortest path problems are the most fundamental and most commonly encountered problem in the study of transportation and communication networks. The shortest path problem arises when trying to determine the shortest, cheapest or the most reliable path between one or many pairs of nodes in a network. More importantly, algorithms for a wide variety of combinatorial optimization problems such as vehicle routing and network design often called the solution of large number of shortest path problems as subroutines. Consequently, designing and testing efficient algorithm for the shortest path problem has been a major area of research in network optimization.

3.1 GENERAL PIPELINE CONSTRUCTION PROCEDURES

Before construction starts, engineering surveys are conducted of the ROW centerline and extra workspaces, and complete land or easement acquisition of private and state lands is finalized. If the necessary land rights or easements are not obtained through good faith negotiations with landowners and the project is approved by the FERC, the pipeline company could use the right of eminent domain granted it an easement under Section 7(h) of the Natural Gas Act (NGA). The pipeline company is still required to compensate the landowners for the Right(s) –of –Way (ROW), as well as for any damages incurred during construction. The pipeline company generally pays the market price for the property. However, the level of compensation is determined by the court system according to state laws regarding eminent domain. Eminent domain is used only as a last resort, because the process can take up to 2 to 3 years (FERC 2007). The landowner normally is compensated a fair market value for a permanent easement, which typically allows the landowner continued use and enjoyment of the aboveground property, with some limitations. The limitations typically prohibit excavation as well as the placement of structures and trees within the easement to preserve safe access for maintenance equipment when necessary and allow for uninhibited aerial inspection of the pipeline system.

The landowner is generally compensated at an amount lower than fair market value when the pipeline company needs only a temporary construction easement, since this land reverts back to the landowner after construction for full use and enjoyment without any restrictions, although ROW cleanup could continue for several years.

Additionally, landowners are compensated for any damages or losses they may incur, such as the loss of crop revenues, as a result of construction across their property. Normally, they are compensated through several growing seasons.

Overland pipeline construction in a rural environment generally would proceed as a moving assembly line, as summarized below. Typically, job-specific work crews would construct the facilities associated with the compressor stations.

Standard pipeline construction is composed of specific activities, including survey and staking of the ROW, clearing and grading, trenching, pipe stringing, bending, welding, lowering-in, backfilling, hydrostatic testing, tie-in, cleanup, and commissioning. In addition to standard pipeline construction methods, the pipeline company would use special construction techniques where warranted by site-specific conditions. These special techniques would be used when constructing across rugged terrain, water bodies, wetlands, paved roads, highways, and railroads.

3.1.1 SURVEY AND STAKING

The first step of construction involves marking the limits of the approved work area (i.e., construction ROW boundaries, additional temporary workspace areas) and flagging the locations of approved access roads and foreign utility lines. Wetland boundaries and other environmentally sensitive areas also are marked or fenced for protection at this time. Before the pipeline trench is excavated, a survey crew stakes the centerline of the proposed trench.

3.1.2 CLEARING AND GRADING

Before clearing and grading activities are conducted, the landowners' fences (if any) are braced and cut, and temporary gates and fences are installed to contain livestock, if present. A clearing crew follows the fence crew and clears the work area of vegetation and obstacles

(e.g., trees, logs, brush, rocks). Grading is conducted where necessary to provide a reasonably level work surface. Root stock is left in the ground in areas where the ground is relatively flat and does not require grading. More extensive grading is required in steep side slopes, vertical areas, or wherever else necessary to avoid bending the pipeline excessively.

3.1.3 TRENCHING

The trench is excavated to a depth that provides sufficient cover over the pipeline after backfilling. Typically, the trench is about 4 to 6 feet wide in stable soils and about 2 to 5 feet deep to the top of the pipe, depending on the pipeline's diameter. This depth allows for the required minimum of 30 to 36 inches of cover. Additional cover for the pipeline is provided at road and water body crossings, while less cover (a minimum of 18 inches) is required in rock. The trenching crew uses a wheel trencher or backhoe to dig the pipe trench.

When rock or rocky formations are encountered, tractor-mounted mechanical rippers or rock trenchers are used to fracture the rock prior to excavation. In areas where mechanical equipment could not break up or loosen the bedrock, blasting is required. The contractor would be required to use explosives in accordance with state and federal guidelines to ensure a safe and controlled blast. Excavated rock would then be used to backfill the trench to the top of the existing bedrock profile.

In areas where there is a need to separate topsoil from the subsoil, the topsoil is graded prior to trenching. The topsoil over the ditch line is segregated for the majority of the project (unless requested otherwise by the landowner). Clearing activity on the spoil side is limited to what is necessary for construction activity. Topsoil is stored in a pile that is separate from the subsoil to allow for proper restoration of the soil during the backfilling process. Spoil typically is deposited on the nonworking side of the ROW, and gaps are left between the spoil piles to prevent storm water runoff from backing up or flooding. Topsoil is returned to its original ground level plus some mounding to account for soil subsidence after the subsoil is backfilled in the trench. As backfilling operations begin, the soil is returned to the trench in reverse order, with the subsoil put back first, followed by the topsoil. This process ensures that the topsoil is returned to its original position.

Figure 3.1 Pipeline Trenching Operations (Source: Photo courtesy of U.S. Pipeline)

3.1.4 PIPE STRINGING, BENDING, AND WELDING

Prior to or following trenching, sections of externally coated pipe up to 80 feet long (also referred to as "joints") are transported to the ROW by truck over public road networks and along authorized private access roads and placed, or "strung," along the trench in a continuous line.

After the pipe sections are strung along the trench and before joints are welded together, individual sections of the pipe would be bent where necessary to allow for fitting the pipeline uniformly with the varying contours of the bottom of the trench. Workers would use a track-mounted, hydraulic pipe-bending machine to shape the pipe to the contours of the terrain. The bending machine uses a series of clamps and hydraulic pressure to make a very smooth, controlled bend in the pipe. All bending must be performed in strict accordance with federally prescribed standards to ensure the integrity of the bend. When a section of pipe requires multiple or complex bends, that work is performed at the factory, or else pipeline fittings such as elbows are installed.

Welding is the process that joins the various sections of pipe together into one continuous length. After the pipe sections are bent, the joints are welded together into long strings and placed on temporary supports. The pipe gang and a welding crew are responsible for the welding process. The pipe gang uses special pipeline equipment called side booms to pick up each join of pipe, align it with the previous joint, and make the first part (a pass called the stringer bead) of the weld. Additional filler passes are made by welders who immediately follow the stringer bead on what is called the welding firing line. Stringer, hot-pass, and capping welders make up the firing line, and they are followed in certain locations by tie-in welders. (On difficult-fit welds, the welder sometimes also back-welds the pipe by welding the welds from the inside to assure the integrity of the weld) The pipe gang then moves down the line to the next section and repeats the process. The welding crew follows the pipe stringing gang to complete each weld.

In recent years, contractors have used semiautomatic welding units to move down a pipeline and complete the welding process. Semiautomatic welding must be completed to strict specifications and still requires qualified welders, and personnel are required to set up the equipment and hand-weld at connection points and crossings.

As part of the quality assurance process, each welder must pass qualification tests to work on a particular pipeline job, and each weld procedure must be approved for use on that job in accordance with federally adopted welding standards. Welder qualification takes place before the project begins. Each welder must complete several welds using the same type of pipe as that to be used in the project. The welds are then evaluated by placing the welded material in a machine and measuring the force required to pull the weld apart. Interestingly, the weld has a greater tensile strength than the pipe itself. The pipe must break before the weld.

One hundred percent of the welds undergo radiographic inspection (X-ray). A second quality assurance test ensures the quality of the ongoing welding operation on-site. In this test, qualified technicians take X-rays of the pipe welds to ensure that the completed welds meet federally prescribed quality standards. The X-ray technician processes the film in a small, portable darkroom at the site. If the technician detects any flaws, the weld is repaired or cut out, and a new weld is made. Another type of weld quality inspection employs ultrasonic technology.

A protective epoxy coating or mastic is applied to the welded joints once the welds are approved. Line pipe receives an external coating, which inhibits corrosion by preventing moisture from coming into direct contact with the steel. This process is normally completed at the coating mill where the pipe is manufactured or at another coating plant location before it is delivered to the construction site. All coated pipes, however, have uncoated areas 3 to 6 inches from each end of the pipe to prevent the coating from interfering with the welding process. Once the welds are made, a coating crew coats the field joint, the area around the weld, before the pipeline is lowered into the ditch.

Pipeline companies use several different types of coatings for field joints, the most common being fusion-bond epoxy, polyethylene heat-shrink sleeves, or heated mastic tape. Prior to application, the coating crew thoroughly cleans the bare pipe with a power wire brush or a sandblast machine to remove any dirt, mill scale, or debris. The crew then applies the coating and allows it to dry prior to lowering the pipe in the ditch. Before the pipe is lowered into the trench, the coating of the entire pipeline is inspected to ensure it is free of defects. The pipeline is then electronically inspected, or "jeeped," for faults or voids in the epoxy coating and visually inspected for faults, scratches, or other coating defects. Damage to the coating is repaired before the pipeline is lowered into the trench.

3.1.5 LOWERING-IN AND BACKFILLING

Before the pipeline is lowered into the trench, an environmental inspector inspects the trench to be sure it is free of livestock or wildlife that may have become trapped in the trench, as well as free of rocks and other debris that could damage the pipe or protective coating. At the end of the day after welding is completed, the pipe crew installs end caps (rubber expandable plugs) at the end of the pipeline to prevent debris and wildlife from entering the pipe. In areas where the trench had accumulated water since being dug, dewatering could be necessary to allow inspection of the bottom of the trench. The pipeline then is lowered into the trench. On sloped terrain, trench breakers (stacked sandbags or foam) are installed in the trench at specified intervals to prevent subsurface water movement along the pipeline.

In rocky areas, the pipeline is protected with a rock shield (a fabric or screen that is wrapped around the pipe to protect it and its coating from damage by rocks, stones, roots, and other debris) or sand aggregate. In an alternative method, the trench bottom is filled with padding material (e.g., finer grain sand, soil, or gravel) to protect the pipeline. Topsoil is not used as padding material.

Lowering the welded pipe into the trench demands the close coordination of skilled operators. By using a series of side-booms (tracked construction equipment with a boom on the side), operators simultaneously lift the pipe and carefully lower the welded sections into the trench. Nonmetallic slings protect the pipe and its coating as it is lifted and moved into position.

The trench is then backfilled using the excavated material. As with previous construction crews, the backfilling crew takes care to protect the pipe and coating as the soil is returned to the trench. The soil is returned to the trench in reverse order, with the subsoil put back first, followed by the topsoil. The segregated topsoil is restored to its original grade and contour last by using either a backhoe or padding machine, depending on the soil makeup.

In areas where the ground is rocky and coarse, crews will either screen the backfill material to remove rocks, bring in clean fill to cover the pipe, or cover the pipe with a material to protect it from sharp rocks. Once the pipe is sufficiently covered, the coarser soil and rock can be used to complete the backfill.

Figure 3.2 Crew Lowering a Pipeline into a Trench (Source: Photo courtesy of U.S. Pipeline)

3.2 SPECIAL CONSTRUCTION PROCEDURES

In addition to standard pipeline construction methods, special construction techniques are used when warranted by site-specific conditions, such as when constructing across paved roads, highways, railroads, steep terrain, water bodies, and wetlands, and when blasting through rock.

The techniques are described below.

Additional construction areas, or temporary extra workspaces, are required for construction at road crossings, railroad crossings, crossings of existing pipelines and utilities, stringing truck turnaround areas, wetland crossings, horizontal directional drilling (HDD) entrance and exit pits, and open-cut water body crossings. These extra workspaces are located adjacent to the construction ROW and could be used for such purposes as spoil storage, staging, equipment movement, material stockpiles, and pull-string assembly associated with HDD installation. Individual extra workspaces would range in size from less than 0.1 to 2 acres and would be returned to their preconstruction condition and former use following completion of construction activities.

3.2.1 ROAD, HIGHWAY, AND RAILROAD CROSSINGS

Construction across paved roads, highways, and railroads would be carried out in accordance with the requirements of the appropriate road and railroad crossing permits and approvals obtained by the pipeline company. In general, major paved roads, highways, and railroads are crossed by boring beneath the road or railroad. Boring requires excavating a pit on each side of the feature, placing the boring equipment in the pit, and then boring a hole under the road at least equal to the diameter of the pipe. Once the hole is bored, a prefabricated pipe section is pushed through the borehole that would consist of either extra-heavy wall-thickness carrier pipe or two pipes consisting of an outer casing pipe and the inner carrier pipe. For long crossings, sections could be welded onto the pipe string just before being pushed through the borehole. Boring activities would result in minimal or no disruption to traffic at road, highway, or railroad crossings. Each boring project is expected to take 2 to 10 days. Operations typically are conducted 24 hours per day, 7 days per week until the boring is completed.

Smaller unpaved roads and driveways are crossed using the open-cut method where permitted by local authorities or private owners. The open-cut method requires temporarily closing the road to traffic and establishing detours. In instances where a reasonable detour is not feasible, at least one lane of traffic is kept open except during brief periods when it is essential to close the road to install the pipeline. Most open-cut road-crossing construction projects (including road resurfacing) take some weeks to complete, depending on soil settlement after compaction. (In general, most pipeline companies prefer to wait several weeks before final resurfacing.) Posting signs at open-cut road crossings and other measures are undertaken to help ensure safety and minimize traffic disruptions.

3.2.2 STEEP TERRAIN

Additional grading may be required in areas where the proposed pipeline route crosses steep slopes. Steep slopes often need to be graded down to a gentler slope to accommodate pipe-bending limitations. In such areas, the slopes are cut away and, after the pipeline are installed, reconstructed to their original contours during restoration.

In areas where the proposed pipeline route crosses laterally along the side of a slope, cut-and-fill grading may be required to obtain a safe, flat, work terrace. Generally, on steep side slopes, soil from the high side of the ROW is excavated and moved to the low side of the ROW to create a safe and level work terrace. Under these circumstances, the topsoil is stripped from the entire width of the ROW. After the pipeline is installed, the soil from the low side of the

ROW is returned to the high side, the topsoil is replaced, and the slope's original contours are restored.

In steep terrain, temporary sediment barriers such as silt fences and certified weed-free straw bales are installed during clearing to prevent the movement of disturbed soil off the ROW.

Temporary slope breakers that consist of mounded and compacted soil are installed across the

ROW during grading, and permanent slope breakers are installed during cleanup. Following construction, seed is applied to steep slopes, and the ROW is mulched with certified weed-free hay or non brittle straw or is covered with erosion-control fabric. Sediment barriers are maintained across the ROW until permanent vegetation is established.

3.2.3 WATER BODY CROSSINGS

The generally preferred method of crossing a water body that is flowing at the time of construction is HDD compared to the open-cut method, since HDD's decreasing cost and lack of environmental impact are making it more popular. The open-cut crossing method involves trenching through the water body while water continues to flow through the trenching area. If no water is flowing at the time of construction, the water body is crossed using conventional upland cross-country construction techniques.

The open-cut crossing method involves excavating a trench across the bottom of the river or stream to be crossed with the pipeline. Depending on the depth of the water, the construction equipment may have to be placed on barges or other floating platforms to complete excavation of the pipe trench. If the water is shallow enough, the contractor can divert the water flow with dams and flume pipe, which can allow backhoes working from the banks or the streambed to dig the trench.

The contractor prepares the pipe for the crossing by stringing it out on one side of the stream or river and then welding, coating, and hydrostatically testing the entire pipe segment. Side booms carry the pipe segment into the stream bed just as they do for construction on land, or the construction crew floats the pipe into the river with flotation devices and positions it for being buried in the trench. Concrete weights or concrete coating ensure that the pipe will stay in position at the bottom of the trench once the contractor removes the flotation devices.

The flume, dam-and-pump, and HDD methods also could be considered as alternative crossing methods. The flume crossing method involves diverting the flow of water across the trenching area through one or more flume pipes placed in the water body. The dam-and-pump method is similar to the flume method except that pumps and hoses are used instead of flumes to move water around the construction work area.

The HDD method involves drilling a hole under the water body and installing a prefabricated segment of pipe through the hole. Before a directional drill is designed, core samples are taken on both sides of the crossing to evaluate the underground rock and sand formations. If the subsurface will support a directional drill, the engineer can design a crossing that establishes the entry and exit points of the pipeline crossing and its profile as it would traverse under the crossing.

The HDD method involves drilling a pilot hole under the water body and banks and then enlarging the hole through successive reaming until the hole is large enough to accommodate a prefabricated segment of pipe. Throughout the process of drilling and enlarging the hole, slurry made of nontoxic fluids (e.g., bentonite and water) is circulated through the drilling tools to lubricate the drill bit, remove drill cuttings, and keep the hole open. This slurry is referred to as drilling mud.

While this drilling is in progress, the line pipe sections are strung out on the far side of the crossing for welding. Once welded, the joints are X-rayed, coated, hydrostatically tested, and then placed on rollers or padded skids in preparation for being pulled through the drilled-out hole.

Figure 3.3 Horizontal Directional Drilling (HDD) Operation (Source: Photo courtesy of U.S. Pipeline)

3.3 ABOVEGROUND FACILITY CONSTRUCTION PROCEDURES

The aboveground facilities are constructed concurrent with pipeline installation, but construction is conducted by special fabrication crews that generally work separately from the pipeline construction spreads.

3.3.1 COMPRESSOR STATIONS

Construction of the compressor stations involves clearing, grading, and revising the sites to the surveyed elevations where necessary for placement of concrete foundations for buildings and to support skid-mounted equipment. Prefabricated segments of pipe, valves, fittings, and flanges are welded at the shop or on-site and assembled at the compressor station site. The compressor units and other large equipment are mounted on their respective foundations, and the equipment is micro-leveled to reduce vibration; then the compressor enclosures are erected around them. Noise-abatement equipment (including sound-attenuating enclosures around the turbines, exhaust stack silencers, and air inlet silencers) and emission control technology are installed as needed to meet applicable federal, state, and/or local standards. Electrical, domestic water and septic, and communications utilities are installed as necessary.

Facility piping, both above and below ground, are installed and hydrostatically tested before being placed into service. Controls and safety devices such as the emergency shutdown system, relief valves, gas and fire detection facilities, and other protection and safety devices are also checked and tested. Upon completion of construction, all disturbed areas associated with the aboveground facilities are finish-graded and seeded or covered with gravel, as appropriate. All roads and parking areas are graveled. Additionally, the compressor station sites are fenced for security and protection.

Somewhat less than 100 workers and five inspectors are required to construct a typical compressor station. Initial site preparation typically takes approximately 16 to 20 weeks, while actual installation requires more than 6 months. The lead time needed to purchase some equipment, such as compressors, is more than 1 year.

Direct emissions would result from the construction of a natural gas compressor station; although construction impacts are expected to be temporary and transient, and the short-term exposure levels are considered minimal. These emissions include exhaust from the construction equipment and vehicle engines and fugitive dust from the disturbed areas along the ROW.

Carbon monoxide emissions are emitted in the largest quantities during construction, followed by TSP, NOx, HC, and SO2 emissions. (http://www.osti.gov/bridge)

3.4 PHYSICAL NETWORKS

Physical networks are perhaps the most common and the most readily identifiable class of networks. Indeed, often when we think of networks, we typically envision a physical network, be it a communication network, an electrical network, a hydraulic network, a mechanical network, a transportation network or increasingly these present days a computer

chip. Table 3.1 summarizes the components of any physical networks that emerge in this varied application setting (Ahuja., Magnanti et.al. 1989)

Table 3.1 Components of Common Physical Networks

Application	**Physical Analog of Nodes**	**Physical Analog of Arcs**	**Flow**
Communications systems	Telephone exchanges computers, transmission facilities, satellites	Cables, fibre optic links, microwave relay links	Voice messages, data, video transmissions
Hydraulic systems	Pumping stations,	Pipelines	Water, gas, oil,

	reservoirs, lakes		hydraulic fluids
Integrated computer circuits	Gates, register processors	Wires	Electrical circuit
Mechanical systems	Joints	Rods, beams, springs	Heat, energy
Transportation system	Intersections, airports, rail yards	Highways, rail beds, airline routes	Passengers freight, vehicles, operators.

3.5 NETWORK ANALYSIS

Natural gas network analysis is used to determine the amount of gas, flow rate of the gas and the pressure used in the pipeline system. Besides that, it can also be used to determine the usage of gas by consumers especially during the peak times. By making the network analysis, time of maintenance and failure of pipeline can be measured. The effect of new load on the pipeline can also be predicted. Generally, network analysis can be divided into three types; via Network Tracing, Network Routing and Network Allocation. Network tracing is done in other to trace the allocation of the particular pipeline in the system. Network routine is done in order to find the optimum path or the shortest path which cost less for the system. Network allocation is done in order to locate all the pipelines into the main support. Our analysis of the network shall be focused in networking routing (Dott, 1997)

3.5.0 NETWORK ROUTING

Route networks are composite entities that frequently model complex distribution and logistics decisions. The traditional operation research transportation problem is illustrative. A shipper with an inventory of goods at its warehouse must ship to geographically dispersed retail centers, each with a given customer demand. Each arc connecting a supply point to a retail centre incurs cost based upon some physical network, in this case the transportation network. Rather than solving the problem directly on the physical network, we preprocess the data and construct transportation routes. Hence, in effect an arc connecting a supply point and a retail centre might represent distribution channel with varied legs:

(i) From a warehouse(by truck) to a rail station,

(ii) From the rail station to a rail head elsewhere in the system,

(iii) From the rail head (by truck) to a distribution centre and

(iv) From the distribution centre (on a local delivery truck) to the final consumer.

If we assign the arc the composite distribution cost of all the intermediary legs, as well as the distribution capacity for this route, this problem becomes a classic network transportation model defined over a bipartite graph: find the flow from the gas reserves to consumers that minimizes overall costs.

Similar application arises in all of the problem settings we have mentioned in our discussion of physical networks. In some applications, however the network might contain intermediary points that serve as transshipment nodes; they neither generate flow nor consume flow. Pumping stations in a natural gas transportation network would be an example. In this application, the network model is a general minimum cost flow problem, rather than a classic transportation problem. (Dott, 1997)

3.5.1 Metering Stations

Metering stations are placed periodically along interstate natural gas pipelines. These stations allow pipeline and local distribution companies to monitor, manage, and account for the natural gas in their pipes. Essentially, these metering stations measure the flow of gas along the pipeline, allowing pipeline companies to track natural gas as it flows along the pipeline.

Metering stations employ specialized meters to measure the natural gas as it flows through the pipeline without impeding its movement. In essence, the metering station is the company's "cash register." Figure 3.4 shows a typical meter station.

Meter/regulator stations are generally constructed adjacent to the cleared pipeline right-of-way (ROW) at each of the receipt and interconnect points to meter the flow and adjust the pressure of natural gas received from or delivered to those systems. A meter/regulator station typically includes meter and regulator equipment, a filter separator, odorant equipment, and a control building housed within a fenced perimeter.

Figure 3.4: A Typical Metering Station (Source: U.S. Pipeline, Inc.)

3.5.2 THE STRUCTURE AND OPERATION OF GAS PIPELINE NETWORKS

Natural gas is produced from wells drilled into hydrocarbon-bearing geological structures beneath the surface of the earth. Natural gas I s composed largely of methane and usually contains a limited amount of impurities such as oxygen, nitrogen, carbon dioxide and sometimes hydrogen sulfide which are natural by-products of gas production (Encarta encyclopedia, 2007)

Natural gas is transported from the well, where it is produced to the burner-tip of the end user through a number of interconnected pipeline networks. Because of its gaseous nature, natural gas must be transported through one completely interconnected pipeline system to avoid leakage to the atmosphere. The system which transports this gas is comprised of a number of networks within each other. These networks are described below.

Natural gas produced from the wells is collected and shipped into a processing plant where moisture and impurities are removed from the gas before it is shipped farther downstream. The network connecting a number of gas wells to a processing plant is called a gathering system. In this arrangement the plant acts as a hub. A hub is a central facility within a network. The plant or hub receives incoming gas from gathering pipes and feeds a smaller number of processed streams existing in the plant. Some of these processed streams might include processed gas, sulphur and liquefied petroleum gases. (Dott, 1997)

Processed gas from many plants is collected by a larger pipeline system, sometimes called a trunk line. A trunk line must have a number of destinations to which processed or sales gas is delivered. At this time in Escravos-Lagos, the Escravos-Lagos Pipeline (ELP) is the main gas trunk line and collects most of the sales gas within the state.

Distribution of the natural gas to most residential, commercial and industrial consumers is done through distribution systems, usually owned by locally distribution companies. Distribution systems are similar to gather systems except they usually much larger in scale and homes and businesses are connected to the network instead of the gas wells or fields.

3.5.3 GENERAL UNIQUE ASPECTS OF GAS PIPELINE NETWORKS

Pipeline transportation is unique in the transportation industry. The following four sub-sections describe some of the important differences which make pipeline networks worthy of special study in the field of transportation networks.

3.5.4 MODE OF TRANSPORTATION TECHNOLOGY

Natural gas is captive to the pipeline mode of transportation because of its gaseous state. Liquefied Natural Gas (LNG) can be transported via truck or ship, but LNG is expensive to produce and must be shipped at a very low temperature making this option prohibitively in most cases.

There are some difficulties in the use of natural gas. The first is the availability: 73% of the world's known reserves are in West Asia (Bangladesh), further east (Myanmar), West Africa (Nigeria) and former Soviet Union states (BP 1998). In addition to this, its low energy density (especially vis-à-vis oil) makes it difficult to store and transport. While oil can easily be shipped by tankers, gas must typically be transported through pipelines, which are capital- intensive. Pipeline technology is well established relatively mature. For long- distance transmission, natural gas is transported through high-pressure (900+p.s.i) pipelines with diameters typically in the three to four (3-4) foot ranges (Tongia, Arunnachalam. et.al, 1998). A transmission system consists of not only pipe to transport the gas but also of compressor stations- to re-pressurize the gas which loses pressure due to friction- at regular intervals. A small fraction of the transported gas is consumed by the gas-driven compressors, though it is possible to use electric compressors instead. The most notable improvements in technology have been for superior materials and advanced welding techniques that have made pipelines thinner walled, safer, and less expensive than before.

The other method of transport, as Liquefied Natural Gas (LNG), is even more capital intensive. This is because natural gas liquefies only at very low temperatures, below- 160 degree Celsius. For a six million (6,000,000) tons/year system (about 8 BCM/year re-gasified), liquefaction plants, LNG tankers, receiving and storage terminals and re-gasification facilities can typically cost over four billion dollars. Because of this, for relatively for short distances- under about 2000 miles-pipelines are less expensive than LNG (Energy Information Administration, 1997b). Strong economies of scales exist for natural gas pipelines, more so than for LNG facilities. The volumes economically transported by a pipeline strongly depend on the pipeline diameter. Due to the non linear effects of friction and pressure losses, doubling the diameter of the pipe allows for about six times the gas flow. Typical transmission pipelines operate most economically at volumes of about 20 BCM/year, or greater at higher pressures (Tongia, Aruncachalam. Et.al.1998). Mode captivity in the gas transportation industry impacts the gas pricing directly. As with transportation of goods in general, improved efficiency in gas shipping this industry may not incorporate efficiency improvements as quickly as might occur in more competitive areas.

3.5.5 CONTINUOUS TRANSPORTATION SYSTEM

Pipeline networks are continuous structures which can receive or deliver gas volumes at any point along the route so long as the necessary mechanical components exist at the location. These components include valve and a metering device with downstream pipeline connections. Continuous transportation systems contrast with discrete systems in which receipts and deliveries may only be made at certain drop-off and pick-up locations. An example of this is an airline route in which passengers and baggage may only board or exist an air plane while it is landed at an airport.

3.5.6 TIME OF GAS TRANSPORT

In the gas pipeline industry, time of travel is of no consequence. Because gas receipts are blended along the length of the pipeline, pipeline operators allow shippers to benefit from "instantaneous delivery". That is, as soon as a quantity of gas is received by a pipeline it instantaneously displaces the same volume of gas at the delivery point.

The unimportance o gas transport time does not; however imply that there is not some cost associated with transporting gas longer distance. It is true that consumers who live farther from the geological supply of natural gas pay higher prices for their gas than consumers close to gas production areas. This additional cost however is borne out of pipeline infrastructure and its operation, but not from actual time of transport from well-head to burner-tip.

3.5.7 DIRECTED NETWORK VS. UNDIRECTED NETWORK

Pipelines networks are largely directed networks. A directed network is composed of links which flow in only one direction. An undirected network encompasses flow in both directions on its links. An urban road system which utilizes no one street is an example of an undirected network.

Pipelines systems tend to be directed because they connect supply and demand centres, and flow is generally from supply to demand. There are, however, some bi-directional pipelines which enable flow in both directions. These pipelines can be useful when oversupply of one or more demand regions occur.

3.5.8 ADVANTAGES, USE AND TRANSPORT OF NATURAL GAS

Natural gas has emerged as the fuel of choice for various uses. It is most extensively used by domestic consumers cooking and heating, petrochemical and fertilizer industries as both fuel and feedstock, and by power producers for generating electricity. While there are substitutes for natural gas in industry (e.g. naphtha for fertilizer plants), current prices makes natural gas more competitive Worldwide trade in natural gas is also growing rapidly, and it reserves are more distributed throughout the world than those of oil. The proven reserves have more than doubled in the last 20 years, increasing the world R/P to 64.1 years in 1997 (BP, 1998). The following are the advantages of liquefied natural gas;

i. Natural gas is an attractive fuel because it is cleaning burning and efficient.
ii. About ninety-seven percent (97%) of the natural gas consumed in Ghana is produced in Nigeria.
iii. Ghana could soon become part of the larger global market by increasing imports of LNG and also become an LNG exporter later after its oil discovery.
iv. West African gas pipeline network will reduce or end the impact of harmful gas flaring hence reducing the impact of global warming.

3.6 MODELING THE PROBLEM

We used the Prim minimal spanning tree algorithm for directed graph G= (*V, E],* where V is the set of nodes and E is the set of edges. Each edge is defined by a node pair (h, k), each edge has a non-negative length. We start at a given node and sequentially add an edge to tree at each of the iterations.

The weight of the graph is the total distance covered in the regional capitals.

Therefore the weight of the graph is given by;

$$\omega(Q) = \sum_{(h,k)\in Q} \omega(h,k)$$

More formally, we define a graph G as an ordered pair G = (V, E) where

- V is a set of vertices (nodes)
- E is a set of edges (links).
- Each edge is a pair of vertices. In other words, each element of E is a pair of elements of V.

A connected weighted graph with vertices V(A to X) and edges E.

Let the vertices V of map = {A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z.}

Edges (E) of map= pair (h, k); where h= A, B, C,…, Z; and k= A, B, C, ..., Z.

The algorithm continuously increases the size of a tree, one edge at a time, starting with a tree consisting of a single vertex, until it spans all vertices.

- Input: A non- empty connected weighted graph with vertices V and edges E in which the weights are non-negative.
- Initialize: V_{new} = {A}, where A is an arbitrary node (starting point) from V, E_{new} = { }
- Repeat until V_{new} = Z:
  - Choose an edge (h, k) with minimal weight such that h is in V_{new} and k is not (if there are multiple edges with the same weight, any of them may be picked)
  - Add k to V_{new}, and (h, k) to E_{new}.
- Output: V_{new} and E_{new} describe a minimal spanning tree

Weight function : $\boldsymbol{E} \rightarrow \boldsymbol{R}$ (assigning length to edges)

Minimum spanning tree: tree that connects all the vertices and minimizes

$$\boldsymbol{\omega(Q) = \sum_{(h,k)\in Q} \omega(h,k)}$$

Since the connection problem is a network problem, it can be solved by the shortest path method. But because of its special nature, it can be solved more easily by Prim's algorithm, which is more efficient for the connection problem.

3.7.0 METHODS OF SOLVING SHORTEST PATH PROBLEMS

3.7.1 SINGLE SOURCE PATHS, NON-NEGATIVE WEIGHTS (DIJKSTRA'S ALGORITHM)

Dijkstra's algorithm, conceived by Dutch computer scientist Edsger Dijkstra in 1959, is a graph search algorithm that solves the single-source shortest path problem from a graph with nonnegative edge path costs, producing a shortest path tree. This algorithm is often used in routing. An equivalent algorithm was developed by Edward F Moore in 1957.

For a given source vertex (node) in the graph, the algorithm finds the path with the lowest cost (i.e. the shortest path) between that vertex and that of every vertex. It can also be used for finding costs of shortest paths from a single destination vertex by stopping the algorithm once the shortest path to the destination vertex has been determined. For example, if the vertices of the graph represent cities and edge path costs represent driving distances between two pairs of cities connected by a direct road, Dijkstra's algorithm can be used to find the shortest route between one city and all other cities. As a result, the shortest path first is widely used in network routing protocols, most notably IS-SI and OSPF (Open Shortest Path First).

3.7.2 ALGORITHM

Let the node we are starting be called the initial node. Let a distance of the node Y be the distance from the initial node to it. Dijkstra's algorithm will assign more initial distance values and will try to improve them step-by-step.

(i) Assign to every node the distance value. Set it to zero for our initial node and infinity for all other nodes.

(ii) Mark all nodes as unvisited. Set initial node as current.

(iii) For current node, consider all its as unvisited neighbours and calculate their distance (from the initial node). For example, if current node (A) has distance of 8, and an edge connecting it with another node (B) is 2, the distance to B through A will be 8+2=10. If the distance is less than the previously recorded distance (infinity in the beginning, zero for the initial node), overwrite the distance.

(iv) When we are done considering all neighbours of the current node, mark it as unvisited. A visited node will not be checked ever again; its distance now recorded is final and minimal.

(v) Set the unvisited node with the smallest distance (from the initial node) as the next "current node" and continue from step 3.

Dijkstra's algorithm finds the shortest path from the source node S to all other node in a network with nonnegative arc lengths. Dijkstra's algorithm maintains a distance label d (i) with each node i, which is an upper bound on the shortest path length from the source node to each node i. at any intermediate step, the algorithm divides the nodes of the network under considerations into two groups: those which it designates as permanently labeled (or permanent) and those which from it designates are temporarily labeled (or temporal). The distance label to any permanent node represents the shortest distance from the source node to that node.

The basic idea of the algorithm is to find out from the source node S and permanently labeled nodes in the order of their distance from the node S. initially, node S is assigned a permanent label of zero, and each other; node j a temporary label equally to infinity. At each iteration, the label of a node I is its shortest distance from the source node along the path whose internal node (i.e. nodes other than S or I itself) are permanently labeled. The algorithm selects a node i with minimum temporary label (breaking ties arbitrarily), makes it permanent, and reaches out from node- that is, scans all edges/arcs emanating from node I to update the distance labels of adjacent nodes. The algorithm terminates when it has designated all nodes permanent.

We can now express Dijkstra's algorithm as a set of steps.

Step 1: assign the permanent label O to the starting vertex.

Step 2: assign temporary labels to all the vertices that are connected directly to the most recently permanent labeled vertex.

Step 3: choose the vertex with the smallest temporary label and assign a permanent label to that vertex.

Step 4; Repeat step 2 and 3 until all vertices have been permanent labels.

Step 5; find the shortest path by tracing back through the network.

Note: Recording the order in which we assign permanent labels to the vertices is an essential part of the algorithm.

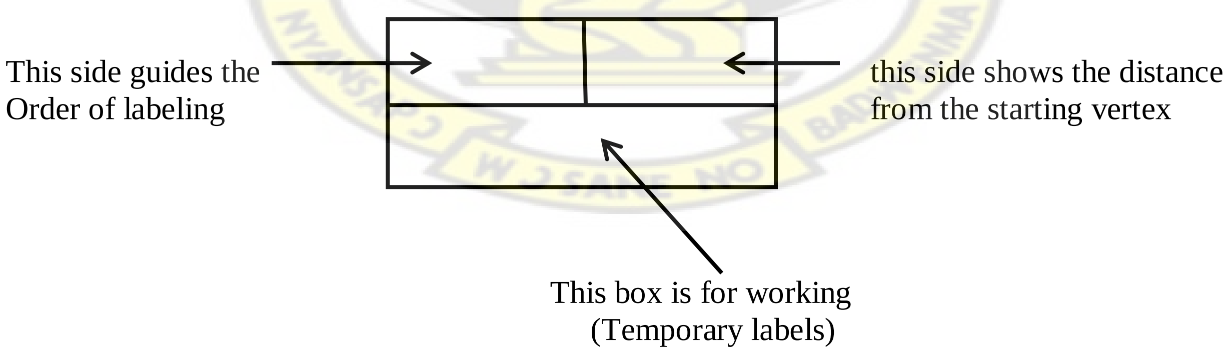

Figure 3.5: Order in which permanent labels are assigned to vertices

The algorithm gradually changes all temporary into permanent ones.

3.7.3 ALL-PAIRS SHORTEST PATH PROBLEM

The shortest path between two nodes might not be a direct edge between them, but instead involve a detour through other nodes. The all-pairs shortest path problem requires that we determine shortest path distance between every pair of nodes in the network.

3.7.4 FLOYD-WARSHALL ALGORITHM

The Floyd- Warshall algorithm obtains a matrix of shortest path distances within O $\{n^3\}$ Computations. The algorithm is based on inductive arguments developed by an application of a dynamic programming technique.

Let $d^k(i, j)$ represents the length of the shortest path from node i to node j subject to the condition that this path uses the node 1, 2, 3,…,k-1 as internal nodes clearly, d^{n+1} (i, j) represents the actual shortest path distance from i to j. the algorithm first computes $d^1(i, j)$ for all node pairs i and j. using d^1 (i, j), it then computes d^2 (i, j) for all pairs of nodes i and j. It repeats the process until it obtains d^{n+1} (i, j) for all node pairs i and j when it terminates. Given d^k (i, j), the algorithm computes $d^{k+1}(i, j) = \min \{d^k(i, k), d^k(i, j)\}$. The Floyd-Warshall algorithm remains of interest because it handles negative weight edges correctly.

3.7.5 MINIMUM-CONNECTOR

These points are to be noted;

1. A connected graph which contains no cycles is called a tree.
2. A spanning tree is a sub graph that includes all the vertices in the original graph is also a tree. A graph will have several trees.

These are all spanning tree.

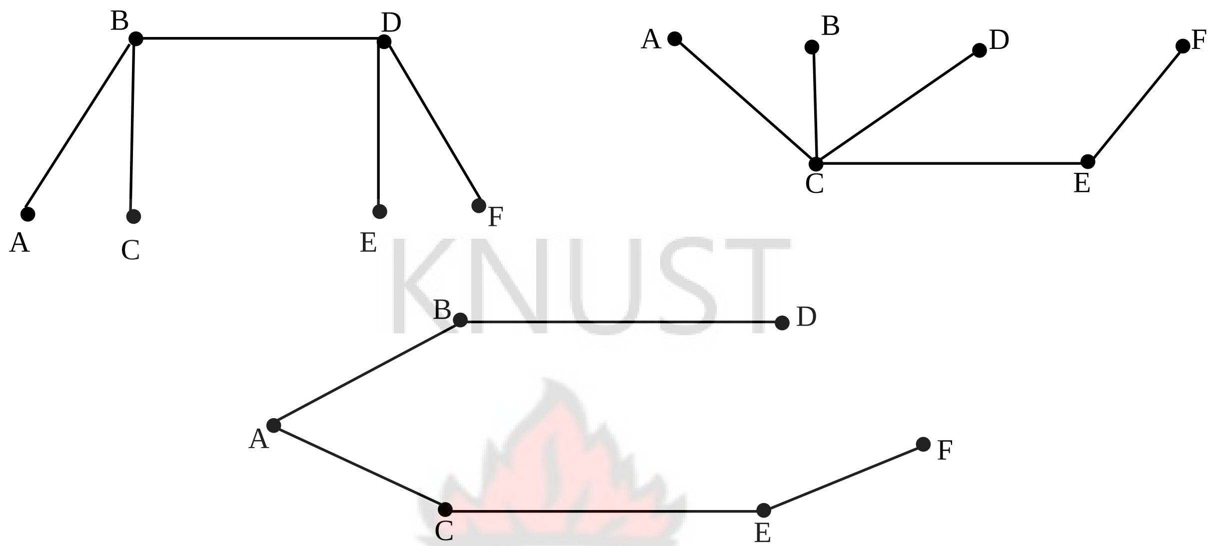

Figure 3.6: Examples of spanning trees

3.7.6 PRIM'S ALGORITHM

Prim's algorithm solves the shortest path problem for a directed graph with non-negative edge weights. For example, if the vertices of the graph represents gas well or roads connecting the towns and edge weights represent distances between pair of wells (or towns) connected by a pipeline, this algorithm can be used to find the shortest route between two gas wells (or towns). The algorithm was discovered in 1930 by mathematician Vojtech Jarnik and later independently by computer scientist Robert Prim in 1957 and rediscovered by Dijkstra in 1959. Therefore it is sometimes DJP algorithm or Jarnik algorithm. The algorithm builds a spanning tree from scratch by fanning out from a single node and adding arc one at a time. It means a tree spanning on a subset S of nodes and a nearest neighbour to S. the algorithm does so by identifying an arc (i, j) of minimum cost in the cut [S, S]. It adds arc (i, j) to the tree, node *j* to S repeats this basic steps until all nodes have been connected. This algorithm is said to be "greedy" since it picks the immediate best option available without taking into account the long-term effects of the choices made. The algorithm is;

Step 1; Start with any vertex.

Step 2; Join this vertex to the nearest vertex.

Step 3; join on the vertex which is nearest to either of those already connected.

Step 4; repeat until all vertices are connected.

Step 5; add the lengths of all the edges included in the minimum length spanning tree.

The correctness of the algorithm follows directly from the fact that each arc that is added to the tree is contained in some minimum spanning tree with the arcs that have been selected in the previous step. The matrix formulation of Prim's algorithm implemented in this thesis is given below.

3.7.6.1 MATRIX FORMULATION OF PRIM'S ALGORITHM

Step 1; choose a start vertex and delete all elements in that vertex's row and arrow its column.

Step 2; Neglecting all deleted terms, scan all arrowed columns for the lowest element and circle that element.

Step 3; Delete the circled element's row and arrow its column.

Step 4; Repeat step 2 and 3 until all rows deleted.

Step 5; the spanning tree is formed by the circled arc.

Step 6; write down the arcs in the order you selected them (Amponsah, 2007).

3.7.7 A MINIMUM CONNECTOR PROBLEM

A company is installing a system of cables to connect all towns in the region. The lower case variables in the network show distances in kilometers. The question is what is the least amount of cable needed?

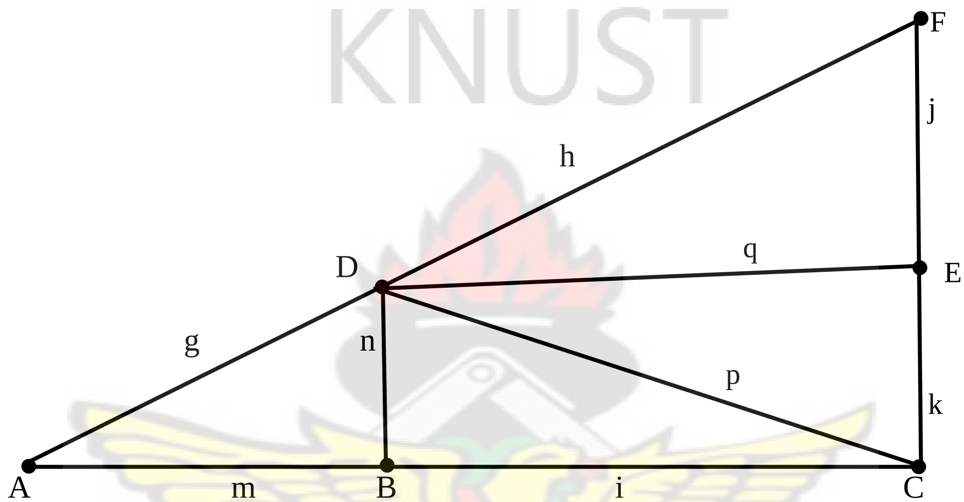

Figure 3.7: Examples of system of cables connecting cities

Prim's algorithms works from a start point and builds up the spanning tree step by step, connecting edges into the existing solution. It can be applied directly to the distance matrix, as well as to work the network itself, so it is more suitable for using a computer if the network is large.

The algorithm can be stated as follows:

Step 1; choose a starting vertex.

Step 2; join this vertex to the nearest vertex directly connected to it.

Step 3; Join the next nearest vertex, not already in the solution to any vertex in the solution, provided it does not form a cycle.

Step 4; repeat until all vertices have been included.

3.8 DATA COLLECTION

Maps and field work are required for pipeline routine, pipeline design and construction. The information and data needed for the analysis will be gathered from the Ghana Highways Authority and Ghana Private Roads and Transport Unions (GPRTU).

3.9 SUMMARY

In this chapter, we considered the method and the modeling of the gas pipeline problem into shortest path problem for easy computation.

The next chapter will focus on analyzing the gas pipeline path from Takoradi to all the regional capital towns and the environmental value and damages revealed by the gas pipeline network.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.0 INTRODUCTION

This chapter analyses the problem of designing the pipeline networks. The existing roads linking the regional capital towns are being used to provide access to the construction of the pipelines connection. The data involves length of road distances (km) between the various regional capital towns. The methodology outlined in the chapter three will be used to identify the overall network layout from Takoradi to all the regional capital towns, the author's own optimal layout using Prim's algorithm and the environmental damages. For easy computation, we let A,B,C,D,E,F,G,H,I, and J represent Takoradi, Cape Coast, Accra, Ho , Koforidua, Kumasi Sunyani, Wa, Tamale, and Bolgatanga respectively.

4.1 COMPUTATIONAL PROCEDURE AND ANALYSIS OF DATA

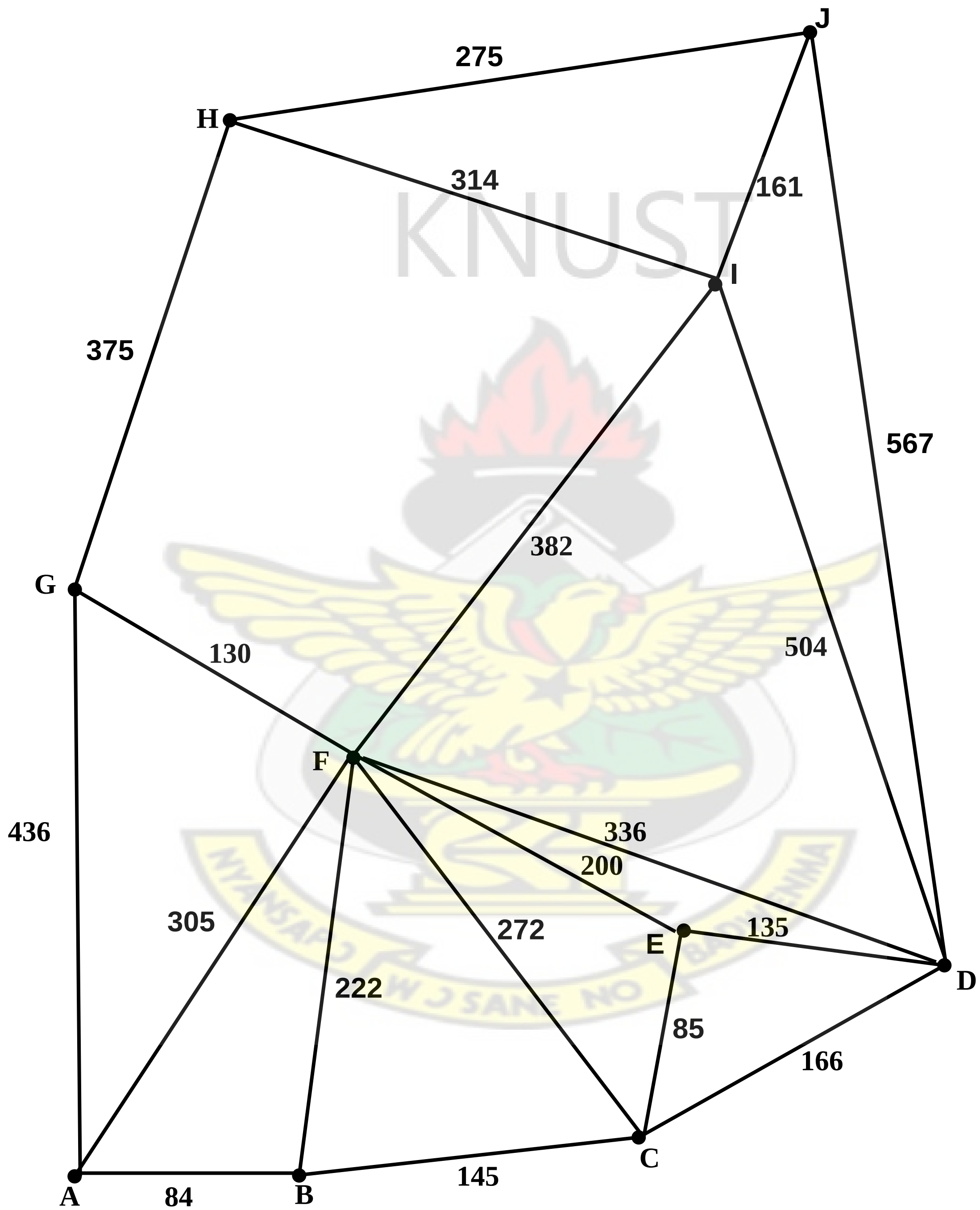

Figure 4.1

Pipeline Network (in km) from Takoradi to all the regional capital towns in Ghana

Source: Ghana High Authority (Not drawn to scale)

The pipelines used in these network systems can measure anywhere from 6 to 48 inches in diameter, although certain component pipe section can consist of small-diameter pipe that is as small as 0.5 inch in diameter. However, this small-diameter pipe is usually used only in gathering and distribution systems, although some is used for control-line or gauge-line purposes. Mainline pipes, the principal pipeline in a given system, are usually between 16 to 48 inches in diameter. Lateral pipelines, which deliver natural gas to or from the mainline, are typically between 6 and 16 inches in diameter. Most major interstate pipelines are between 24 and 36 inches in diameter.

Table 4.1: DISTANCE MATRIX OF THE NETWORK

	A	B	C	D	E	F	G	H	I	J
A	∞	**84**	∞	∞	∞	**105**	**436**	∞	∞	∞
B	**84**	∞	**145**	∞	∞	**222**	∞	∞	∞	∞
C	∞	**145**	∞	**166**	**85**	**272**	∞	∞	∞	∞
D	∞	∞	**166**	∞	**135**	**336**	∞	∞	**504**	**567**
E	∞	∞	**85**	**135**	∞	**200**	∞	∞	∞	∞
F	**305**	**222**	**272**	**336**	**200**	∞	**130**	∞	**382**	∞
G	**436**	∞	∞	∞	∞	**130**	∞	**375**	∞	∞
H	∞	∞	∞	∞	∞	∞	**375**	∞	**314**	**275**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	**275**	**161**	∞

Prim's Algorithm is now applied to the distance matrix above with the solution taken straight from the graph shown alongside.

MATRIX METHOD

Choose the starting vertex, A. Delete the row A. Look for the smallest entry in column A.

Table 4.2:Information1

	1 ↓									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
~~**A**~~	~~∞~~	~~**84**~~	~~∞~~	~~∞~~	~~∞~~	~~**105**~~	~~**436**~~	~~∞~~	~~∞~~	~~∞~~
B	**(84)**	∞	**145**	∞	∞	**222**	∞	∞	∞	∞
C	∞	**145**	∞	**166**	**85**	**272**	∞	∞	∞	∞
D	∞	∞	**166**	∞	**135**	**336**	∞	∞	**504**	**567**
E	∞	∞	**85**	**135**	∞	**200**	∞	∞	∞	∞
F	**305**	**222**	**272**	**336**	**200**	∞	**130**	∞	**382**	∞
G	**436**	∞	∞	∞	∞	**130**	∞	**375**	∞	∞
H	∞	∞	∞	∞	∞	∞	**375**	∞	**314**	**275**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	**275**	**161**	∞

Figure 4.2: Solution 1

AB is the smallest edge joining A to the other vertices. Put edge AB into solution. Delete row B. Look for the smallest entry in columns A and B.

Table 4.3: Information 2

	1 ↓	2 ↓								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
~~**B**~~	~~**84**~~	~~∞~~	~~**145**~~	~~∞~~	~~∞~~	~~**222**~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~
C	∞	(**145**)	∞	**166**	**85**	**272**	∞	∞	∞	∞
D	∞	∞	**166**	∞	**135**	**336**	∞	∞	**504**	**567**
E	∞	∞	**85**	**135**	∞	**200**	∞	∞	∞	∞
F	**305**	**222**	**272**	**336**	**200**	∞	**130**	∞	**382**	∞
G	**436**	∞	∞	∞	∞	**130**	∞	**375**	∞	∞
H	∞	∞	∞	∞	∞	∞	**375**	∞	**314**	**275**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	**275**	**161**	∞

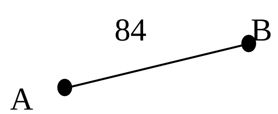

Figure 4.3: Solution 2

BC is the smallest edge joining A, B and C to the other vertices. Put edge BC into solution. Delete row C. Look for the smallest entry in columns A, B and C.

Table 4.4: Information 3

	1 ↓ A	2 ↓ B	3 ↓ C	D	E	F	G	H	I	J
~~C~~	~~∞~~	~~145~~	~~∞~~	~~166~~	~~85~~	~~272~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~
D	∞	∞	166	∞	135	336	∞	∞	504	567
E	∞	∞	(85)	135	∞	200	∞	∞	∞	∞
F	305	222	272	336	200	∞	130	∞	382	∞
G	436	∞	∞	∞	∞	130	∞	375	∞	∞
H	∞	∞	∞	∞	∞	∞	375	∞	314	275
I	∞	∞	∞	504	∞	382	∞	314	∞	161
J	∞	∞	∞	567	∞	∞	∞	275	161	∞

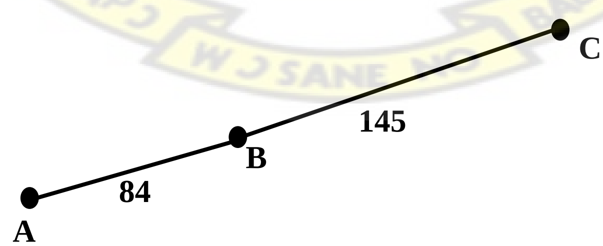

Figure 4.4: Solution 3

CE is the smallest edge joining A, B, C and E to the other vertices. Put edge CE into solution. Delete row E. Look for the smallest entry in columns A, B, C and E.

Table 4.5: Information 4

	1 ↓	2 ↓	3 ↓		4 ↓					
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
D	∞	∞	**166**	∞	**135**	**336**	∞	∞	**504**	**567**
~~**E**~~	~~∞~~	~~∞~~	~~**85**~~	~~**135**~~	~~∞~~	~~**200**~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~
F	**305**	**222**	**272**	**336**	**200**	∞	**130**	∞	**382**	∞
G	**436**	∞	∞	∞	∞	**130**	∞	**375**	∞	∞
H	∞	∞	∞	∞	∞	∞	**375**	∞	**314**	**275**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	**275**	**161**	∞

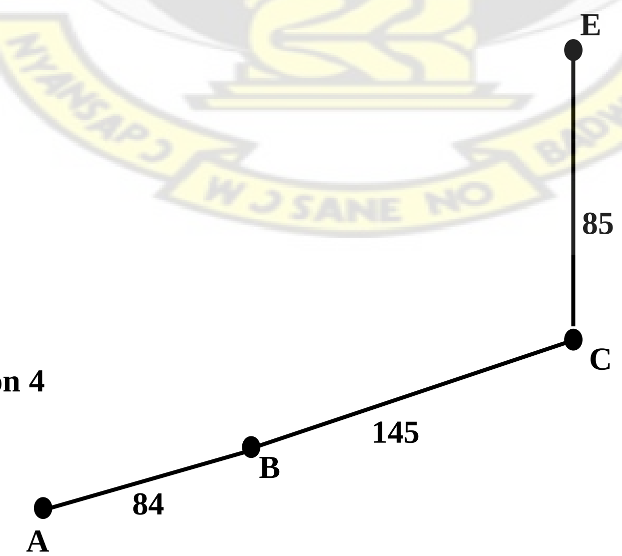

Figure 4.5: solution 4

ED is the smallest edge joining A, B, C, E and D to the other vertices. Put edge ED into solution. Delete row D. Look for the smallest entry in columns A, B, C, E and D

Table 4.6: Information 5

	A (1)	B (2)	C (3)	D (5)	E (4)	F	G	H	I	J
~~**D**~~	~~∞~~	~~∞~~	~~**166**~~	~~∞~~	~~**135**~~	~~**336**~~	~~∞~~	~~∞~~	~~**504**~~	~~**567**~~
F	**305**	**222**	**272**	**336**	**200**	∞	**130**	∞	**382**	∞
G	**436**	∞	∞	∞	∞	**130**	∞	**375**	∞	∞
H	∞	∞	∞	∞	∞	∞	**375**	∞	**314**	**275**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	**275**	**161**	∞

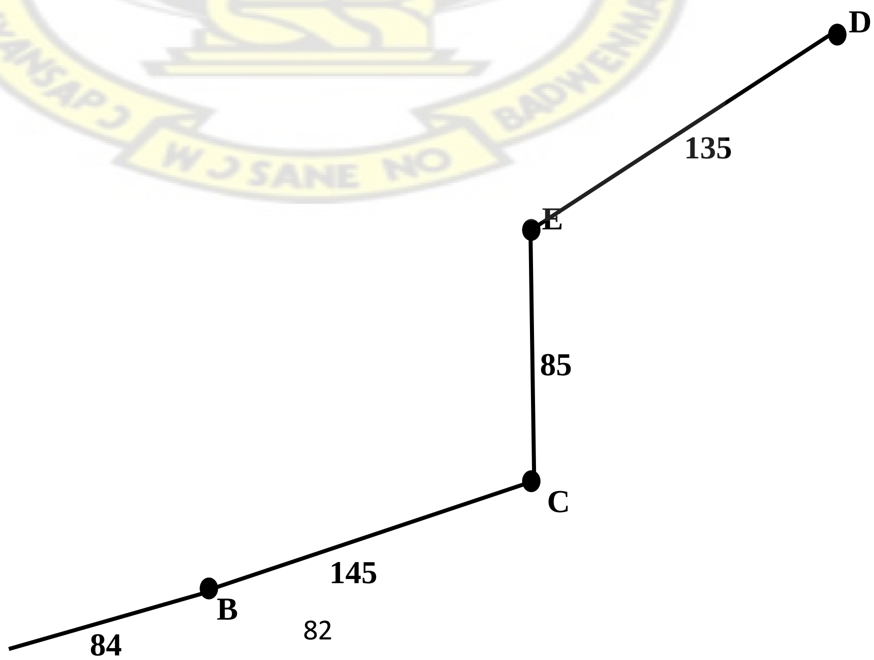

Figure4.6: Solution 5

DF is the smallest edge joining A, B, C, E, D and F to the other vertices. Put edge DF into solution. Delete row F. Look for the smallest entry in columns A, B, C, E, D and F

Table 4.7: Information 6

	1 ↓ A	2 ↓ B	3 ↓ C	5 ↓ D	4 ↓ E	6 ↓ F	G	H	I	J
~~F~~	~~**305**~~	~~**222**~~	~~**272**~~	~~**336**~~	~~**200**~~	~~∞~~	~~**130**~~	~~∞~~	~~**382**~~	~~∞~~
G	**436**	∞	∞	∞	∞	**(130)**	∞	**375**	∞	∞
H	∞	∞	∞	∞	∞	∞	**375**	∞	**314**	**275**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	**275**	**161**	∞

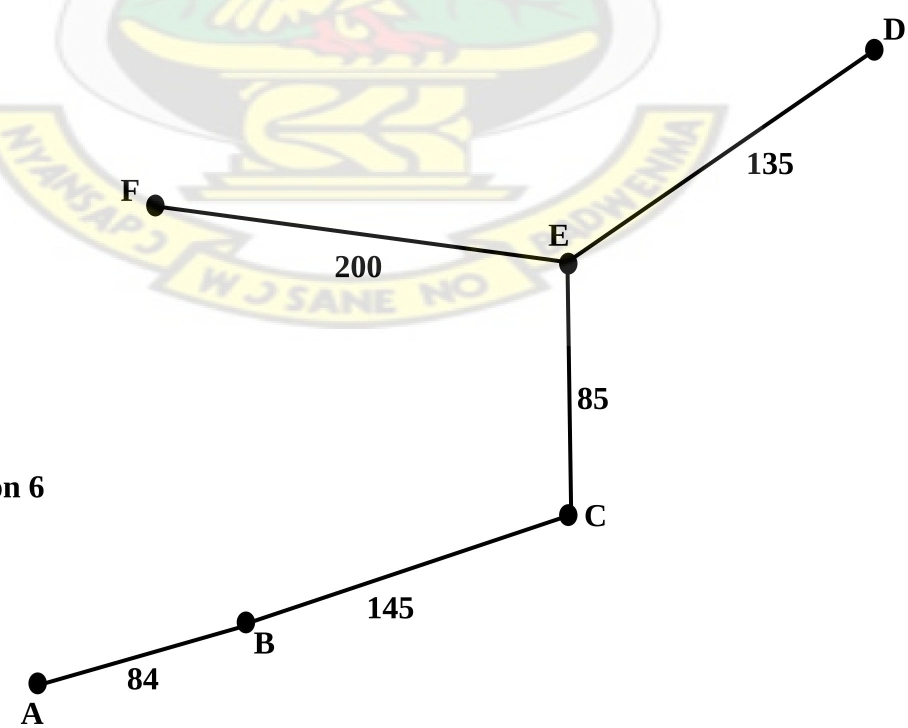

Figure 4.7: Solution 6

FG is the smallest edge joining A, B, C, E, D, F and G to the other vertices. Put edge FG into solution. Delete row G. Look for the smallest entry in columns A, B, C, E, D, F and G

Table 4.8: Information 7

	A (1)	B (2)	C (3)	D (5)	E (4)	F (6)	G (7)	H	I	J
~~G~~	~~**436**~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~**130**~~	~~∞~~	~~**375**~~	~~∞~~	~~∞~~
H	∞	∞	∞	∞	∞	∞	(**375**)	∞	**314**	**275**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	**275**	**161**	∞

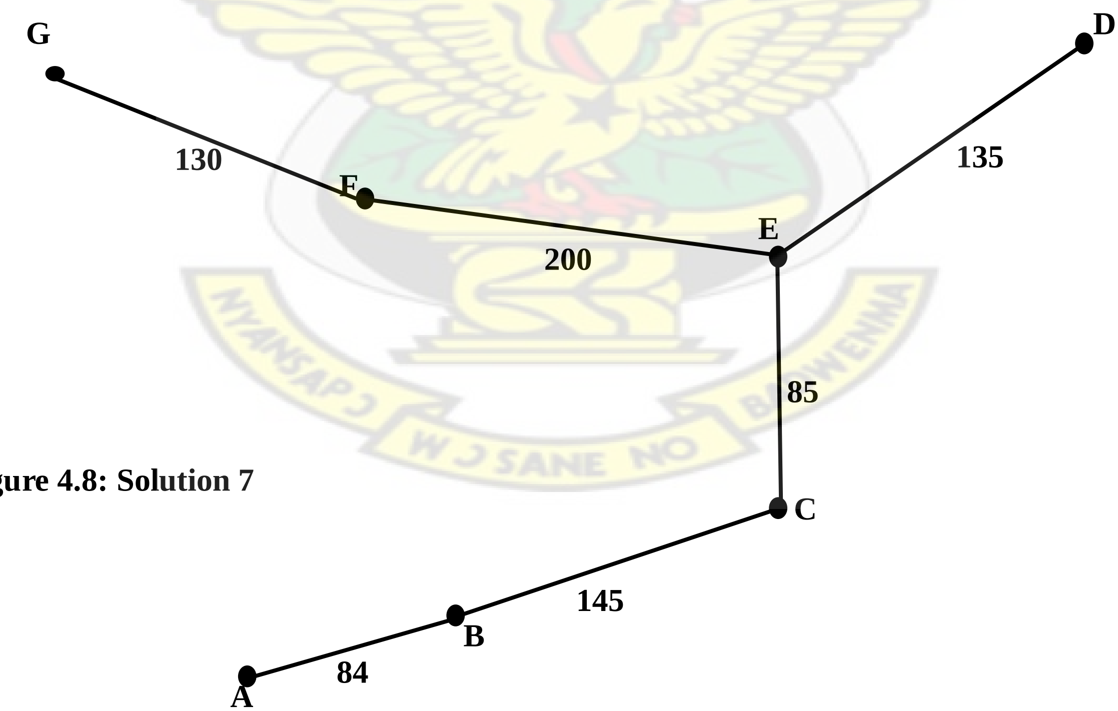

Figure 4.8: Solution 7

GH is the smallest edge joining A, B, C, E, D, F, G and H to the other vertices. Put edge GH into solution. Delete row H. Look for the smallest entry in columns A, B, C, E, D, F, G and H.

Table 4.9: Information 8

	1 ↓	2 ↓	3 ↓	5 ↓	4 ↓	6 ↓	7 ↓	8 ↓		
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
~~**H**~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~∞~~	~~**375**~~	~~∞~~	~~**314**~~	~~**275**~~
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
J	∞	∞	∞	**567**	∞	∞	∞	(275)	**161**	∞

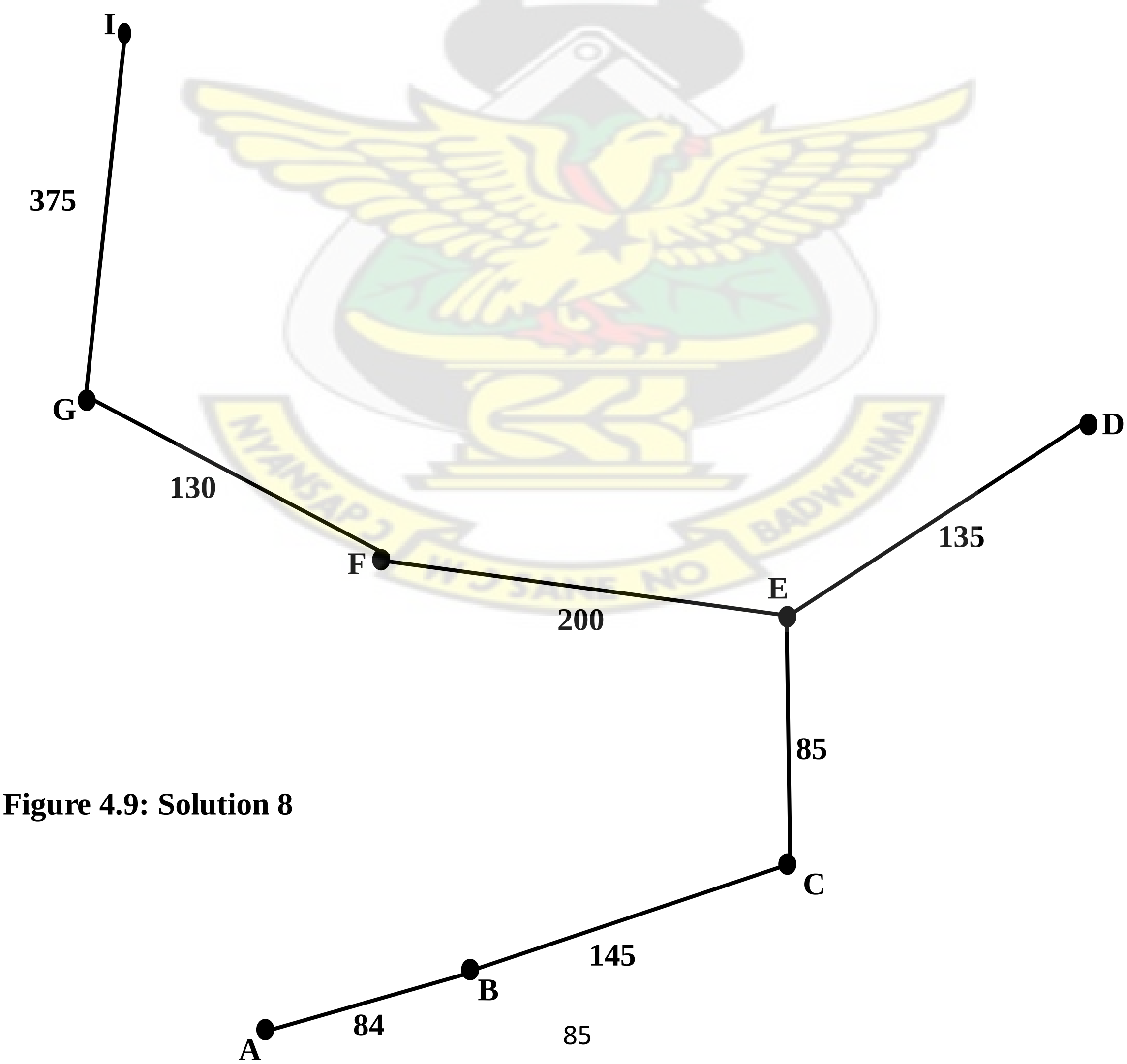

Figure 4.9: Solution 8

HJ is the smallest edge joining A, B, C, E, D, F, G, H and J to the other vertices. Put edge HJ into solution. Delete row J. Look for the smallest entry in columns A, B, C, E, D, F, G, H and J.

Table 4.10: Information 9

	1	2	3	5	4	6	7	8	10	9
	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
I	∞	∞	∞	**504**	∞	**382**	∞	**314**	∞	**161**
~~**J**~~	~~∞~~	~~∞~~	~~∞~~	~~**567**~~	~~∞~~	~~∞~~	~~∞~~	~~**275**~~	~~**161**~~	~~∞~~

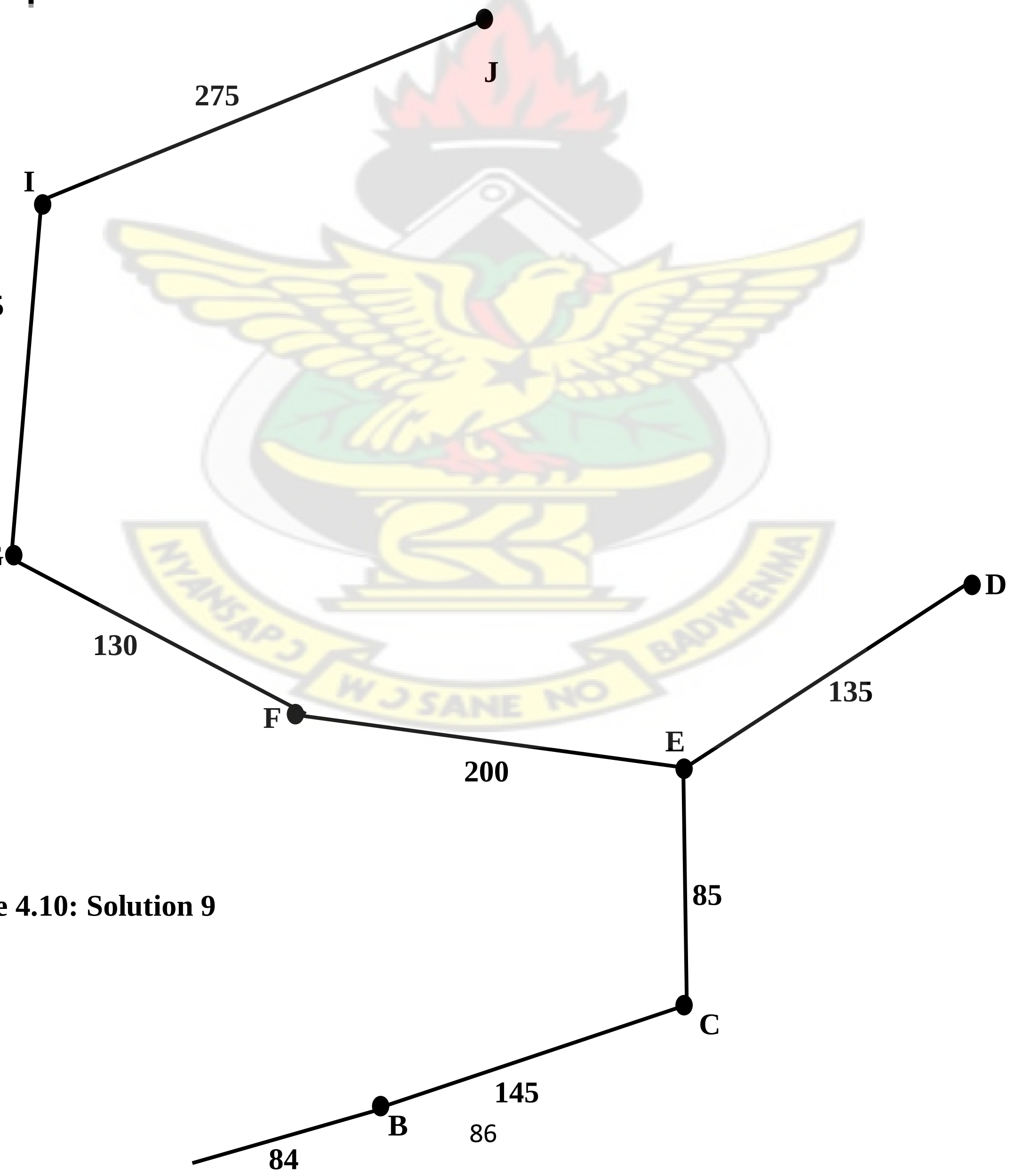

Figure 4.10: Solution 9

- A

JI is the smallest edge joining A, B, C, E, D, F, G, H, J and I to the other vertices. Put edge JI into solution.

Table 4.11: Information 10

	1 ↓ A	2 ↓ B	3 ↓ C	5 ↓ D	4 ↓ E	6 ↓ F	7 ↓ G	8 ↓ H	10 ↓ I	9 ↓ J
~~I~~	~~∞~~	~~∞~~	~~∞~~	~~**504**~~	~~∞~~	~~**382**~~	~~∞~~	~~**314**~~	~~∞~~	~~**161**~~

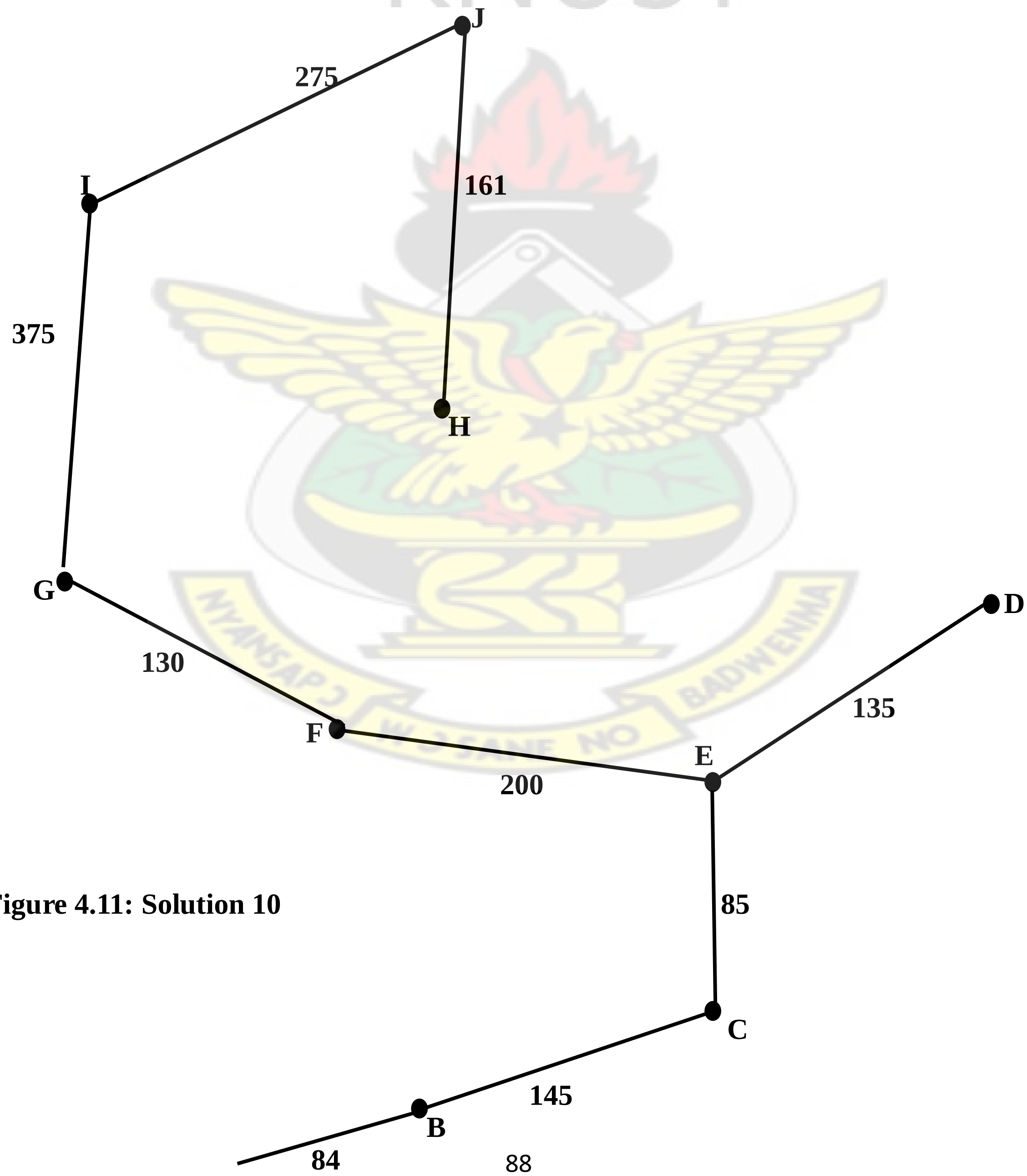

Figure 4.11: Solution 10

●
A

Table 4.12: Summary of Matrix Representation of the Pipeline Network.

A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	
A	∞	**84**	∞	∞	∞	∞	∞	∞	∞	∞
B	**84**	∞	**145**	∞	∞	∞	∞	∞	∞	∞
C	∞	**145**	∞	∞	**85**	∞	∞	∞	∞	∞
D	∞	∞	∞	∞	**135**	∞	∞	∞	∞	∞
E	∞	∞	**85**	**135**	∞	**200**	∞	∞	∞	∞
F	∞	∞	∞	∞	**200**	∞	**130**	∞	∞	∞
G	∞	∞	∞	∞	∞	**130**	∞	**375**	∞	∞
H	∞	∞	∞	∞	∞	∞	**375**	∞	∞	**275**
I	∞	∞	∞	∞	∞	∞	∞	∞	∞	**161**
J	∞	∞	∞	∞	∞	∞	∞	**275**	**161**	∞

4.2 DISCUSSION

Figure 4.1 represents the pipe network to the regional capital towns in Ghana.

The alphabets represent nodes at the regional capital towns. The above map was designed out of the original map for the purpose of the research work.

From the table, distances between nodes are indicated and nodes without direct contact are given infinity sign. The total distance covered by the map is computed as 5094km.

Using the Prim's algorithm, the optimal solution and the minimized connection distance are drawn below.

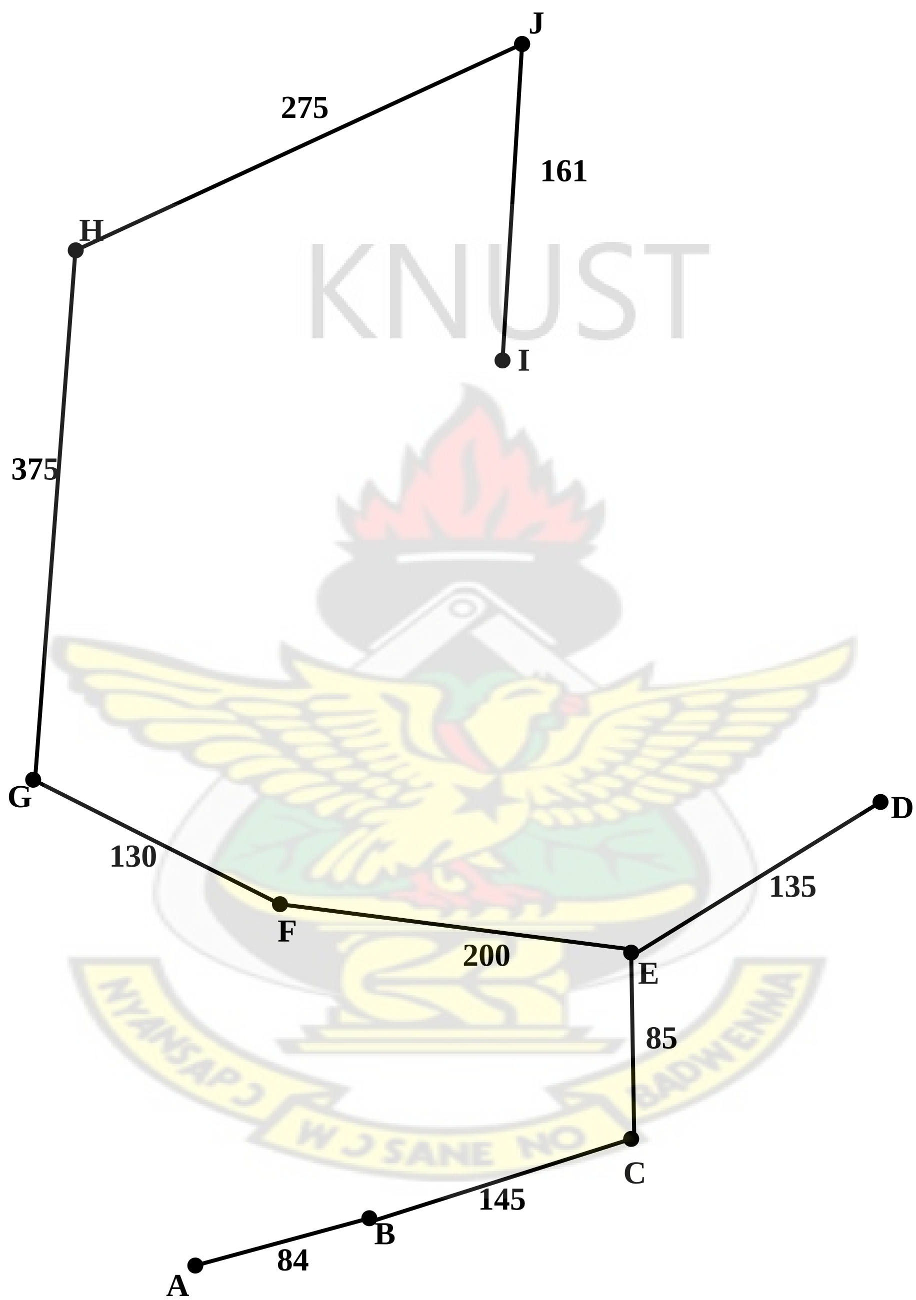

Figure 4.12: Final Solution Map

Total distance covered in the new map is **1,590km**

4.3 ANALYSIS

Analysis of result generated from Prim's algorithm solution is presented below:

- We observe the map has become smaller from the original map.
- The number of pipes in the network has also reduced as compare to that of the original pipe network provided by the map.
- The difference between the distance covered by the old map and the distance covered by the new map after the use of the Prim's algorithm is computed as:

  5094km – 1590km = 3504km
- The percentage reduction in the distance as compared to the distance of the original map is computed as 3504/5094 × 100 = 68.79%. This means that after the use of the Prim's algorithm, there is 68.79% reduction in the pipe network of the original map.
- The application of the findings is that, the pipe network connecting the regional capital towns has been reduced drastically.
- Supposing a pipeline with a specified diameter is GH¢x for y metre long, then the price for each can be computed as follows:

  Total distance/y × GH¢x = Total price
- Total price for the original map is:

  5094/y × GH¢x = GH¢504x/y
- Total price for Prim's algorithm map is 1590/y × GH¢x =GH¢1590x/y
- The difference between the total price of the original map and that of the new map after the use of the Prim's algorithm is computed as:

GH¢5094x/y – GH¢1590/y = GH¢3504x/y

4.4.0 ENVIRONMENTAL VALUE REVEALED BY PIPELINES

The environmental damage potentially caused by pipelines include disturbance of soil, forest, rivers and wetlands, noise from compressor stations to during pipeline discharge, and risk of pipeline leakage or rapture. Environmental valuation is a method by which monetary values are placed upon environmental attributes which enables these attributes and associated damage or risk, to be included in project cost-benefit analysis.

4.4.1 ENVIRONMENTAL VALUES AS AN AID TO DICISION-MAKING

Placing any kind of value on the environment is a difficult thing to do. This is true with the almost all "public good". A public good is something to which everyone has not paid for in the same fashion as private goods, such as automobiles and microwave ovens. Clean air, beautiful views and quietness may all be considered to be public goods. The concept discussed in the chapter have been extensively applied in recent years among researchers and academics looking for new ways to approach environmental problems, and this concept are discussed in detail in Dott et al (1996b)

Their applicability in industry has been limited because of practical difficulties associated with the same of the valuation methods. In addition, researchers have found widely varying results for different studies, making the 'correct' correct value difficult for determine.

Standard cost-benefit analysis weighs the cost and benefits of a proposed project, almost always in monetary terms. Usually, the project with the highest Net Presents Value (NPV), or timeadjusted net benefit, is the one which is pursued. Using valuation techniques, environmental cost can be added into the cost-benefit analysis, forming one of the project costs.

The environmental costs could be used to compare the economic viability of two or more alternative projects, the shortest link-length pipeline network connecting a number of nodes to a gas processing plant could represent the cost optimal pipeline network if environmental costs were insignificant or ignored.

The cost of constructing the pipeline, and the cost associated with the environmental damage incurred are included using the approach. On the other hand, some of the links around environmentally sensitive area (ESA's), such as wetlands or river crossings are re-directed resulting in a longer total pipeline length. In this case, the construction cost of the longer pipeline network would be the only one main cost item.

The two options described above would not entirely avoid environmental degradation, but the comparison of the two will indicate the preferred route. If society values wetland and rivers, then a longer pipeline route would be chosen.

As expressed by Zube (1980) information on the value of the can also be helpful for governmental agencies in setting policies and direction for spending on our environmental property zoning and development planning, to name a few areas. The difficulty people may have placing monetary value on environmental goods and human life are catered for by the engineers who understand that some risk of death or injury associated with their designs, as much as we try to minimize them.

4.4.2 AGRICULTURE AND SOILS

The majority of the proposed pipeline route will crosses agricultural land. Much of this is in intensive arable use, producing crops and root crops. There will inevitably be some temporally disruption to farming activities during pipeline construction.

All migration measure will be detailed within formal legal agreements with landowners and occupiers. Soil will be handled in accordance with best practice guidelines to protect soil fertility. Pre-and post construction remedial land drainage system will be installed to ensure agricultural drainage system continue to function. All reasonable precautions in line with current best practice will be taken to prevent the spread of plant and animal and agricultural weeds during construction. Arable land is expected to be returned to normal use by the following crop growing season.

4.4.3 WATER RESOURCES AND FLOOD RISKS

During the construction phase, there is the potential for sediments or pollutants to be released to water courses or ground water as a result of surface run off or leaching. Where open cut crossing are proposed, there is the potential for physical damage to watercourse. All construction will be taken in accordance with EPA guidance to ensure that adverse impacts on the water environment are avoided. Method statements will be prepared and agreed with the EPA and landowner/occupiers for all work at watercourse crossing (including reinstatement). The decision to employ trenchless techniques for major watercourse crossing will prevent disturbances to the river bed and flood defenses and limit the potential for pollution of these features. The proposed pipeline will not reduce flood plain storage capacity as it will be buried.

4.4.4 ECOLOGY

Arable land is generally of limited ecological value. However, a number of protected species occur along the proposed pipeline route. There will be temporary loss of habitats during construction of fish species in watercourses.

The proposed pipeline route and construction techniques should be selected to minimize ecological impacts. A range of biodiversity enhancement measures will be implemented including planting at the proposed pipeline extension.

4.4.5 EMISSIONS

A number of residential properties located close to pipeline construction activities may experience an increase in noise levels during construction.

These potential impacts will be mitigated and controlled through a construction Environmental Management Plan and consultation with the local Environmental Health Officer.

4.4.6 TRAFFIC AND TRANSPORT

Construction of the proposed pipeline will result in temporary increase in traffic flow with potential impacts to offer road users. The greatest transportation requirement during construction is the delivery of the steel pipe lengths to the working width. Construction of the road crossings has the potential to cause disruption and delay to road users.

Proposed mitigation measures to minimize traffic disruption will be detailed to comprehensive Traffic Management Plan (TMP) to be agreed with the Ghana Highways Authority (GHA) prior to any works commencing.

The TMP will identify any road restrictions and agreed traffic routes, specify signage and temporary traffic controls and any additional measures to minimize impacts. The number of journeys will be minimized and materials could be sourced locally where feasible. The proposed pipeline will be installed under roads using trenchless construction techniques to minimize traffic construction. Access will be maintained while the pipe is being installed by placing across trench or temporary diversions.

4.4.7 SOCIO-ECONOMICS

The will be some economic benefit during pipeline construction as a result of local employment opportunities and the use of local services and businesses, although this is not yet considered to be significant at a regional scale. There will also be a negative and economic impact as a result of disruption to farming activities, although this is not considered to be significant at a regional scale.

In addition, there may be some temporary loss of tranquility and visual attractiveness of the area local to the pipeline and disruption to Right of Way during pipeline construction.

Measures including dust suppression and noise reduction techniques will be taken to reduce the impact of the construction works on the amenity value of roads and Public Right of Way.

Rights of Way will generally be kept open, during construction by incorporating gates or stiles along the working width. Where it is necessary to temporarily close or divert Public Rights of Way to ensure public safety, this will be agreed by the parties involved.

4.4.8 GEOLOGY AND GROUND CONDITIONS

There is the potential for the pollution of watercourses and drift deposits (shallow geology) as a result of accidental fuel, oil or waste leaks or from importation of contaminated materials. A method statement for dealing with unexpected contamination will be prepared and submitted to the Authority in charge for agreement prior to any works commencing on site. All secondary materials imported to the site will have previously been analyzed for the presence of leachable contaminants.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.0 INTRODUCTION

This chapter comprises drawing of conclusions based on the outcome of the experimentations.

5.1 CONCLUSION

The findings in chapter 4 signify that Prim's Algorithm can be used to reduce the network systems. The supply of natural gas from Takoradi to other parts has become very difficult due to no pipe line network systems connecting the gas from Takoradi to other regional capital towns in Ghana. The Thesis adequately provide enough solutions to that effect

The total distance covered by the pipe line network if the existing road networks are used from Takoradi to all the regional capitals towns in Ghana is 5,094km. After Prim's Algorithm was used, the total distance covered is 1,590km. Considering the original map, total distance covered by the pipe network system was reduced by 68.79% when the Prim's Algorithm was used to reduce the pipe network.

Environmental damages are other significant findings in this research. Implementations of these environmental solutions in this research will reduce the impact of these problems in construction of the pipe network. In as much as some environmental corridors are deemed impossible for the implementation, transportation engineers and industrial mathematicians are encouraged not to disinclined to implement this Algorithm when the environment permit (Donkoh, 2010)

In conclusion, the objectives of the research have been achieved by minimizing the pipe network and providing environmental solutions. It also means that the Prim's Algorithm can be used in reducing all pipe networks in the country to smaller, more efficient and less costly in the country. To minimize pipe network systems, the Prim's Algorithm should be used to reduce the distance coverage and the price involved in the changing of the pipe network systems.

5.2 RECOMMENDATIONS

- The government in need of providing gas pipe network should employ operational researchers to use Prim's algorithm to minimize cost and distances.
- Existing roads with many curves should be straightened to further minimize the distances since construction of pipe networks makes use of these roads.
- Communication, transportations and network can also employ the use of shortest path problem especially, Prim's Algorithm to plan their network systems. It will minimize the network, save money and human resources but still meet the need of their customers.
- The author advises that the optimal network flow of the gas pipeline should follow the path provided in Figure 4.14 in chapter 4.
- Individuals can also use the Prim's Algorithm to plan their pipe network, electrical network and other networks in construction of their building.
- Operational researchers should be assigned to every ministry to help in minimization of cost and resources.
- Environmental factors should be considered when pipe networks are being layout.

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APPENDIX A

COST SOLUTION TABLE

Branch Name	Start Node	End Node	General Cost	Pipe Length	General Cost
A	0	1	0	y	0
B	1	2	84x	y	84x
C	2	3	145x	y	145x
E	3	4	85x	y	85x
D	4	5	135x	y	135x
F	5	6	200x	y	200x
G	6	7	130x	y	130x
H	7	8	375x	y	375x
I	8	9	275x	y	275x
J	9	10	161x	y	161x
Total					1590x

APPENDIX B

COST SOLUTION TABLE

Branch Name	Start Node	End Node	General Cost	Cumulative General Cost
A	0	1	0	0
B	1	2	84x	84x
C	2	3	145x	229x
E	3	4	85x	314x
D	4	5	135x	449x
F	5	6	200x	649x
G	6	7	130x	779x
H	7	8	375x	1154x
I	8	9	275x	1429x
J	9	10	161x	1590x