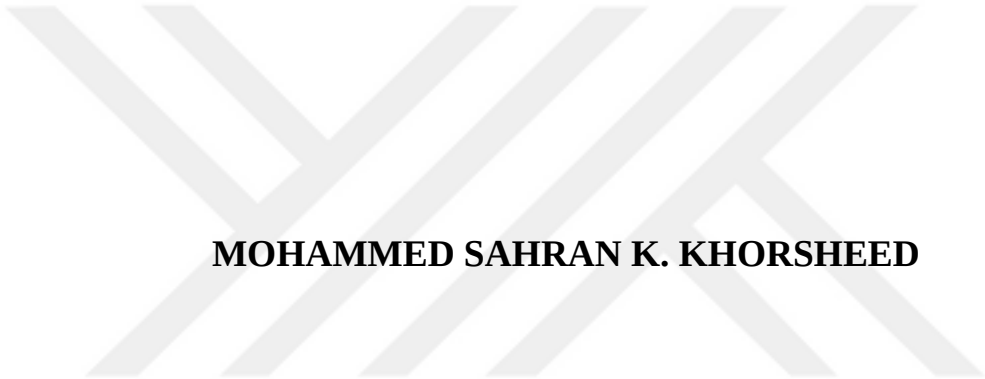


**REPUBLIC OF TURKEY
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

AUTOMATED ROUTE SEARCH FOR PIPELINE DESIGN



MOHAMMED SAHRAN K. KHORSHEED

**MSc. THESIS
DEPARTMENT OF GEOMATIC ENGINEERING
PROGRAM OF GEOMATICS**

**ADVISER
ASSOC. PROF. DR. NURSU TUNALIOĞLU**

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A thesis submitted by Mohammed Sahran K. KHORSHEED in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 22.06.2018 in Department of Geomatic Engineering, Geomatics Program.

Thesis Adviser

Assoc. Prof. Dr. Nursu TUNALIOĞLU
Yıldız Technical University

Approved By the Examining Committee

Assoc. Prof. Dr. Nursu TUNALIOĞLU
Yıldız Technical University

Assoc. Prof. Dr. Bahattin ERDOĞAN, Member
Yıldız Technical University

Assoc. Prof. Dr. Tefik ÖZLÜDEMİR, Member
İstanbul Technical University

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LIST OF SYMBOLS

Δx	Differences in x-coordinates.
Δy	Differences in y-coordinates.
Δh	Differences in height.
x_{start}	x-coordinates of the start points.
y_{start}	y-coordinates of the start points.
h_{start}	Height of the start points.
x_{End}	x-coordinates of the end points.
y_{End}	y-coordinates of the end points.
h_{End}	Height of the end points.
$ \Delta x $	Absolute value of x-coordinates differences.
$ \Delta y $	Absolute value of y-coordinates differences.
α_{SE}	Azimuth value start-end line computed from North towards endpoint.
i	Iteration number.
x_{sp}	x-coordinates of the searched points computed on the generated arc.
y_{sp}	Searched points y-coordinates computed on the generated arc.
h_{sp}	Height values of the searched points computed from interpolated surface.
x_p	x-coordinates of the previous points.
y_p	y-coordinates of the previous points.
x_{op}	x-coordinates of the optimal points.
y_{op}	y-coordinates of the optimal points.

LIST OF ABBREVIATIONS

DTM	Digital Terrain Model.
Azi	Azimuth value measured from North (positive y-axis) and rotate clockwise.
ID	Identification number for the optimal points.
3-D	Three-Dimensional.
Min	Minimum value.
Max	Maximum value.
h_{Start}	Start point height.
h_{End}	End point height.
abs	MATLAB code to compute absolute values.
rand	MATLAB code to generate random values.
Diff. h	Differences in height (in meter).
Slope1	Slope between start and intermediate point in the problematic area.
Slope2	Slope between intermediate and end point in the problematic area.
Start-P (x, y, h)	Three-dimensional coordinates of start point.
End-P (x, y, h)	Three-dimensional coordinates of end point.
Default. P. h	Height of the points calculated from the original slope (in meter).
Optimal. P. h	Height of the calculated optimal points (in meter).
Dist $(Start ==> End)$	Calculated distance between start and end point (in meter).
Azi $(Start ==> I.P)$	Azimuth between start and the intermediate point in the problematic area (in degree).
Azi $(I.P ==> End)$	Azimuth between intermediate and end point in the problematic area (in degree).
T-Dist $(Start ==> I.P)$	Total horizontal distance between start and intermediate point in the problematic area (in meter).
T-Dist $(I.P ==> End)$	Total horizontal distance between intermediate and end point in the problematic area (in meter).

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ABSTRACT

AUTOMATED ROUTE SEARCH FOR PIPELINE DESIGN

Mohammed Sahran K. KHORSHEED

Department of Geomatic Engineering
MSc. Thesis

Adviser: Assoc. Prof. Dr. Nursu TUNALIOĞLU

Water transmission refers to the transportation of the water from the source to the treatment plant and to the area of distribution. The facility may be realized in three ways, as free-flow (gravity flow), pressurized pipelines (pumping systems) and a combination of them depending on the conditions of the topography, where the pipeline passes through and in terms of the subsequent complex hydraulic processes. Among them, free-flow conduits (canals, aqueducts, and tunnels) are preferred in hilly areas or in areas where the required slope of the conduit more or less coincides with the slope of the terrain. In the free-flow system, the water reservoir placed in the higher elevation of a hill is taken and transmitted to the required place such as residential areas.

In the preliminary design of pipeline route, the horizontal alignment design is an important factor in terms of connection of the pipes, which should be realized in certain angles due to flowing and construction goals. Meanwhile, the vertical alignment design, which should provide appropriate longitudinal slopes to perform flow, should be considered simultaneously while planning the horizontal alignment. Although the details of design standards vary with the project area and construction manner, most of the issues involved in geometric design are similar for all water transportation types. Preliminary design is applied to compute the appropriate slopes permitted to free-flow in pipelines used as the most common way of finding appropriate route consideration of the earth topography.

This study aims to propose an algorithm automatically connecting two given points for pipeline route preliminary design solutions. The proposed model offers an automatic connection between two ends on a generated terrain due to azimuth angle of the searched points, step interval, horizontal coordinate differences to draw the closest terrain slope as well as to select the more suitable alignment in three steps: First, it compares the slopes between consecutive points and zero-line then selects the minimum difference (with a permissible value). Second, minimum differences in h-value is applied to the results of

the first stage as a second criterion (with some permission value also). Third, the shortest distance is applied to the results of the first and second stages as the third and last criterion. This algorithm applied to different digital terrain models including valleys, hills, flats etc. uses negative slopes for free-flow. Moreover, an option for the problematic areas where more than one slope is needed concerning terrain topography to circumvent the lands on which passage is prohibited for any reason (historical, cultural, religious, etc.) and to find the locations of the intermediate points coordinates especially in mountain areas. Consequently, the resulting optimized alignment is non-backtracking, smooth, close to the assigned slope and the shortest path between two points depending on given criteria as much as possible.

Key words: Digital Terrain Model (DTM), Optimization, Pipeline Design, Preliminary Design



BORU HATTI TASARIMINDA OTOMATİK GEÇKİ ARAMA

Mohammed Sahran K. KHORSHEED

Harita Mühendisliği Anabilim Dalı

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Su iletimi, suyun kaynağından arıtma tesislerine ve dağıtım alanlarına taşınmasını ifade eder. Bu işlem, serbest akış (yerçekimi akışı) ile iletim, basınçlı boru hatları (pompalama sistemleri) ile iletim ve boru hattının geçeceği topoğrafyanın koşulları ile birlikte karmaşık hidrolik şartlara bağlı olmak üzere bunların bir kombinasyonu olarak üç şekilde gerçekleştirilebilir. Bunların arasında, serbest akışlı kanallar (kanallar, su kemerleri ve tüneller) engebeli alanlarda veya kanal iletimi için gerekli eğimin çoğunlukla arazinin eğimi ile karşılandığı bölgelerde tercih edilir. Serbest akış sisteminde, bir tepenin yüksek kotuna yerleştirilen su rezervuarı alınır ve yerleşim alanları gibi gerekli yere iletim sağlanır.

Boru hattı güzergâhının ilk tasarımında, yatay hat tasarımı, akış ve inşaat imalatları açısından belirli boru birleşme açıları altında planlanması gerektiğinden boruların birbirine bağlanması önemli bir faktördür. Bununla birlikte, su iletiminin gerçekleştirilmesi için uygun boyuna eğimleri sağlaması için gereken düşey hattın tasarımı, yatay hat tasarımı ile aynı anda değerlendirilmelidir. Her ne kadar, tasarımın detay standartları, projeye ve inşaat imalat koşullarına göre değişiklik gösterse de, su iletiminde pek çok geometrik tasarım konuları benzerlik göstermektedir. İlk tasarım, arazi topoğrafyasını dikkate alarak boru hatlarında serbest akışa olanak veren uygun boyuna eğimlerin belirlenmesinde uygulanmaktadır.

Bu çalışma, boru hattı güzergâhı ön tasarım çözümleri için, verilen iki noktayı otomatik olarak bağlayan bir algoritma önerisini amaçlamaktadır. Önerilen model, oluşturulan arazi yüzeyi üzerinde iki nokta arasında, ara noktaların açıklık açısı, arama mesafesi ve ara noktalara ait yatay koordinat farklarına bağlı olarak araziye en yakın eğimli güzergâh hattının seçimini amaçlamaktadır. Bu işlem üç aşamada önerilmektedir. İlk aşamada, ardışık noktalar arasındaki boyuna eğimler ile arazinin sıfır poligonu hattına ait eğim karşılaştırılır ve minimum olduğu noktalar (belirli bir tolerans değeri ile) bulunur. İkinci aşamada, ikinci bir kriter olarak ilk aşamada bulunan noktaların arasında minimum h-

değeri (belirli bir tolerans değeri ile). Üçüncü aşamada ise, en kısa mesafe koşulu, ikinci aşamada bulunan noktalara uygulanır. Çalışmada, serbest akışı sağlayan negatif boyuna eğimli hatların oluşturulması için vadi, engebeli ve düz araziler vb. gibi farklı arazi yüzeyleri kullanılmıştır. Ayrıca, arazinin yapısına bağlı olarak birden fazla eğim ile geçilmesi gereken problemleri bölgelerde, verilen çözüm algoritması tekrarlanmaktadır. Sonuç olarak, elde edilen optimum hat, geriye dönüşü olmayan, düzgün, akış için gerekli belirlenmiş boyuna eğim değerine yakın ve mümkün olduğunca ölçütlere bağlı olarak iki nokta arasındaki en kısa yol olarak bulunmaktadır.

Anahtar Kelimeler: Sayısal Arazi Model (SAM), Optimizasyon, Boru Hattı Tasarımı, Ön Tasarım



CHAPTER 1

INTRODUCTION

1.1 Literature Review

Transportation is an important thing in human life, whether, in the past or today's in our modern world, it helps people to reach places where they want to be as soon as possible and to transport goods easily, according to the means, which will be used in travels.

At the beginning of history, transportation was restricted to walking [1-3]. For specific purposes, pathways were developed such as guiding to resources of watercourse, encampment, the ideal place for hunting and food resources, etc. As the human needs to carry goods and transports over long distances, the rational thought in a new way to facilitate this transport, so he benefited from the animals that he continually contacted them (such as camels, donkeys, horses, etc.) and used as a means of personal transport and goods together [2, 3]. Then, the invention of the first wooden wheels in Mesopotamia (Iraq now) opened the way in front of the wheeled transportation [2-4]. This step was considered as a new step in the development of civilization and means of transportation.

Modern transportation is one of the most critical inventions resulting from the tremendous scientific progress witnessed by the human civilization as a whole, which has emerged to meet the human needs to move around, especially after the lifestyle of people began to change, cities have expanded incomparably and can no longer rely on slow traditional means of transport [2].

Transportation has evolved considerably over time, moving from simple primitive forms to complex forms that have managed to carry humans out of the globe, thus providing tremendous and essential services.

Generally, the transportation has different modes and classifications. The following is the outline of these classifications:

- **Land Transportation:** This includes various forms, such as highways (cars, bicycles, buses of all kinds, etc.) and railways (train, tramway, etc.). Where Land Transportation considered as one of the most common forms of transportation used to transport passengers from one area to another on land.
- **Air Transportation:** This included aircraft of different sizes. Which helps to transport passengers and goods between different areas very quickly, but it is expensive compared to other types of transport.
- **Naval Transportation:** This type of transport was favorite in the past before the invention of the aircraft, but it is still used today to transport commercial goods and less in people transportation. It can be subdivided into Seaway and inland waterways.
- **Pipeline Transportation:** This type of transport is used to transport materials between extraction, filtering, and storage sites and it can subdivide into gas-petrol line transportation and water transportation.
- **Cable Transportation:** Which includes electricity transmission lines (escalator, aerial tramway, elevator, etc.) and telephone lines.

In addition to above classification, [5] pointed out that the most used means at present can be summarized to air, land, water, tunnel, tube, and cable transportations. Then, further classified transportation to urban transit with a motor (public transportation and individual transportation) and without motor (pedestrian and bicycles).

While [6] mentioned according to the economic opportunities, energy sources and the topographic characteristic of the land, the transportations modes can be developed. Then the transportation is divided into two types according to the material carrying (passenger and goods) and classified the public transportation system in the urban to three subtypes, which are roadway, railway, and seaway.

[7] defined maritime transport as the most widely used, convenient and cheaper means of transporting carrying heavy goods for long distances (2.5 times than railways and 7 times than highways more affordable), and approximately 90% of the international commercial assets in the most of world and turkey did through the seaway transportations. Then classified and grouped the transportation system for maritime transport, airways transportation, railway transportation, highway transportation, river road transportation and pipeline transportation respectively.

[8] classified the transportation means to four subdivisions depending on the type of the transporter and the motion, which are highway transportation, railway transportation, airway transportation, and water transportation.

Further, transportations have different subject's classification, and its modes can be subdivided furthermore into many categories. One of the exciting classes is pipelines transportations, which has more effect on the economies of many countries around the world through transferring many quantities of liquids and gases for long distances in safely way.

Data infrastructures to be used in the preliminary design is paramount importance in the planning, and in the construction processes of the planned routes as well. In this context, the sensitivity of late research approaches is based on the quality and quantity of land data to be obtained locally. As a result of the developing technology, there has also been an improvement in data collection and analyzing procedures. For example, total station, laser scanning systems, global navigation satellite systems, and remote sensing methods have taken the place of traditional data collection methods today, which are ease of implementation, collecting and processing essential data in short time intervals over large areas. However, depending on the mentioned above, the system to be used for data aggregation is changing. The sensitivity of the study directly affected by the method of capturing data, therefore; it is one of the essential factors in the route planning process [9] besides, different factors were reviewed by the researchers and authors in various topics.

As known, route alignment design and its optimization is very important procedure in the defining and selecting optimal alignment through an infinity generated alignments between any two known ends, or maintenance an existing route (by adding more intermediate points or dropping redundant points from it, to be more smooth, suitable, shortest and economical path), besides the data infrastructures and international design standards, various constrains, factors and different important design parameters should be considered and satisfied in the route design progress. However, satisfying all those parameters causes time-consuming and leads to make the route design and the alignment optimization one of the most complex engineering problems. In the traditional procedure of routes design and optimization problems, resolved mainly over designer experiences, and intuition to select, analyze and check only a few alignments through an infinity alternative drawn between two known ends. Thus, the optimal one among the alternatives

may be neglected due to this limitation. With the development of the digital computers and the assistance of different sophisticated techniques, several mathematical models were developed and introduced to the scientific area to overcome and resolve the problems in the alignment selection and optimization instead of the human judgments in addition to achieve more with less input and get accurate results in less time depending on the applied criteria's [10], these models used either in the optimization process for two dimensional alignments (horizontal or vertical alignment), or for three dimensional alignments (horizontal and vertical alignments together). Therefore, according to their uses it can be classified and grouped in to three main group:

- **Horizontal alignment optimization**

In the route design, the horizontal alignment is defined as one of the geometric design elements, which consists of a number of intersected tangents and circular curves connected to each other at known points, and in some cases a transition curves should be added to make the connection and thus, the generated alignment results in more feasible and smooth as much as possible. Thus, the designer should be careful in the design of horizontal alignments and select the alignments that achieve the economic standards depending on the topography [11]. Therefore, a lot of studies and approaches have been introduced for the horizontal alignment optimization processes, here we mention some of them:

- **Calculus of variations:**

It is one of the horizontal alignment optimization approaches based on the minimizing the integral of a function through finding the suitable curve in space connecting two ends [12]. Therefore, it is mainly developed to optimize a particular category of optimization issues. [13] used the concept of the calculus of variations for the horizontal alignment in the highway to derive Optimum Curvature Principle where the criterion function in the defined region of a highway to be built between two given cities or two main points is presented as a hypothesis for this method. Besides the proposed example, which utilized for two integrated approaches (where the first integrated approach was the arc of circle algorithm, and the second one was intrinsic equation procedure for path approximation) applied for Optimum Curvature Principle test purposes, [14, 15] were used the Optimum Curvature Principle also for construction cost's optimization through finding the horizontal alignment in an expressway. Calculus of variations method utilized also in the

transportation studies for the maritime route optimization through dynamic ice field by [16]. However, regardless of the modeling and calculation process in the calculus of variations method which is characterized kind of with some complexity, and the inabilities in calculation of discontinuous cost components, calculus of variations has continuous searched space in general, the generated alignment is smooth, and through it the global optimum is possible to be obtained and found.

➤ **Network optimization:**

In this approach, the horizontal alignments are treated as a network problem for optimization process, and to solve this problem one of the network optimization approaches (i.e. shortest path algorithm) can be applied, where the alignments is defined as a number of arcs joining between two ends (start and end points). In the development of the Generalized Computer Aid Route Selection system (GCARS), [17] borrowed the same concept for the cost problems, where the total cost is determined by combining all individual costs with relative weightings, and as a final step a grid network is actualized and built from the cost model through joining all the points in the grid network and assigning the costs to each connection point. The same concept of the network optimization also can be found in the early studies and researches in Miami University and Massachusetts Institute of Technology (MIT) as the Organization for Economic Co-operation and Development (OECD) [18]. However, network optimization has advanced algorithms for problem solving, the global optimum is possible to be found, and simple and easy for alignment optimization but to achieve these attributes it needs large capacity memory for computations, and the generated alignment from this method is not smooth.

➤ **Dynamic programming:**

This approach has been developed to solve large and complex optimization issues with basic principle states. The problem can be subdivided into stages covering the entirety, where each stage is developed in a manner that contributes to the target function is independently added from each stage. However, start and end points of the generated alignment by this model for horizontal alignment optimization are connected with a line and the stages are placed as perpendicular lines on this line (alignment) at equally spaced intervals, where each of these stages have nodes or grids on the perpendicular line. The calculation of the objective function through the process will start in reverse from the end of the stages to the first stage and the connections between next stages nodes and the

current stages nodes will be done through accepting only known and limited nodes from the next one to be connected to the current one, and in this way the curvature constraints will be satisfied for the resulting alignment. [19] and [20] were utilized the dynamic programming in their studies for horizontal alignment optimization. However, dynamic programming has advanced algorithms for problem solving, the global optimum is possible to be found as much as possible, it is simple and easy for alignment optimization but the generated alignment from this program is not smooth and backward bends are too difficult to be handled.

➤ **Genetic Algorithms (GAs):**

Genetic algorithms were first developed by John Holland and colleagues at the University of Michigan. Holland has done his research through natural selection and genetic evolution to search for and find the optimum. Throughout the process, it has been taken as an example that adaptation to the environment of the individual in the biological system becomes more suitable and computer software has been developed in the problems of finding the optimum and machine learning [21]. Genetic algorithm is a search method obtained by applying the conservation of the best and the natural selection principle to the computers through simulation. Most practical optimization problems involve mixed variables (continuous and intermittent) and discontinuities in the research field. Genetic algorithm is a good solution for these situations. [22] presents the use of genetic algorithms and geographic information systems together for the optimization of the horizontal highway alignments between two known points. The proposed approach is used for alignment optimization over a land characterized by highly irregular topography and the results must conform to the standards of the highway design. The objective function is based on some environmental impacts for various cost. However, according to the proposed model, the generated alignment in the numerical example presented as a preliminary design of the horizontal alignments.

➤ **Mixed integer programming:**

[23] proposed an optimization model for horizontal alignments and cross section, which clearly includes the impact of the integrity of the design elements on the alignment design based on the minimum design standards and real collision experience, where the safety is determined through the predictable collisions at the consecutive geometric elements of the highway alignment. The formulation of the proposed model includes different

constraints (geometric, collision and physical) in addition to another geometric constraints for compound curves, and through the objective function the mean collisions of the highway is minimized. The horizontal alignments parameters allowed to changes in a specified range. Furthermore, this model is applied and presented on three different numerical examples (new alignment, existing alignment, and compound curve requirement). In the first example, the proposed two-lane highway alignments have six tangents with five horizontal curves, while for the second one the alignment already has four tangents with three circular curves, and without physical obstructions. However, the resulted horizontal alignment from this model have smooth horizontal curves, short tangents length, and greater lane with shoulder length. Ones more, large tangents with small radius situations is considered also in the calculations and controlled through increasing the collision modification factor.

- **Vertical alignment optimization**

Vertical alignments are very important geometric design elements, which directly effects the cost functions, designed based on the least cost standards related to the topography along the horizontal alignments. Gradient and the vertical curvature are considered as the significant elements for this alignment. The following developed approaches and method used for the optimization of this alignment [11]:

- **Enumeration:**

[24] proposed a model for vertical alignment by selecting a number of points represent the stations along the horizontal alignment at each equal distance and the elevation at each station is then determined for minimizing earthwork costs and selection of the route slopes through satisfying the geometric design qualifications. At each iteration, combinations of intersection points are selected to check if the resulting line of alignment is possible. The constraints to be checked include the minimum and maximum longitudinal slopes, the minimum distance to be provided between the reverse curves, and the height change interval at each station. If no constraint is achieved, the current line is eliminated and a new set of points is selected and the operations are repeated. If all constraints are met and a viable outcome occurs, the program calculates the earthwork cost for each excavation pavement. After this calculation, the program checks whether the amount of borrowing-warehouse volume obtained exceeds the borrowing capacity to be borrowed. As a result, the intersection point sequence giving the minimum change in soil volume is presented

as the optimum result. However, in numeration model, most of the important constraints are taken in consideration, the global optimum is possible to be found, and the resulted alignments categorized as realistic alignments. Regardless of the above, instead of a continuous search space discontinuous solution is available and generally not efficient.

➤ **Dynamic programming:**

In this model each intermediate point that constitutes the alignment is considered as a step in dynamic programming. Every situation that occurs at all stages consists of a series of points with different heights at each station. [25] has developed a dynamic programming model by combining linear programming and transportation problems in order to optimize vertical alignments. This model was developed in Spain and has been named OPYGAR (Optimization and Automatic Generation of Longitudinal Profiles). The program have been presented in two steps. In the first step, the dynamic programming model produces the optimum profiles according to the cost of the given transport distance, where the gradient constraints can be calculated by limiting the set of possible intersection points corresponding to the given intersection points. A new solution proposal for transport distance cost based on optimal solution with dynamic programming is obtained by applying Hungarian Algorithm in transportation problems [26]. Based on the new transport distance and the cost solution, the optimum length of the cross section is re-established by the dynamic programming method, and this process is repeated until it is merged at one point. The results of the first step are approximated by a series of cubic polynomial functions, and then a linear programming model is used at each intermediate point for the absolute curvature values to be reduced and minimized as possible. The final generated alignments in [25], is different than the produced one through the dynamic programming where presented alignment in dynamic programming is represented as fragmented pieces of segments. The derived alignment from the dynamic programming is optimized for transportation cost and smoothed through applying a linear programming model for this purpose and the final alignment produced in OPYGAR program. Dynamic programming method for vertical alignment optimization can also be seen in [27] for an existing road's profile optimization by minimizing the cost of the earthwork with assist of an interpolation and a set of quadratic spline function to present the appropriate alignment, where the gradient constraints can easily be employed for an alignment constructed at any points after first and second derivatives applied on the presented alignment. [28] employed also the dynamic programming in the proposed discrete and a

continues model on a numerical example for vertical alignment optimization processes, where [29] was used the same numerical example with some additional analysis for vertical alignment optimization through dynamic programming model. However, dynamic programming has advanced algorithms for problem solving, the global optimum is possible to be found, it is as much as possible simple and easy for alignment optimization but the generated alignment from this program is not smooth, and instead of a continuous search space discontinuous solution is available.

- **Three-Dimensional alignment optimization (Horizontal and Vertical)**

The approaches in this group developed for the alignment optimization processes in the horizontal and vertical:

- **Numerical search:**

One of the simultaneous optimization models generated for a three-dimensional optimization is [10] model in 1989. This model is the extension of the model they created for vertical transition optimization [28], the model first proposed as a problem of calculus of variation, but according to the complexity of the Euler- Lagrangian equations required an improvement and some additional development on the model to solve the problems and to do that, the alignment interpolated and the constraints changed to an one dimensional constraints by using cubic spline functions and constraint transcription respectively. At the end of the developments, the model was defined as nonlinear program constrained by the coefficient vectors of the decision variables to the spline function. Despite of the improvements in this model, the objective function still has some integrals difficult to be solved, thus quasi Newton descent algorithm was advised and utilized to facilitate the calculations. However, in numerical search most of the important constraints were taken into consideration and utilized for different types of costs, continuous search space involved, and the resulted alignments categorized as realistic alignments. On the other hand it has multiple local optimum points, the modeling and calculation process is characterized with complexity, and cannot calculate discontinuous cost components.

- **Neighborhood search heuristic with mixed integer programming (MIP):**

A heuristic approach was proposed by [30] for three-dimensional highway alignment problems satisfying the main elements of the design standards, taking into account a different requirement and mechanisms for heavy vehicle velocities on upgrades. The proposed approach started by entering the all requirements (i.e. codes, restriction terrain

and heuristic parameters) to generate the initial alignment, and then through three consecutive iterative stages, the three-dimensional alignment will be generated with speed profile. Where the horizontal alignment is selected between two ends based on the design elements, and with assistance of mathematical formulation the computations of two ends positions, direction and required radius are done, furthermore, land costs are added to the designed model for the restricted areas (which suggested to be approximately in circular shapes as much as possible to decrease the complexity in the computations) and according to encroachment value the penalties will be computed. While the vertical alignment will be generated first in the stage one of this model with less accuracy, and then through some enhancement (moving the intersection points and inserting the design elements) the outputted vertical alignments produced with a higher accuracy. This model applied on two different terrain, with C language code uses CPLEX 6.51 callable library, where the first example took approximately 15.2 hours for 1039 iterations, and the other one took 19.6 hours for 909 iterations.

Besides the main three groups above (horizontal, vertical, and three-dimensional optimizations), a number of studies have also been introduced to formulate the optimization problems for the land transportation alignments (highway or railway) through determining the intermediate point's positions and the formed curve, the developed approaches divided in to two categories (direct and indirect) depending on the way of the intermediate point's locations calculations [31]:

- **Direct approaches**

The coordinates of the intersection points and the radii of the curve are determined directly after treating them as variables.

- **Indirect approaches**

The coordinates of the final intersection point and the radii of the curve are determined and derived from the generated optimal path.

Throughout all the mentioned approaches and methods, Genetic Algorithms (GAs) occupied an important space in the land transportation alignments optimization for long periods, in 1998 and depending on the concepts of this algorithm, Jong developed the methodology of the Highway Alignment Optimization (HAO), the consecutively implemented enhancements on (HAO) assisted the complex optimization problems for different environmental phenomena's to be solved and became possible especially after integrating it with the database of Geographic Information System (GIS) [31-33]. [34-36]

continued the improvements and the studies of the [37] models for the rail transit routes optimization, to detect and determine the station's positions along the transit lines besides the transit alignments optimization. One of applicable alternatives of the Genetic Algorithms is the [38] algorithm for search and find the closest results to the optimal highway alignment formulated from the general social behavior of bird flocking and fish schooling. Multi objective models (i.e. [39], [40]) are also developed and presented for land transportation alignments optimization problems besides the mentioned algorithms and methods above.

Generally, the selection and optimization process of an alignment generated between two ends (source and destination) play an important role in all transportation modes (i.e. roads or railways, pipelines, etc.) and a lot of techniques and mathematical models and programs have been introduced and utilized to give more realistic results in least time, cost, and with minimum error as much as possible and all this achieved with computations some of them characterized by flexibility and ease, and the others with complexity depending on the type, amount and size of the problem in a side, and the method of solution together with the mechanism used to find the appropriate solution on another side. In addition to this, in terms of the engineering design of the route, despite the differences in the transportation means, most of them have the same problem, and all converge in almost one point, which is to find the most proper and more appropriate path between two ends, therefore some of the above models (deterministic and stochastic optimization models) have been applied to the same problems in pipelines and pipelines network (especially for water supply and transmission). Below, some of them are mentioned:

➤ **Enumeration model in pipelines:**

This technique utilized to simulate each possible set of discrete sizes of pipe, and the most appropriated to the pressure constraints will be selected as the least cost network. One of the enumeration models proposed for pipe network optimization is introduced by [41] depending on the original criteria of the enumeration by means of pipe size and costs, and can be considered as an improvement model of what was presented in [42], and [43], where the objective of optimization processes is defined as a tool that helps the designer for finding the final solution based on a set of requirements and constraints besides the designer experiments. Thus, the important requirement for the optimization program is listed and viewed based on their importance. In [41] algorithm, firstly, all pipes are

identified according to the size for optimization process of a new proposed project or only a number of pipes required to be added to an existing project for enhancements objectives. For both of them, a list has been already prepared to achieve this purpose. In the second step, the required cost for each pipe to be checked and compared to the resulting values through a file designed especially for many cost functions. At the end of the progress, the results, which only meet all of the requirements for construction will be saved as a new best solution for the introduced problem. However, this algorithm offered an alternative solution (i.e. Pareto optimal solutions), that can be provided great flexibility, and can be utilized easily for additional consideration (i.e. the cost computation at different points for water providing purposes).

➤ **Genetic Algorithms (GAs) in pipelines:**

It's a search algorithm with stochastic operators [21] based on the survival of the fitness, where the main frame of this algorithm was proposed by [44]. In GAs, the problems are introduced as environment, the possible solution treated as the population were the old populations will assist in the generation of the new populations, each x , y , and h (individuals) is encoded in to string known as chromosome, then the production of the offspring will be done depending on fitness of the selected individuals at each generation. [45] utilized GAs in the optimization of the steady state serial pipeline, as approximate solutions by the means of genetic algorithms operators: reproduction, crossover, mutation. Where the crossover, mutation, and the number of population has been set equal to 0.7, 0.01, and 100 respectively in the determination near optimal solutions through the total alternative, the operation was realized and programmed in Pascal for the objectives of reducing the most power while providing a certain flow and sustaining the allowed pressures.

In addition to [45] study for pipeline operation optimization with genetic algorithms, [46] utilized genetic algorithms for structural optimization, [47] used GAs in the control system optimization for aerospace utilizations. While [48] and [49], introduced models for submarine and ground pipelines for minimizing cost purposes with simulated annealing.

However, the earliest study introduced for pipeline optimization with GAs is in [50] for optimization two phase pipelines route problems. The proposed algorithm with hydraulic computations and optimization standards for route has been used for methane collecting

realized on a digital map with population size, number of generations, arithmetic crossover and uniform mutations probabilities for genetic algorithm set to 200, 1000, 0.95, and 0.2 respectively. The optimal route on the complex topography between two ends computed automatically as a straight line after 500 generation and continued straighten till the 1000 generation terminated and the best route has been achieved.

It has been cleared from the mentioned and presented algorithms and models whether, in the past or recent in this section, the process of finding the optimal alignment between two points plays an important role in the design and optimization route processes, and directly affect the calculation of the possible minimum cost. Furthermore, the optimal path in the optimization of the three-dimensional alignment operations has been achieved, where the vertical alignments selected based on the determined horizontal alignments.

In this research, the process of finding the optimal path between two ends will be reverse to what will have presented, where the vertical alignment will be computed first based on the horizontal coordinates differences, direction, and step interval between to ends, and then depending on the vertical alignment slopes and some criteria, the horizontal alignment will be generated between the selected known ends as a preliminary study. More details and explanations are presented in the **Chapter 3** of this thesis.

1.2 Objective of the Thesis

This study aims to propose an algorithm automatically connecting two or more known points for route planning search between two known ends as preliminary design solutions. The proposed model offers an automatic connection between the selected two ends on a generated terrain (real terrain and simulated terrain) due to the azimuth angle of the searched points, step interval, horizontal coordinate differences to draw the closest terrain slope, As well as to select the more suitable alignment in three steps: First, it compares the slopes between consecutive points and the zero-line then decides the minimum difference (with some permission value) approximately most of the results will be chosen at this stage. Second, minimum differences in h-value is applied to the results of the first stage as a second criterion (with some permission value also). Third, the shortest distance is applied to the results of the first and second stages as the third and last criterion (without permissions). Moreover, an option for the problematic areas where more than one slope is needed concerning terrain topography to find the locations of the intermediate points coordinates (between start and end points). Consequently, the resulting optimized

alignment is non-backtracking, smooth, close to the assigned slope (The value of the assigned slope that the alignment will have after selecting the starting and ending points can be chosen automatically by accepting the amount from the differences in height and distance between the two points or manually inserting it to ensure that the slope does not exceed the desired amount of the project implementation, especially in the areas of steep slopes.) and the shortest path between two points depending on given criteria as much as possible.

1.3 Hypothesis

In this study, a new approach is proposed in determining the probable pipeline route and the three dimensional coordinates of the all intermediate points between two ends on a generated terrain, based on the topographical structure of the land, three-dimensional coordinates of the selected start and end points, fixed slope, fixed step interval which represents the length of pipe from joint to joint and in our case represents the radius of the circle where the searched points will be generated on it with angular space equal to 0.5° and distributed from 0° to 360° , and depending on the position of the end point in the different quarter of the coordinates system this circle will be changed to an arc with the same radius and oriented towards the end points. The automated algorithm imitates the zero line approach, which is commonly used for alignment design, by a certain vertical alignment and then determine the horizontal alignment. With the proposed approach it's planned to automatically assign the coordinates of the appropriate intermediate points between two known ends by taking the three-dimensional coordinates of the selected start and end points on the terrain as starting criteria.

CHAPTER 2

PIPELINE TRANSPORTATION

Pipeline transportation is one of the most important, common and the safer transportation modes when it is compared with trains or trucks, especially in the cases of sensitive liquids transportations, despite being invisible or underground constructed in the most projects, it is primarily related to most of our daily activities. Pipelines before thousands of years successfully used to transport water and sewage. Then, according to the significant improvements in the technology sectors fundamentally in pipelines, assisted in producing larger, stronger and longer pipes extended around the world [51, 52].

Pipelines generally defined as consecutive segments of the line connected at points called joint. Each piece of this line is called pipe used to transport different materials (liquids and gases) above/under the ground through these pipes with different sizes, lengths and materials over considerable distances between two different places (in the same country or between countries). Besides water and sewages transportations, nowadays, pipelines used to transport the extracted oils and gases from the sources over long distances for different purposes.

Currently, different pipelines system in the world exist everywhere in the form of networks or as individual routes based on the continued growth and the expansion of the cities, all of them has their company provides the ways to transport the materials between two places and according to the statistics, and the observations from 124 countries use pipelines for different purposes of carrying [53], the total number of the pipeline length in a km is 4,425,478.00, where the United States ranked first with the highest percentages 50.28% followed by China, Russia, Canada, Hungary, and Ukraine respectively to represent approximately 80.28% of the total pipelines in the world, while Turkey and Iraq came in the ranking 26 and 33 respectively, with another 118 countries the remaining percentages of the total pipelines are represented. The rates are shown in Figure 2.1, and

the specific details for the pipelines length of 124 country shown in the Table A.1 sorted from the longest to a shorter length.

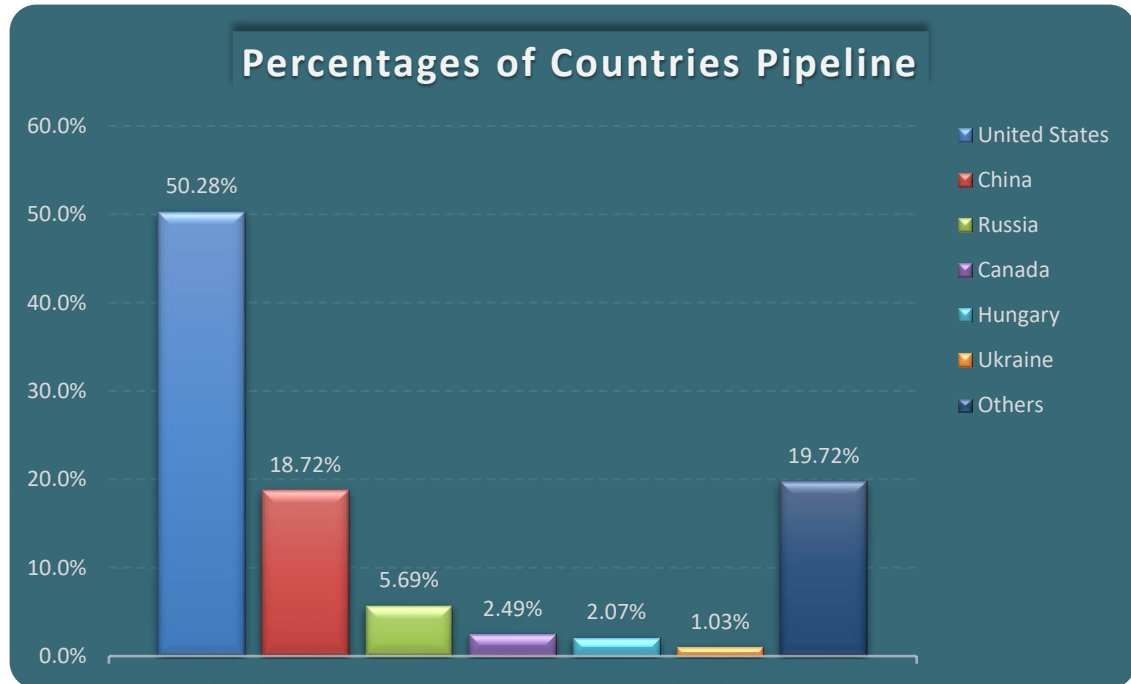


Figure 2.1 The percentages of 124 countries pipeline length

Pipelines can be classified into different categories [51]:

- Water, sewers, oil, product, natural-gas pipelines, etc. based on the transported materials through the pipe.
- Offshore, inland, in-plant, mountains, outer space pipelines (on another planet for experiments and explorations) depending on the environments.
- Steel, plastic, cast-iron, concrete pipelines, according to the material in which the pipes were built.
- Finally, based on the supports and type of burial it can be divided into aboveground, underground, elevated, and submarine pipelines.

In addition to the above classifications, pipelines can be classified into further categories also depending on the purpose of use: Collecting pipelines (Complex networks of smaller pipelines with the aim of transporting oil/natural gas from wells to a processing plant through short and small diameters pipelines). Transportation pipelines (Commonly, carries oil, gas and refined products between cities, countries even continents through long pieces and large diameters pipelines). These networks include several compressor stations in gas lines or pump stations for unrefined and multi-products pipelines.

Moreover, distribution pipelines can be added to this list where, in this type of classification, materials and products are delivered to consumers via small-diameter pipelines. Figure 2.2 shows a sample of pipeline networks on different terrains for various purposes.

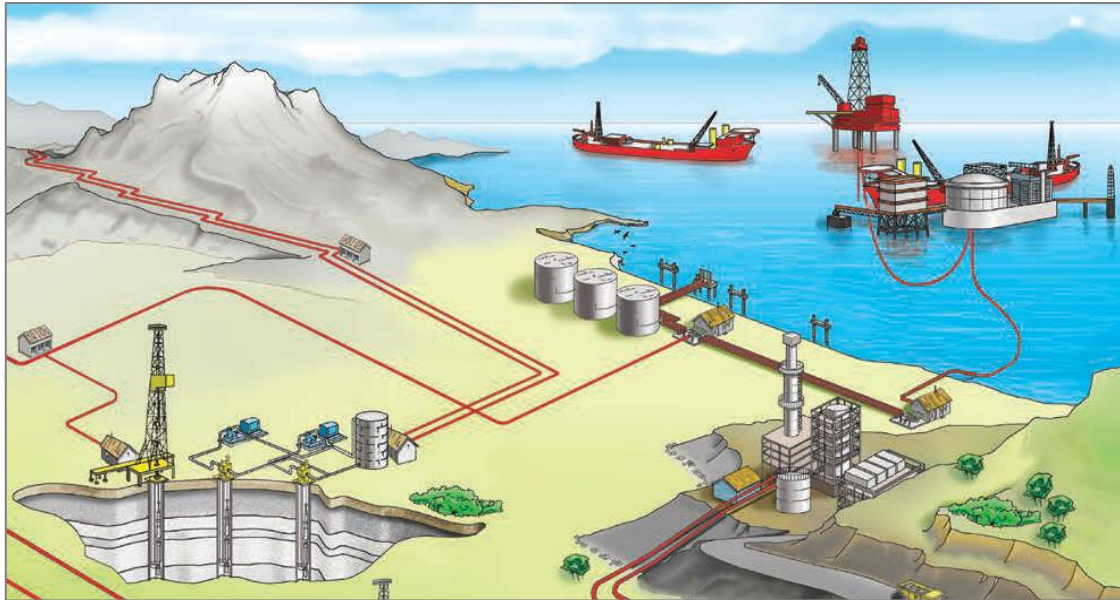


Figure 2.2 Illustration of pipeline networks

Water transmission is one of the pipelines transportation's modes, refers to the transportation of the water from the source to the treatment plant and then to the area of distribution. This facility may be realized in three ways:

- Free-Flow (Gravity Flow),
- Pressurized Pipelines (Pumping Systems) and
- A combination of them depending on the conditions of the topography, where the pipeline passes through and regarding the subsequent complex hydraulic processes.

Among them, free-flow conduits with its different forms are favored in mountain areas or in areas where the required slope of the conduit more or less coincides with the slope of the terrain. In the free-flow system no equipment is required, the water reservoir placed in the higher elevation of a hill, then taken and transmitted to the required place (distribution area) depending on the gravity's energy to provide the required pressure and energy to assist in turn the movements of the water through the pipeline (the differences in height between the Start and End points represents this energy), and pipeline length. However, depending on the terrain where the pipeline will be generated pipe size is also

one of the important factors to provide this energy between the two ends, therefore in same cases more than one pipe size will be required, and when the pipe size is changed the cross-sectional area of the pipe will be affected, thus, the flow will also be affected in turn because it is directly related to the correctional area of the pipe multiplied by the velocity. In the water free-flow systems, the water will be in the static level and the friction value is equal to zero (friction represents the lost energy according to the water flowing inside a pipe with roughness wall or water's temperature or suspended particles in the transported water) till the flow starts between the two ends and the system's situation changed from static to dynamic equilibrium, and for the both situations, the energy levels for the all points in the system will be represented by Hydraulic Grade line (HGL). Where this line drawn as a horizontal line from the start points towards the end points with the same height of the start points in the static equilibrium, while the same line will be aligned downwards from the water reservoir (with slope determined from the height differences between the Start and End points). Figures 2.3 and 2.4 show the free-flow system for water transportation with the hydraulic grade line for both conditions static and dynamic between the two ends, and an example of constructed pipeline in mountain areas for fluids transportation respectively.

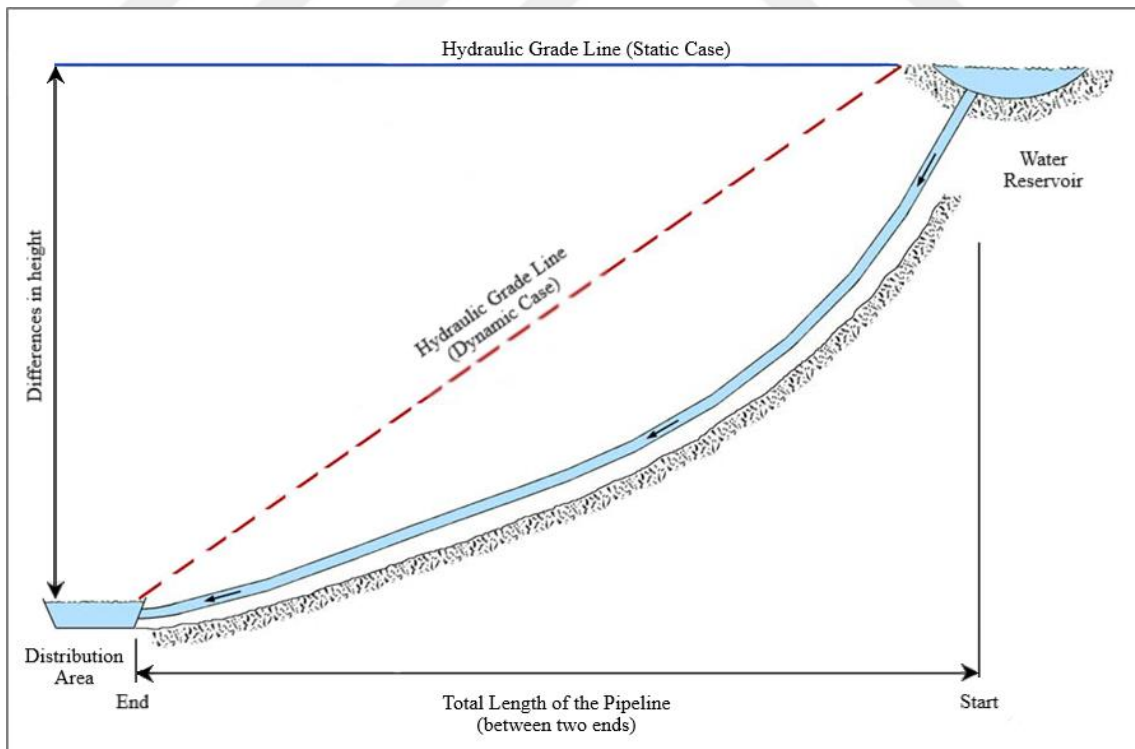


Figure 2.3 Water free-flow system



Figure 2.4 Fluids transportation through pipeline in mountain areas

Additionally, one of the important projects in the field of water supply and transportation is the Turkey – North Cyprus (TRNC) project (or KKTC Su Temin Projesi in Turkish) for water transmission through pipelines under Mediterranean Sea which started from Alaköprü Dam in the southern of Turkey (23 km length, high density polyethylene pipes with a nominal diameter of 1500 mm) crossing the Mediterranean Sea via hanging pipe system (80.151 kilometer length, and 250 meter height under the mean sea level with high density polyethylene pipes of a nominal diameter equal to 1600 mm, and a length of 500 meters each) to Geçitköy Dam in the northern coast of Cyprus (Turkish Republic of Northern Cyprus) (3 km length high density polyethylene pipes with a diameter of 1400 mm) Thus, it's considered as the one of the largest and the unique projects in the world constructed for water supply using hanging pipe system under sea. However, the total length of the constructed pipeline from Start to End points is 106.3 kilometer, provides the Northern Cyprus annually $75 \times 10^6 \text{ m}^3$ of water. Where, 50.3% of this water can be used for drinking purposes and the remain percentages for plants irrigation. Figure 2.5 show the route of the constructed pipelines in this project [54].

Another example of the great projects designed for water transportation, is the Great Man-Made River (GMMR) project, which was built in Libya for fresh water supply purposes

from the aquifers in southern east – southern west of Libya to the northern parts through a network of prestressed concrete cylinder underground pipes [51].



Figure 2.5 TRNC project: constructed pipelines route [54].

CHAPTER 3

A NOVEL APPROACH WITH ZERO-LINE FOR PIPELINE DESIGN

In the preliminary design of pipeline route, the horizontal alignment design is an essential factor regarding the connection of the pipes, which should be realized in certain angles due to flowing and construction goals. Meanwhile, the vertical alignment design, which should provide appropriate longitudinal slopes to perform flow, and should be considered simultaneously while planning the horizontal alignment. Although the details of design standards vary with the project area and construction manner, most of the issues involved in geometric design are similar for water transportation types. Preliminary design is applied to compute the appropriate slopes permitted to free-flow in pipelines used as the most common way of finding proper route consideration of the earth topography.

As known, the projection of the all transportation modes centerlines on the topographical map, or on the earth is known as route (the path between two points Start and End). The process of connecting two ends (with known coordinates), will give many alternative paths depending on a set of elements and engineering standards. Generally, the route alignment optimizations deal with finding the best alternative routes between any two ends (known coordinates). However, besides the mentioned algorithms, models and solutions in the **Chapter 1** for route selecting and alignment optimization, alternative approaches introduced and applied also with various criteria to find the optimal path between two known points for different purposes, one of these alternatives is zero-line solutions.

Zero-line is a theoretical line in the form of an opened polygon with broken lines connecting two known points, passes through the all intermediate control points and represent the proper paths between these two ends on the ground with specific constant slopes always termed as zero-polygon where the total volumes of cut and fill is equal to

zero. If there is more than one path connecting the start and end points and they have a zero-line property, the path with the lowest number of broken lines is selected.

The proposed approach, designed by using MATLAB codes on the same concepts of zero-line with simple improvements to get better results depending on the coordinates of the Start and End points inside the boundary limit of the study area, and an automatic evaluation of data will be started after Start and End points selections to check the behavior of the possible study area's data at each point and considering all possibilities to draw and select the optimal route between these two ends taking into account the longitudinal slope of the vertical alignment condition. Furthermore, the intermediate points between any to ends will represent the positions of the joints on the selected route depending on the given pipe length. Figure 3.1 represents the flowchart of the proposed algorithm.

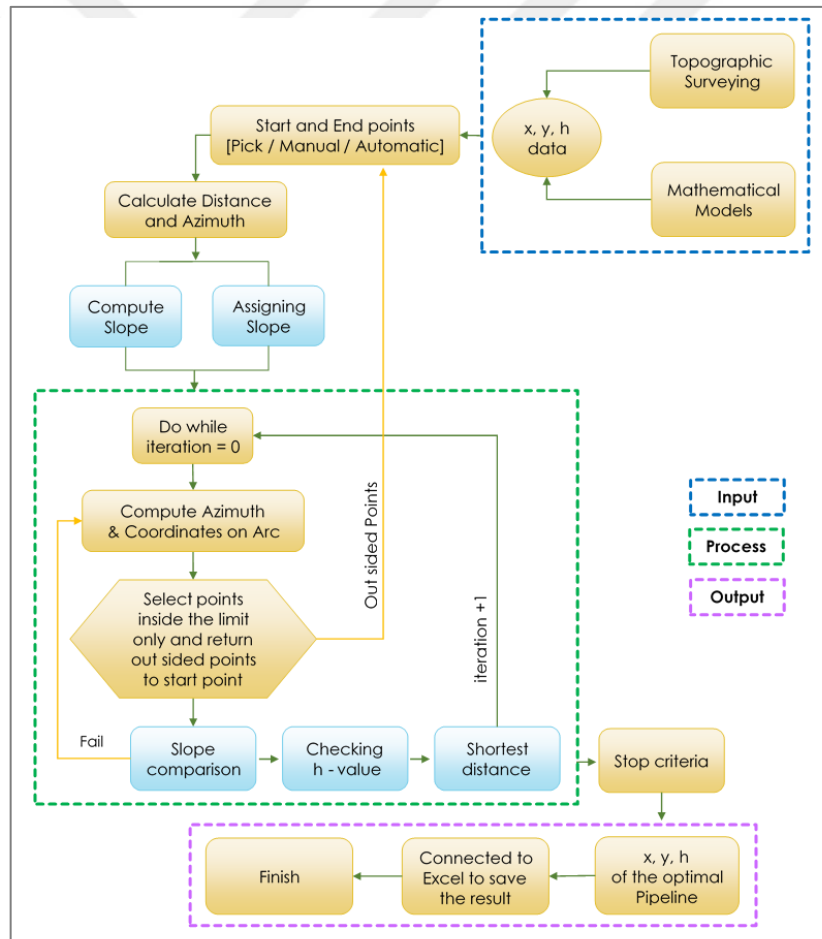


Figure 3.1 Flow chart of the designed approach

After the algorithm is run, in the commend window first requirement will be to enter the number of the experiment which helps in saving the outputs of the approach after the goal is achieved as shown in Figure 3.2 (Default value is 1).



Figure 3.2 Command window when the program run

Then, it's will trying to read the x , y , h data as input (from .txt File or using our simulation model which designed for this purpose), after that, an interpolation (Scattered Interpolant provided by MATLAB) is performed on the data set of the inputted x , y , h data together with the mesh grid with suitable intervals (Cartesian grid in two or three-dimensional space which returns the two-dimensional grid coordinates depending on the original vectors x & y , then, anew variables defined as x_m & y_m in a matrix form, where each row in the matrix x_m is a copy of the original vector x , and each column in the matrix y_m is a copy of original vector y , as a result the grid will be represented by the coordinates of x_m and y_m with rows and columns equal to the length of the y and x respectively [55]). Besides the interpolation, MATLAB code for Scattered Interpolant supports also the extrapolation. However, the general form of this code is:

S equal to scattered interpolant (x , y , h , Interpolation Method, Extrapolation Method) where;

1. S represents a variable used to return the interpolant value of the inputted data.
2. x , y , h is the inputted data.
3. Interpolation Method: there is three interpolation methods supported by the MATLAB for the Scattered Interpolant (where the correct sign in front the methods represents the handled method in this approach):
 - ❖ Linear Interpolation: it's a continuous interpolation, and the MATLAB code for Linear Interpolation is "linear".
 - ✓ Natural Neighbor Interpolation: it is continuous also except at the dataset locations, and the MATLAB code for this type of interpolation is "natural".
 - ❖ Nearest Neighbor Interpolation: discontinuous interpolation method, and in the MATLAB represented as "nearest".
4. Extrapolation Method: it can be one of the followings methods (where the correct sign in front the methods represents the handled method in this approach):
 - ❖ Linear Interpolation: represented as "linear" in the codes.

- ❖ Nearest Neighbor Interpolation: represented as “nearest”.
- ✓ None of them will return the queries out of convex hull to Nan, in the MATLAB this extrapolation method for Scattered Interpolant is represented as “none”.

After the coordinates file is loaded to the program, the interpolation and the mesh grid with space interval equals to 1.2 is selected and applied on the data, in automatically pattern a surface with a contour map (6 m contour intervals) will be generated to represents the inputted x, y and h from the data files. So, the horizontal axis in the generated surface will represents the x-values, vertical axis represents the y-values and the heights represented by a contour lines, and with respect to the height value of the points in the data file they will be colored with different colors ranged from dark blue to yellow, Figures 3.3 and 3.4 show the generated surface from real data to represents the real terrain model and the generated surface from random points with mathematical formulas designed for this purpose to represents the simulated terrain model respectively.

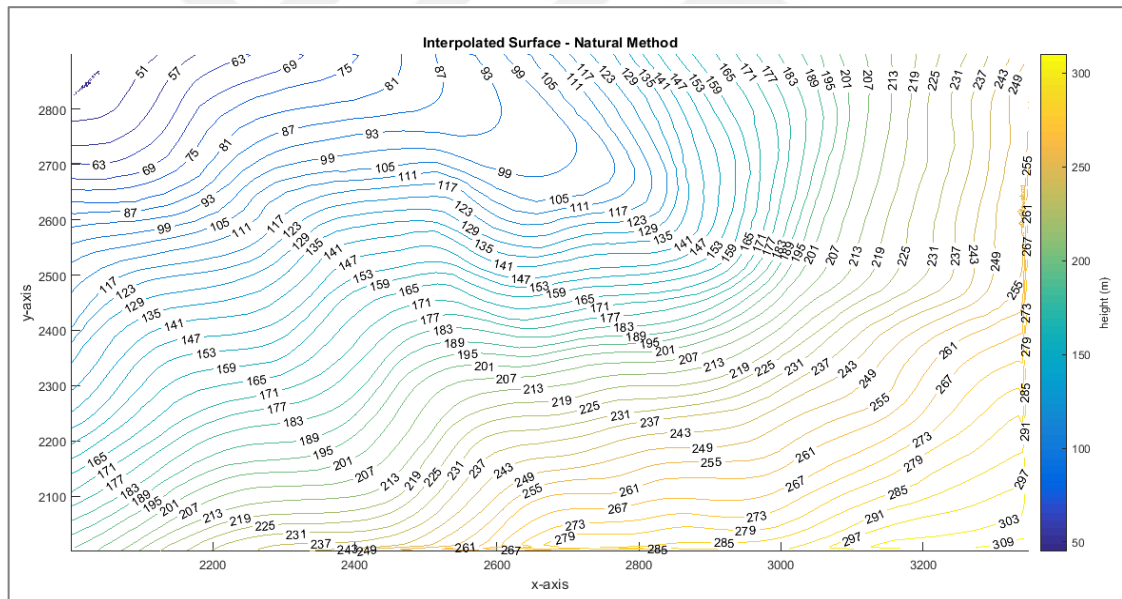


Figure 3.3 Generated surface from real data

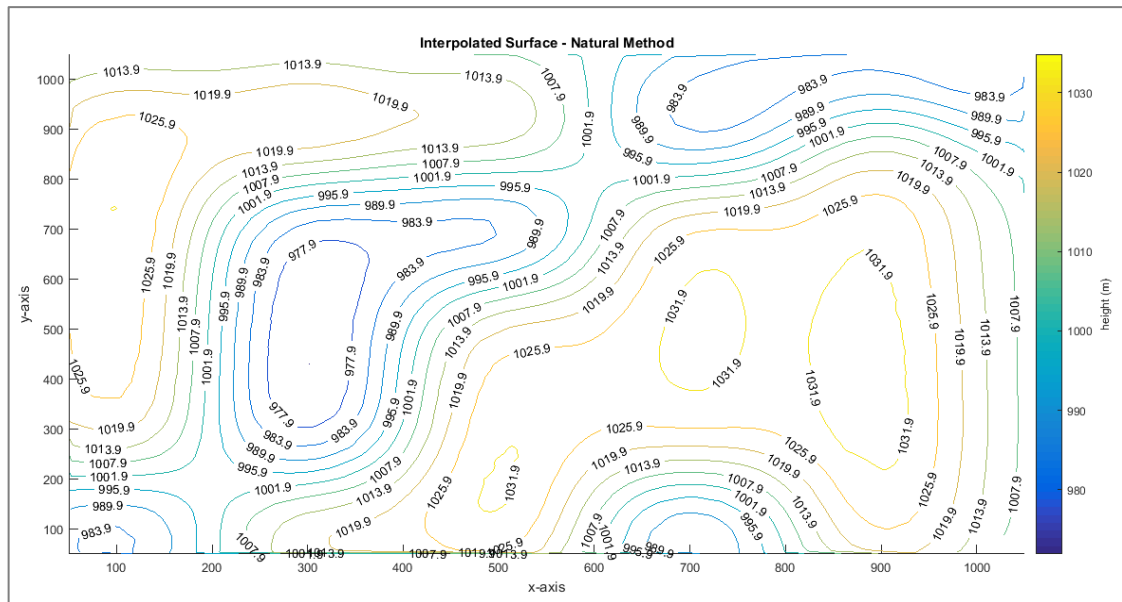


Figure 3.4 Generated surface from simulated model

The next step is the selecting three-dimensional coordinates of the Start and End points for appropriate path, and for this purpose three options have been designed and added to the algorithm:

- Pick points from the screen [Default]

This option will give the user the ability to pick the points from the generated surface for the Start and End points individually, and it is considered as the default option, Figure 3.5 shows this option.

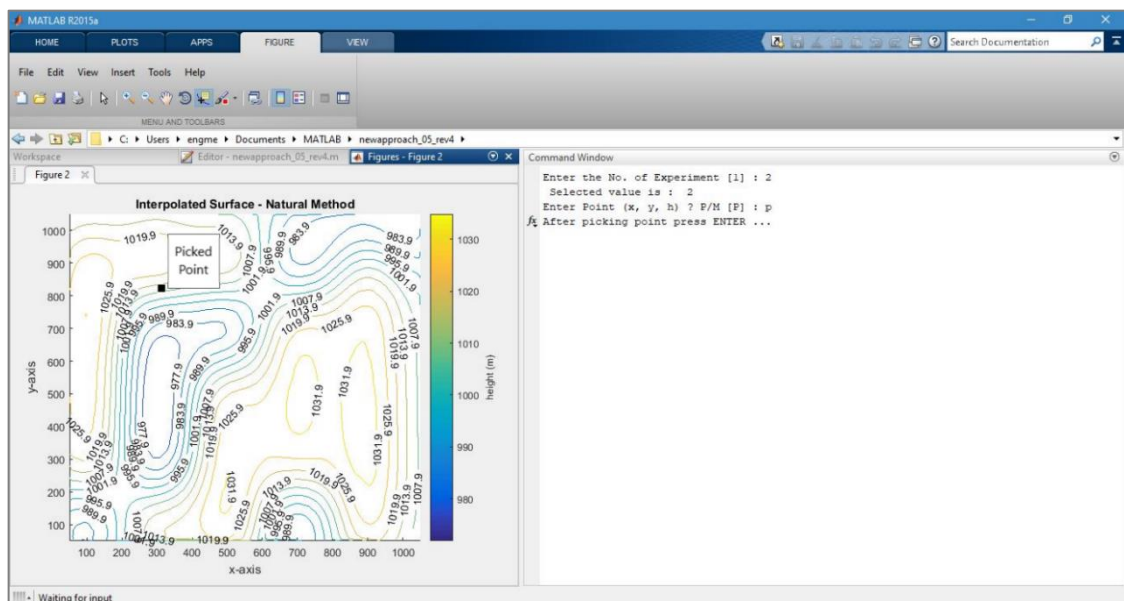


Figure 3.5 Start and End points selections [Pick option]

➤ Entering the x, y, h values Manually

By selecting this option, the user will be asked to enter the x, y, h coordinates consecutively for the Start and End points, as shown in the Figure 3.6.

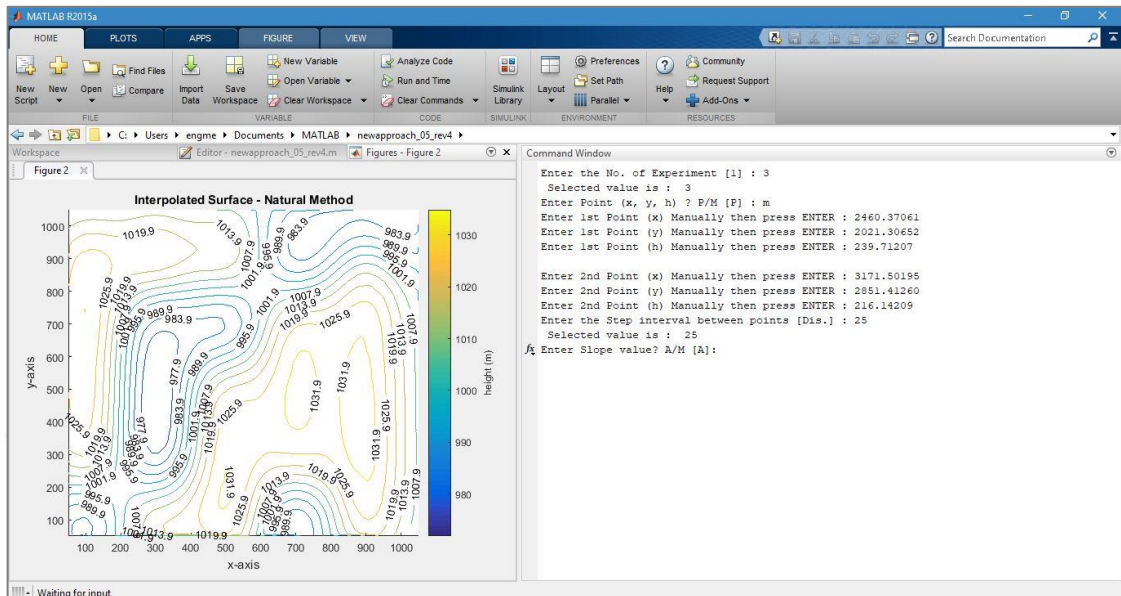


Figure 3.6 Start and End points selections [Manually option]

➤ Reading the coordinates from Excel program

This option added to the algorithm to give the users an ability to read the coordinates of the Start and End point directly from Excel program, and it's useful for time-consuming in the selecting the two ends, this can be achieved by using the following MATLAB code to read Start and End points coordinates from Excel and Figure 3.7 clarify the work of this option:

$$st = xlsread('mxconnection', 'origin', 'B4: D4'); \quad (3.1)$$

$$fsh = xlsread('mxconnection', 'origin', 'B5: D5'); \quad (3.2)$$

Where:

st represents the Start point.

fsh represents the End point.

mxconnection Excel file name.

origin Excel file sheet name.

B4: D4 & B5: D6 Cells names that contain x, y, h values in Excel file sheet for the Start and End points respectively.

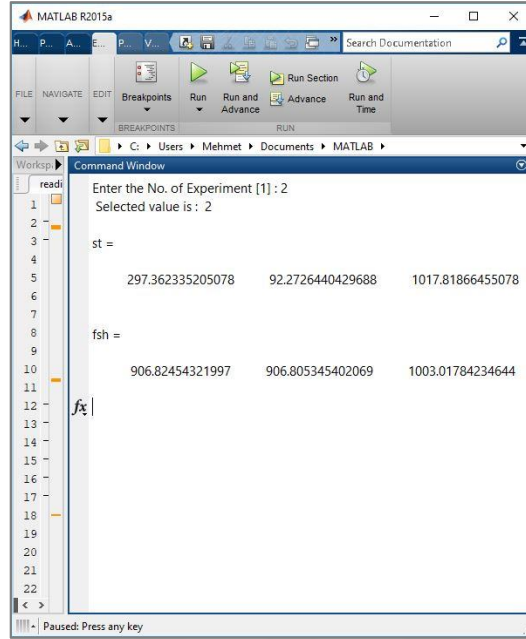


Figure 3.7 Start and End points selections [from Excel directly]

After Start and End points selecting inside the boundaries limit were done successfully, the selected two ends will be connected with a straight black line on the digital terrain surface, the distance and azimuth between them are automatically calculated from horizontal coordinates differences through the following formulas:

$$\Delta x = x_{End} - x_{Start} \quad (3.3)$$

$$\Delta y = y_{End} - y_{Start} \quad (3.4)$$

$$Dist = \sqrt{(\Delta x)^2 + (\Delta y)^2} \quad (3.5)$$

And then the calculated distance is multiplied by a value equal to 1.1, which represents the coefficient of the calibration of the horizontal distance. Later, in the command window, the space interval requested to be entered as an integer value which represents the segment length of the pipe (distance between joints), and to compute the slope between Start and End points, one of the following options can be used:

- Automatically calculated from height differences [Default]
- Manually for the projects required assigning slope (i.e. slope $\leq 15\%$, < 0 and etc.)

Thus, in the later computations, the computed or entered slope will be used as a reference and constant value. Figures 3.8 and 3.9 show both options. For the automatic options of pipeline slope determination, the differences in the vertical components of the Start

and End points is calculated first and divided then by the total length of the pipeline from the previous step:

$$\Delta h = h_{End} - h_{Start} \quad (3.6)$$

$$Slope = \Delta h / Dist \quad (3.7)$$

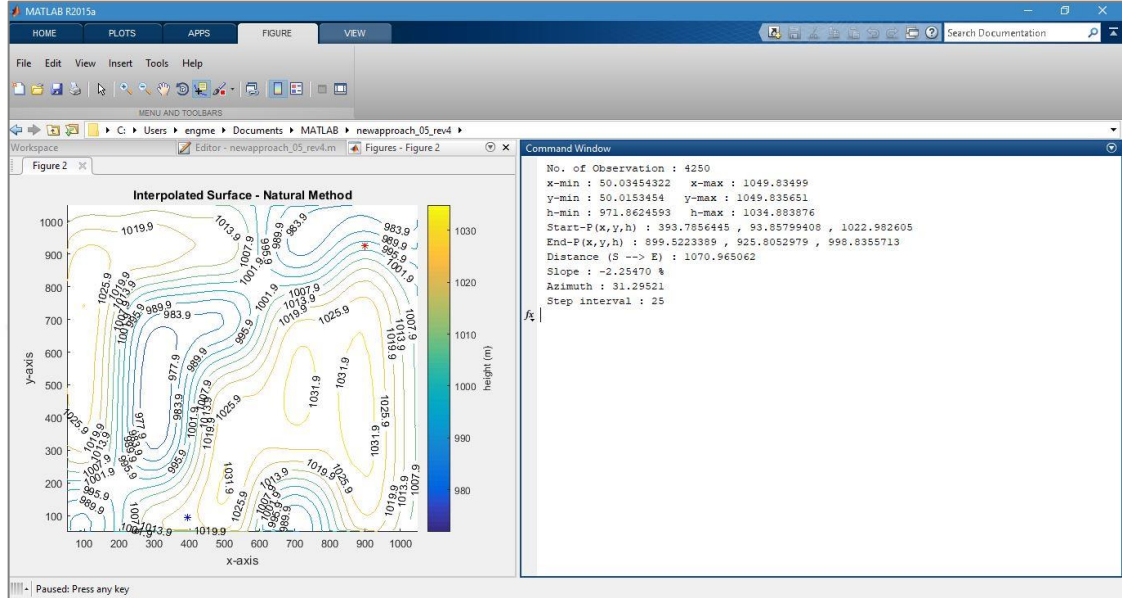


Figure 3.8 Slope calculation options [Automatically calculated]

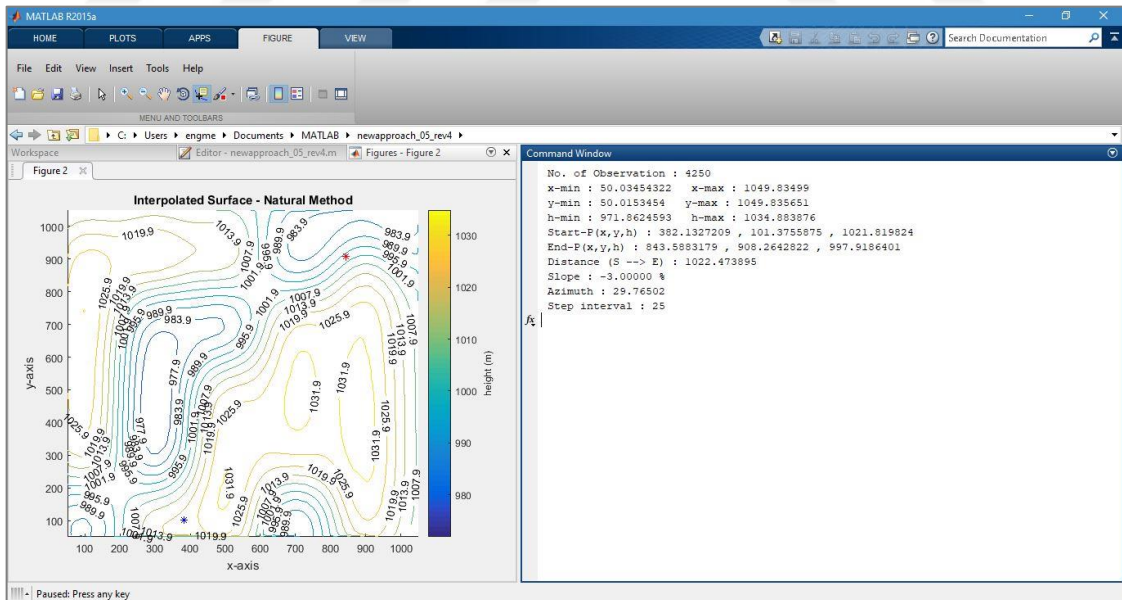


Figure 3.9 Slope calculation options [Manually entered]

The next step is the calculation of the straight line direction's from the North which represents the Azimuth of the line connecting the two ends on the generated terrain:

$$\alpha_{SE} = \tan^{-1}(\Delta x / \Delta y) \quad (3.8)$$

After that, the searched points will be drawn and distributed on a circle (0° to 360°) with an angular space equal to 0.5° (perform 181 points) and radius equal to the Space interval (represent the pipe length) as shown in Figure 3.10.

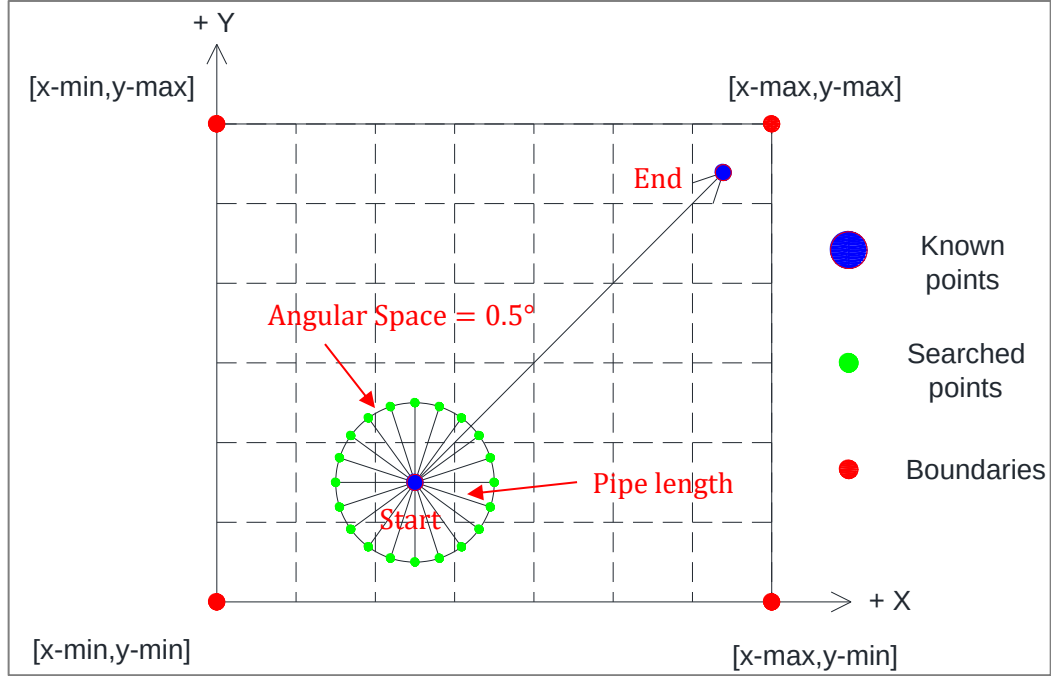


Figure 3.10 Generated searched points with angular space and pipe length

Then, according to the different possible locations of the End point in each quarter as shown in the Figure 3.11, this circle will be changed to an arc (with same radius of the circle), and different conditions and criteria's are added to the algorithm to assist the determination of the azimuth value for each point in the iteration process:

1) if $\Delta x > 0$ & $\Delta y > 0$

$$\alpha_{SE} = \alpha_{SE} \quad (3.9)$$

2) if $\Delta x > 0$ & $\Delta y < 0$

$$\alpha_{SE} = \alpha_{SE} + 180^\circ \quad (3.10)$$

3) if $\Delta x < 0$ & $\Delta y < 0$

$$\alpha_{SE} = \alpha_{SE} + 180^\circ \quad (3.11)$$

4) if $\Delta x < 0$ & $\Delta y > 0$

$$\alpha_{SE} = \alpha_{SE} + 360^\circ \quad (3.12)$$

5) if $\Delta x = 0$

$$\alpha_{SE} = 90^\circ \quad (3.13)$$

6) if $\Delta y = 0$

$$\alpha_{SE} = 0^\circ \quad (3.14)$$

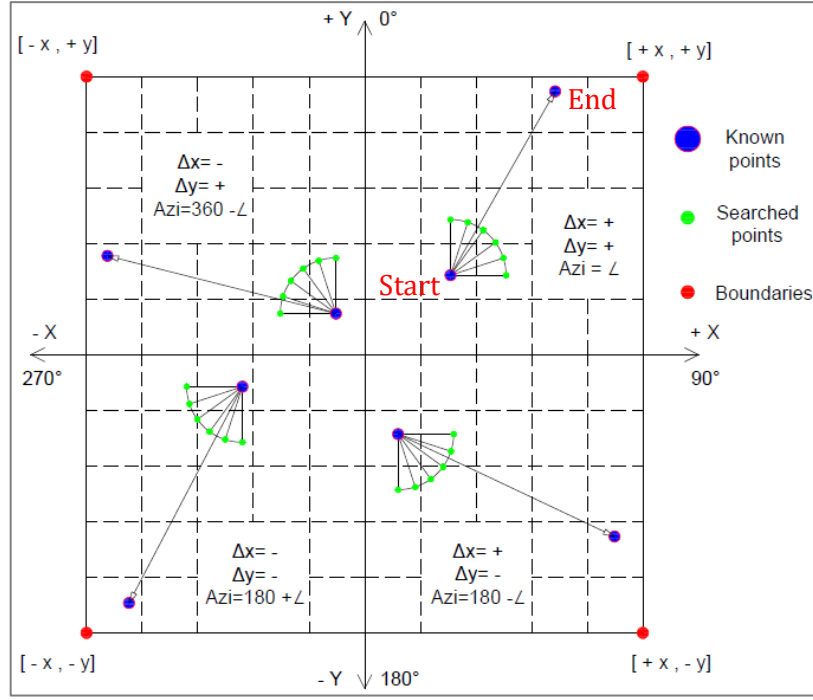


Figure 3.11 Possible situations of the searched points on the arc in each quarter

Where the azimuth for the iteration points is calculated from the horizontal coordinate differences between the Newpoints and the Endpoint on the path. However, to keep the generated arc always directed towards the End point and to determine the horizontal component's coordinates (x, y) of the searched points at each iteration depending on the direction of the generated arc, supplementary conditions and equations are used together in three different situations to achieve that:

a) The first five condition represents the first situation, and Figure 3.12 used to illustrate these conditions as a shaded region with blue color.

1) if $\alpha_{SE} > 5^\circ$ & $\alpha_{SE} < 85^\circ$

$i = 1 : 181$ and $\theta = 0^\circ : 0.5 : 90^\circ$

$$x_{sp(i)} = x_p + Step\ interval \times \sin(\theta_{(i)}) \quad (3.15)$$

$$y_{sp(i)} = y_p + Step\ interval \times \cos(\theta_{(i)}) \quad (3.16)$$

2) if $\alpha_{SE} > 95^\circ$ & $\alpha_{SE} < 175^\circ$

$i = 1 : 181$ and $\theta = 0^\circ : 0.5 : 90^\circ$

$$x_{sp(i)} = x_p + Step\ interval \times \sin(\theta_{(i)} + 90^\circ) \quad (3.17)$$

$$y_{sp(i)} = y_p + Step\ interval \times \cos(\theta_{(i)} + 90^\circ) \quad (3.18)$$

3) if $\alpha_{SE} > 185^\circ$ & $\alpha_{SE} < 265^\circ$ & $|\Delta y| > |\Delta x|$

$i = 1 : 181$ and $\theta_1 = 90^\circ : 0.5 : 180^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{1(i)} + 90^\circ) \quad (3.19)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{1(i)} + 90^\circ) \quad (3.20)$$

4) if $\alpha_{SE} > 185^\circ$ & $\alpha_{SE} < 265^\circ$ & $|\Delta y| < |\Delta x|$

$i = 1 : 181$ and $\theta_1 = 90^\circ : 0.5 : 180^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{1(i)} + 90^\circ) \quad (3.21)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{1(i)} + 90^\circ) \quad (3.22)$$

5) if $\alpha_{SE} > 275^\circ$ & $\alpha_{SE} < 355^\circ$

$i = 1 : 181$ and $\theta = 0^\circ : 0.5 : 90^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{(i)} + 270^\circ) \quad (3.23)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{(i)} + 270^\circ) \quad (3.24)$$

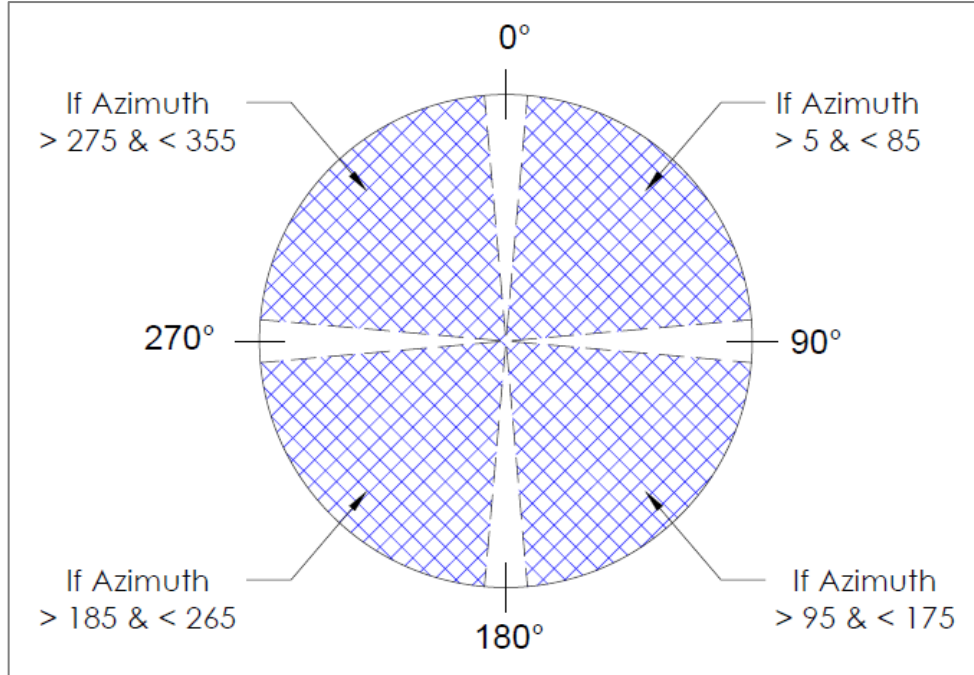


Figure 3.12 Searched points direction on the generated arc 1st situation

b) While the conditions from 6 to 9 represents the second situation and Figure 3.13 used to illustrates these conditions as a shaded region with blue color.

6) if $\alpha_{SE} \geq 85^\circ$ & $\alpha_{SE} \leq 95^\circ$

$i = 1 : 181$ and $\theta_2 = -45^\circ : 0.5 : 45^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{2(i)} + 90^\circ) \quad (3.25)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{2(i)} + 90^\circ) \quad (3.26)$$

7) if $\alpha_{SE} \geq 175^\circ$ & $\alpha_{SE} \leq 185^\circ$ & $|\Delta y| > |\Delta x|$

$i = 1 : 181$ and $\theta_3 = 45^\circ : 0.5 : 135^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{3(i)} + 90^\circ) \quad (3.27)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{3(i)} + 90^\circ) \quad (3.28)$$

8) if $\alpha_{SE} \geq 175^\circ$ & $\alpha_{SE} \leq 185^\circ$ & $|\Delta y| < |\Delta x|$

$i = 1 : 181$ and $\theta_3 = 45^\circ : 0.5 : 135^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{3(i)} + 90^\circ) \quad (3.29)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{3(i)} + 90^\circ) \quad (3.30)$$

9) if $\alpha_{SE} \geq 265^\circ$ & $\alpha_{SE} \leq 275^\circ$

$i = 1 : 181$ and $\theta_2 = -45^\circ : 0.5 : 45^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{2(i)} + 270^\circ) \quad (3.31)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{2(i)} + 270^\circ) \quad (3.32)$$

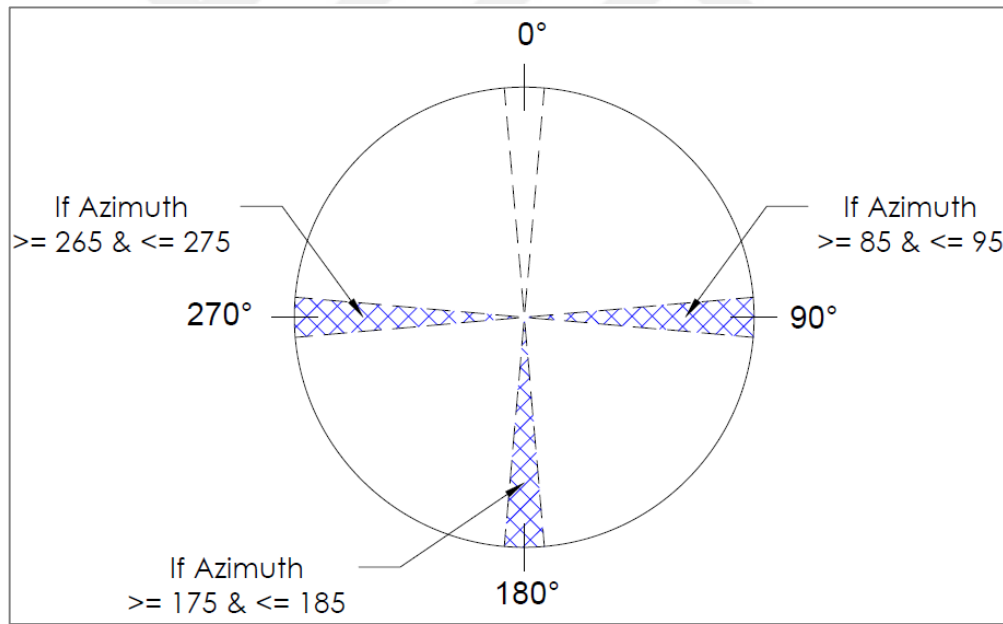


Figure 3.13 Searched points direction on the generated arc 2nd situation

c) And the final two conditions in this set is the condition 10 and 11 which represents the third situations and Figure 3.14 illustrates these two conditions as a shaded region with blue color and separated with red line in the direction of zero.

10) if $\alpha_{SE} \geq 0^\circ$ & $\alpha_{SE} \leq 5^\circ$

$i = 1 : 181$ and $\theta_2 = -45^\circ : 0.5 : 45^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{2(i)}) \quad (3.33)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{2(i)}) \quad (3.34)$$

11) if $\alpha_{SE} \geq 355^\circ$ & $\alpha_{SE} \leq 360^\circ$

$i = 1 : 181$ and $\theta_2 = -45^\circ : 0.5 : 45^\circ$

$$x_{sp(i)} = x_p + \text{Step interval} \times \sin(\theta_{2(i)}) \quad (3.35)$$

$$y_{sp(i)} = y_p + \text{Step interval} \times \cos(\theta_{2(i)}) \quad (3.36)$$

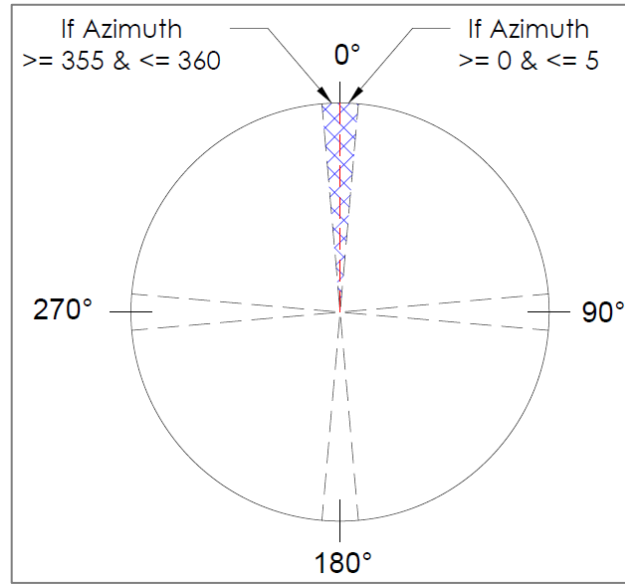


Figure 3.14 Searched points direction on the generated arc 3rd situation

After the all direction are checked, and the most convenient one has been selected to determine the (x, y) coordinates of the searched points on the arc by the general formula of coordinates calculation for each situation and iterations (as mentioned above), the vertical component (h – value) of the searched points on the generated arc determined automatically from the interpolated surface through the following MATLAB codes at each iteration for all computed (x, y) coordinates:

$$S = \text{scatteredInterpolant}(x, y, h, 'natural', 'none') \quad (3.37)$$

$$h_{sp(i)} = S(x_{sp(i)}, y_{sp(i)}) \quad (3.38)$$

In this way, the three-dimensional coordinates (x, y, h) of the searched points on the arc are calculated (181 points at each iteration). The next step will be finding the differences between the value of the longitudinal slope of the starting and ending points and the slope values calculated between the Start and End points on the generated arc. Then, through

these differences, the minimum difference between these values will be selected with some permission value equal to 0.0003 to represent the results of the first criteria proposed to find the optimal route between two given points. After that, the points were successes from the first criteria will pass to the next checking which is finding the minimum differences in h-value, and in this step the points will be selected with permission value equal to 0.00015. Then, the total distances between start succeeded points on the arc, and the end point is calculated. As a third and final criterion in this approach, the shortest distance is applied to the successes results of the first and second criteria to select the shortened one among the total calculated distances. This approach is work as a filtration of the result depending on the given criteria where the most of the results will be filtrated in the first criteria which are the slope comparison's, and the successful points will pass to filtrate in the second criteria, and the final criteria will represent the final filtration in this approach to select optimal points between two ends. In addition to the above conditions and criteria's, an internal secondary conditions are added to this approach to select points inside boundary limits only (especially when the points selected near the boundaries or passes near them) and return the out sided points to the start point for the x, y coordinates by the assistance of the following conditions for the left, right, top and bottom limits respectively, and the three main criteria will apply then to the remaining points to choose the optimal point among them:

1) if $x_{sp(i)} \leq \min(x)$ for the Left limit

$$x_{sp(i)} = x_{Start} \quad (3.39)$$

$$y_{sp(i)} = y_{Start} \quad (3.40)$$

2) if $x_{sp(i)} \geq \max(x)$ for the Right limit

$$x_{sp(i)} = x_{Start} \quad (3.41)$$

$$y_{sp(i)} = y_{Start} \quad (3.42)$$

3) if $y_{sp(i)} \leq \min(y)$ for the Top limit

$$x_{sp(i)} = x_{Start} \quad (3.43)$$

$$y_{sp(i)} = y_{Start} \quad (3.44)$$

4) if $y_{sp(i)} \geq \max(y)$ for the Bottom limit

$$x_{sp(i)} = x_{Start} \quad (3.45)$$

$$y_{sp(i)} = y_{Start} \quad (3.46)$$

Figure 3.15 shows how this condition is saved for two ends selected on a terrain (using real data) with a profile of the optimal route, optimal route on digital terrain model and optimal route on contour map respectively from left to right (slope = -1.577% and mean of the residuals = -0.045 m).

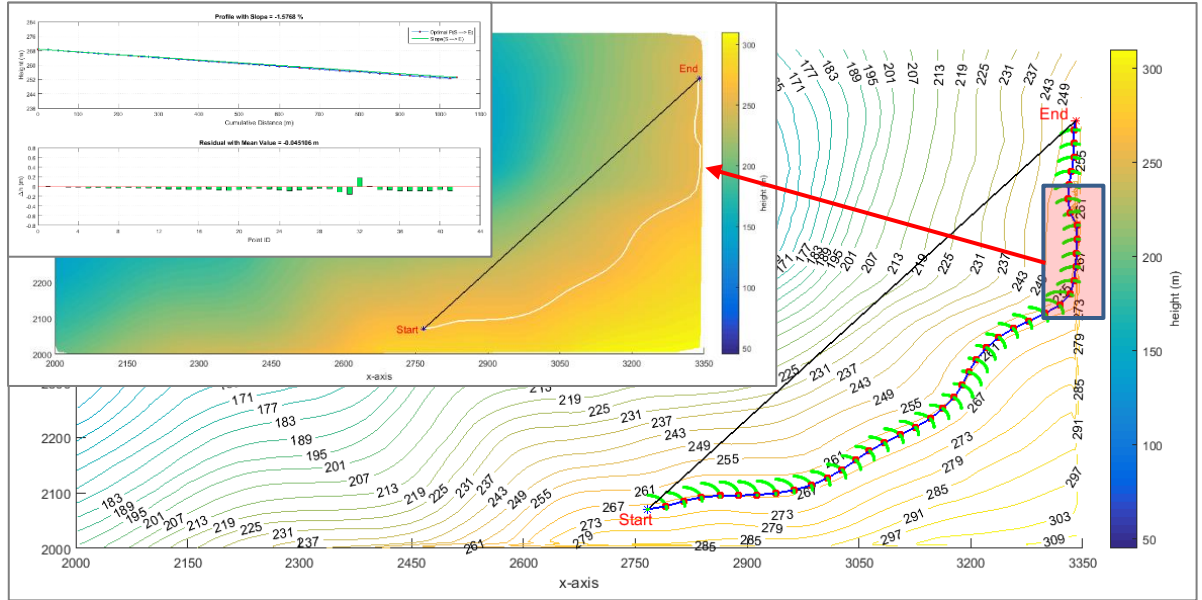


Figure 3.15 Boundary conditions for two ends

Finally, after the all conditions are executed and the optimal points between the two ends are determined and connected with line represents the optimal route between given two ends on a digital terrain model, this algorithm is designed to repeat itself till the stop criteria is achieved, and the stop criteria in our approach is the following code:

$$\left\| (x_{op(i)}, y_{op(i)}) - (x_{End}, y_{End}) \right\| \leq \text{Step interval} \quad (3.47)$$

Where:

$x_{op(i)}, y_{op(i)}$ represents the coordinates of the optimal points for x and y components respectively.

x_{End}, y_{End} represents the coordinates of the End points for x and y components respectively.

CASE STUDY

This algorithm has been applied on two different terrain models and three different cases to explain the computation processes briefly, and to illustrate the all results in figures and tables, besides the elapsed time that the algorithm taken in the computation to find the optimal route between two known ends on the generated surface for each case separately, these computations are realized by using MATLAB codes, and Laptop Dell vostro 1015 Intel Core 2 Duo CPU processors, SSD installed RAM, and Windows 10 pro operating system.

4.1 Case1: Real Terrain Model

Generated from 2605 points with three-dimensional coordinates for a surveyed area extended from 2000.355 to 3348.94 m and 2000.097 to 2899.783 m for x and y coordinates limits respectively while h value is represented by values extended from 45 to 310 m.

For this case, first, Start and End points are selected from the screen (Table 4.1 shows the coordinates for each component) and then automatically calculating is selected for slope to determine all required data and important parameters from the differences in coordinates between the selected two points in the preparation of determining the optimal route between these points (Table 4.2 shows these elements).

Table 4.1 Start and End points coordinates case (1)

Point	x (m)	y (m)	h (m)
Start	2460.37061	2021.30652	239.71207
End	3171.50195	2851.41260	216.14209

Table 4.2 Important parameter and elements to find the optimal route case (1)

No. of Observation : 2605
x-min : 2000.355 x-max : 3348.94
y-min : 2000.097 y-max : 2899.783
h-min : 45 h-max : 310
Start-P _(x, y, h) : 2460.37061 , 2021.30652 , 239.71207
End-P _(x, y, h) : 3171.50195 , 2851.41260 , 216.14209
Dist (S ==> E) : 1202.36788
Slope : -1.96030 %
Azi : 40.58585
Step interval : 25

After pressing Enter in the command window the program will start the calculations of the optimal points coordinates (which represent the points where the pipes will be connected) through the generated searched points (green points) on the terrain besides the slope values for each calculated point from the previous point, which assist in checking and tracking that the selected points have the same original slope or nearest to it as much as possible (depending on the given criteria's) through calculation process, and for this case study the 49 optimal points are selected from 8869 generated points (181points at each iteration) with space interval equal to 25 m. Table 4.3 illustrates the 3-D coordinates for these points with their slopes.

Table 4.3 Optimal points coordinates case (1)

ID	x (m)	y (m)	h (m)	Slope
1	2482.12950	2033.61711	239.23156	-1.74730%
2	2501.82977	2049.00864	238.77162	-1.67249%
3	2518.87973	2067.29249	238.31597	-1.65693%
4	2533.03988	2087.89564	237.82957	-1.76872%
5	2545.72834	2109.43637	237.31089	-1.88610%
6	2557.46513	2131.51006	236.84592	-1.69083%

Table 4.3 (cont'd)

7	2569.20192	2153.58375	236.35171	-1.79711%
8	2583.36208	2174.18691	235.87912	-1.71851%
9	2602.92728	2189.74977	235.37919	-1.81794%
10	2626.10688	2199.11494	234.87698	-1.82622%
11	2650.64756	2203.88516	234.37444	-1.82742%
12	2674.67910	2210.77610	233.90691	-1.70011%
13	2698.52202	2218.29374	233.41726	-1.78055%
14	2722.15999	2226.43294	232.93887	-1.73958%
15	2745.33958	2235.79811	232.45750	-1.75045%
16	2768.90562	2244.14328	231.94662	-1.85776%
17	2793.16301	2250.19133	231.46073	-1.76687%
18	2817.66113	2255.17553	230.93410	-1.91500%
19	2841.91852	2261.22357	230.42997	-1.83321%
20	2866.32592	2266.63456	229.90553	-1.90706%
21	2890.52961	2272.89406	229.38123	-1.90655%
22	2914.16758	2281.03327	228.90208	-1.74237%
23	2936.63743	2291.99255	228.43737	-1.68986%
24	2957.48458	2305.79097	227.93777	-1.81671%
25	2976.91322	2321.52398	227.45886	-1.74149%
26	2995.63712	2338.08948	226.94896	-1.85418%
27	3013.00358	2356.07298	226.44073	-1.84809%
28	3030.52631	2373.90424	225.95554	-1.76433%
29	3047.57627	2392.18808	225.49255	-1.68362%
30	3064.78513	2410.32244	224.99240	-1.81872%
31	3080.68709	2429.61305	224.49313	-1.81554%
32	3098.36476	2447.29072	223.98779	-1.83758%
33	3117.51587	2463.36041	223.48556	-1.82629%
34	3135.65023	2480.56928	222.98266	-1.82871%
35	3146.99999	2502.84444	222.48283	-1.81759%
36	3152.62377	2527.20369	221.97792	-1.83602%

Table 4.3 (cont'd)

37	3154.14998	2552.15706	221.48275	-1.80062%
38	3155.24046	2577.13327	220.99259	-1.78243%
39	3156.98438	2602.07237	220.50469	-1.77417%
40	3160.46370	2626.82907	220.00987	-1.79932%
41	3165.23393	2651.36975	219.53623	-1.72234%
42	3166.97784	2676.30885	219.02906	-1.84426%
43	3170.45717	2701.06555	218.55387	-1.72797%
44	3171.11159	2726.05699	218.05778	-1.80396%
45	3171.76602	2751.04842	217.55075	-1.84372%
46	3171.54785	2776.04747	217.06657	-1.76065%
47	3171.98416	2801.04366	216.56144	-1.83686%
48	3170.45795	2825.99703	216.07769	-1.75907%
49	3168.71404	2850.93613	215.58225	-1.80159%

Figure 4.1 shows the horizontal alignment drawn as a blue line connecting the optimal points with the Start and End points on a contour map (with a contour interval equal to 6m), and the generated pipeline route on the DTM represented in the Figure 4.2 with a white line connected to the Start and End points.

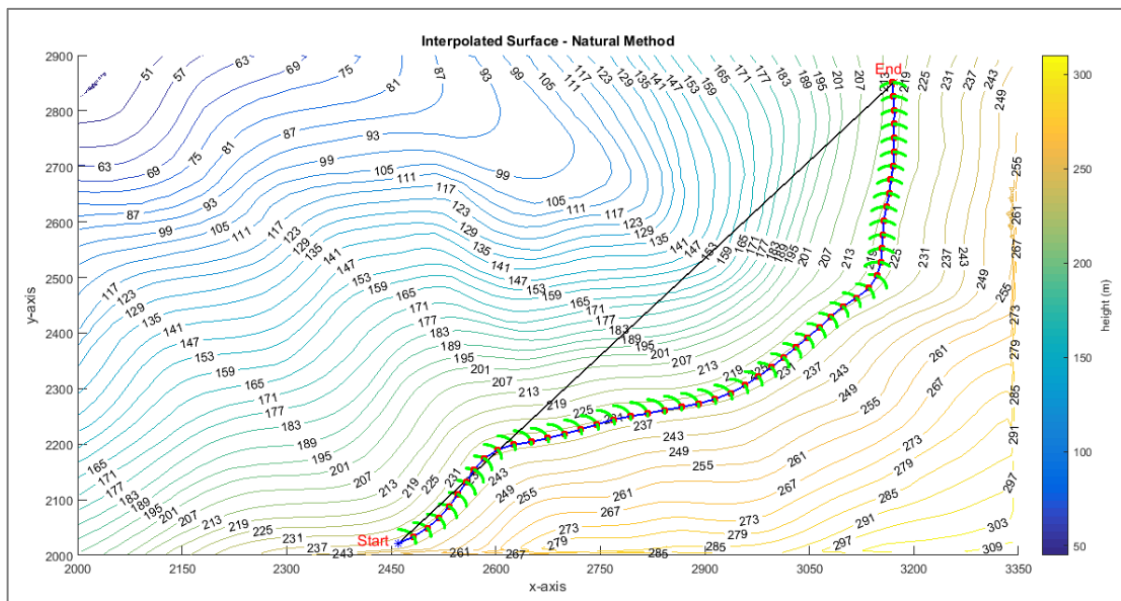


Figure 4.1 Optimal horizontal alignment on contour map case (1)

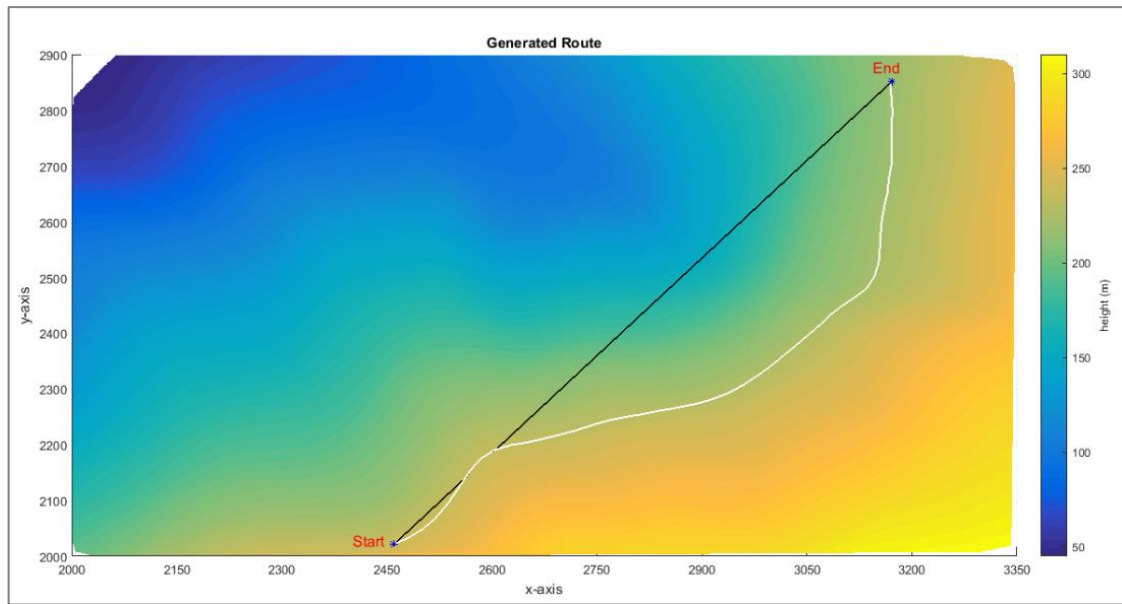


Figure 4.2 Optimal horizontal alignment on DTM case (1)

Furthermore, the differences in height between the optimal points height (Optimal. P. h) and the calculated points from the original slope (between start and end points Default. P. h) are computed as residual values (for the all 49 points) and tabulated in the Table 4.4 as Diff. h.

Table 4.4 Differences in height case (1)

ID	Default. P. h	Optimal. P. h	Diff. h
1	239.22199	239.23156	0.00957
2	238.73192	238.77162	0.03971
3	238.24184	238.31597	0.07413
4	237.75177	237.82957	0.07780
5	237.26170	237.31089	0.04920
6	236.77162	236.84592	0.07429
7	236.28155	236.35171	0.07016
8	235.79147	235.87912	0.08765
9	235.30140	235.37919	0.07779
10	234.81133	234.87698	0.06565
11	234.32125	234.37444	0.05319
12	233.83118	233.90691	0.07573

Table 4.4 (cont'd)

13	233.34110	233.41726	0.07615
14	232.85103	232.93887	0.08784
15	232.36095	232.45750	0.09655
16	231.87088	231.94662	0.07574
17	231.38081	231.46073	0.07992
18	230.89073	230.93410	0.04337
19	230.40066	230.42997	0.02931
20	229.91058	229.90553	-0.00505
21	229.42051	229.38123	-0.03928
22	228.93044	228.90208	-0.02836
23	228.44036	228.43737	-0.00300
24	227.95029	227.93777	-0.01252
25	227.46021	227.45886	-0.00135
26	226.97014	226.94896	-0.02118
27	226.48006	226.44073	-0.03933
28	225.98999	225.95554	-0.03445
29	225.49992	225.49255	-0.00737
30	225.00984	224.99240	-0.01744
31	224.51977	224.49313	-0.02664
32	224.02969	223.98779	-0.04190
33	223.53962	223.48556	-0.05406
34	223.04955	222.98266	-0.06688
35	222.55947	222.48283	-0.07664
36	222.06940	221.97792	-0.09147
37	221.57932	221.48275	-0.09657
38	221.08925	220.99259	-0.09666
39	220.59917	220.50469	-0.09449
40	220.10910	220.00987	-0.09923
41	219.61903	219.53623	-0.08280
42	219.12895	219.02906	-0.09989

Table 4.4 (cont'd)

43	218.63888	218.55387	-0.08501
44	218.14880	218.05778	-0.09103
45	217.65873	217.55075	-0.10798
46	217.16866	217.06657	-0.10208
47	216.67858	216.56144	-0.11715
48	216.18851	216.07769	-0.11082
49	215.69843	215.58225	-0.11618

Then, mean of the differences in height are calculated and shown together with the vertical alignment (Profile) in Figure 4.3, which reflects the capability of designed approach in finding the optimal routes for pipelines between the selected two ends. The Elapsed time for this case example is 6.941354 seconds.

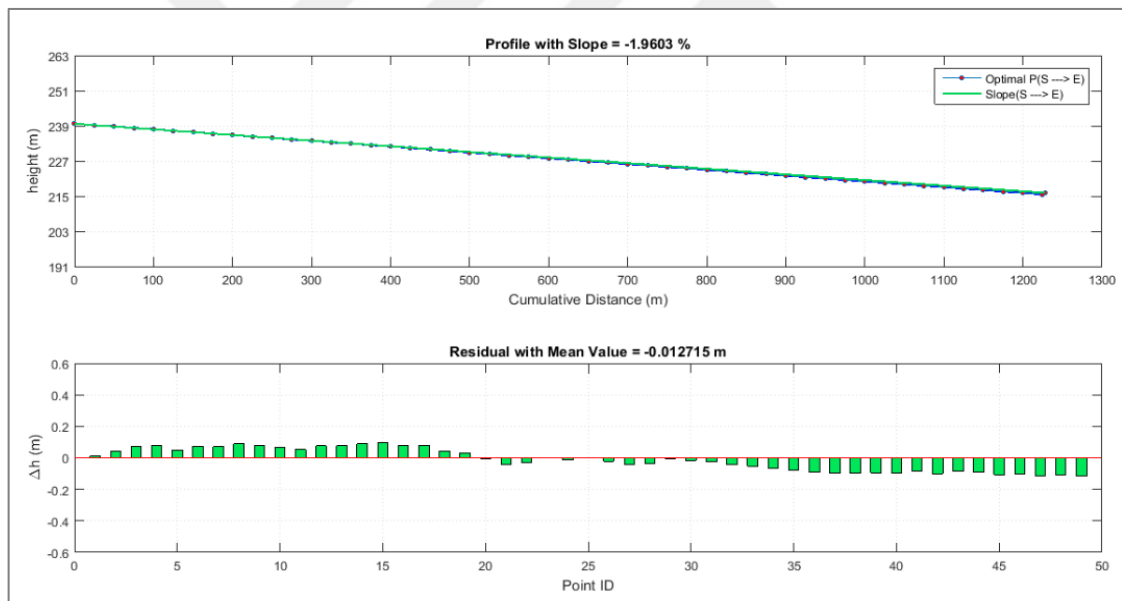


Figure 4.3 Optimal vertical alignment and residuals case (1)

4.2 Case2: Simulated Terrain Model

Generated from 4250 points with three-dimensional coordinates by using following MATLAB code for each component:

$$x = 50 + \text{abs}(1000 * \text{rand}(4250,1)); \quad (4.1)$$

$$y = 50 + \text{abs}(1000 * \text{rand}(4250,1)); \quad (4.2)$$

$$h = 1000 - (\exp(-(0.00007 * (x-100).^2 + 0.00004 * (y-100).^2))) * 22.... \quad (4.3)$$

$$+(\exp(-(0.00007 * (x-300).^2 + 0.00004 * (y-100).^2))) * 22....$$

$$+(\exp(-(0.00007 * (x-500).^2 + 0.00004 * (y-100).^2))) * 26....$$

$$\vdots \quad \vdots$$

$$\vdots \quad \vdots$$

Extended from 50.03454 to 1049.83499 m and 50.01534 to 1049.83565 m for x and y coordinates limits respectively, while the height is represented by values extended from 971.86246 to 1034.88388 m. For simulated terrain model's case, Start and End points are selected by using the second alternative option for input which is Manually option from the command window for the x, y, and h coordinates respectively (Table 4.5 shows the coordinates for each component), and then automatically calculating is selected for slope to determine all required data and important parameters in the preparation of determining the optimal route between the entered two ends (Table 4.6 shows these elements).

Table 4.5 Start and End points coordinates case (2)

Point	x (m)	y (m)	h (m)
Start	399.43823	89.35766	1023.40820
End	915.05243	902.63885	1003.75262

Table 4.6 Important parameter and elements to find the optimal route case (2)

No. of Observation : 4250
x-min : 50.03454 x-max : 1049.83499
y-min : 50.01534 y-max : 1049.83565
h-min : 971.86246 h-max : 1034.88388
Start-P _(x, y, h) : 399.43823 , 89.35766 , 1023.40820

Table 4.6 (cont'd)

End-P _(x, y, h) : 915.05243 , 902.63885 , 1003.75262
Dist _(S ==> E) : 1059.25163
Slope : -1.85561 %
Azi : 32.37439
Step interval : 25

From the command window, the program started the calculations of the optimal points coordinates on the terrain through the generated searched points (green points) and the slopes for each determined point from the previous point (depending on the given criteria's) after pressing Enter. For this case study, 7602 searched points are created (181 point at each iteration) and 42 points are selected among them to represent the optimal points with space interval equal to 25 m. Table 4.7 shows the 3-D coordinates for these points with slopes.

Table 4.7 Optimal points coordinates case (2)

ID	x (m)	y (m)	h (m)	Slope
1	399.43823	114.35766	1023.00166	-1.47833%
2	404.63602	138.81135	1022.52255	-1.74223%
3	412.98120	162.37739	1022.04712	-1.72884%
4	421.12040	186.01535	1021.59320	-1.65062%
5	428.63805	209.85827	1021.15112	-1.60757%
6	434.26182	234.21753	1020.65835	-1.79186%
7	439.03205	258.75821	1020.16615	-1.78982%
8	442.51137	283.51491	1019.71608	-1.63661%
9	445.34145	308.35420	1019.28625	-1.56302%
10	447.30293	333.27714	1018.79222	-1.79650%
11	448.39342	358.25334	1018.35356	-1.59510%
12	449.26590	383.23811	1017.87409	-1.74356%
13	452.52906	408.02423	1017.40247	-1.71498%
14	454.92520	432.90914	1016.95695	-1.62006%
15	457.75528	457.74844	1016.46796	-1.77815%

Table 4.7 (cont'd)

16	465.48071	481.52485	1015.97881	-1.77871%
17	477.60095	503.39034	1015.50633	-1.71810%
18	494.65091	521.67418	1015.05863	-1.62800%
19	515.96691	534.73665	1014.59583	-1.68292%
20	538.53154	545.49943	1014.12274	-1.72033%
21	559.96073	558.37538	1013.63994	-1.75563%
22	578.09509	575.58424	1013.15503	-1.76332%
23	592.07491	596.31018	1012.70165	-1.64864%
24	602.64036	618.96788	1012.26583	-1.58479%
25	610.36579	642.74429	1011.82317	-1.60969%
26	616.62529	666.94798	1011.32975	-1.79427%
27	622.46142	691.25723	1010.87181	-1.66522%
28	629.35236	715.28877	1010.41041	-1.67781%
29	638.91944	738.38576	1009.94040	-1.70915%
30	654.13848	758.21959	1009.47285	-1.70018%
31	675.33968	771.46757	1009.01281	-1.67286%
32	699.11609	779.19300	1008.55510	-1.66439%
33	723.31978	785.45250	1008.07289	-1.75350%
34	747.22740	792.76179	1007.61481	-1.66574%
35	770.15391	802.73052	1007.15776	-1.66200%
36	790.63271	817.06993	1006.70578	-1.64359%
37	808.76707	834.27879	1006.22956	-1.73168%
38	825.65682	852.71073	1005.76658	-1.68359%
39	843.17955	870.54199	1005.28455	-1.75281%
40	861.75817	887.27025	1004.83498	-1.63482%
41	884.13153	898.42520	1004.37390	-1.67665%
42	908.71291	902.98109	1003.91819	-1.65711%

Figures 4.4 and 4.5 shows the horizontal alignment as a blue line connecting the selected optimal points with the Start and End points on the contour map (with contour interval equal to 6m), and the generated pipeline route on the DTM with a white line connecting Start and End points respectively.

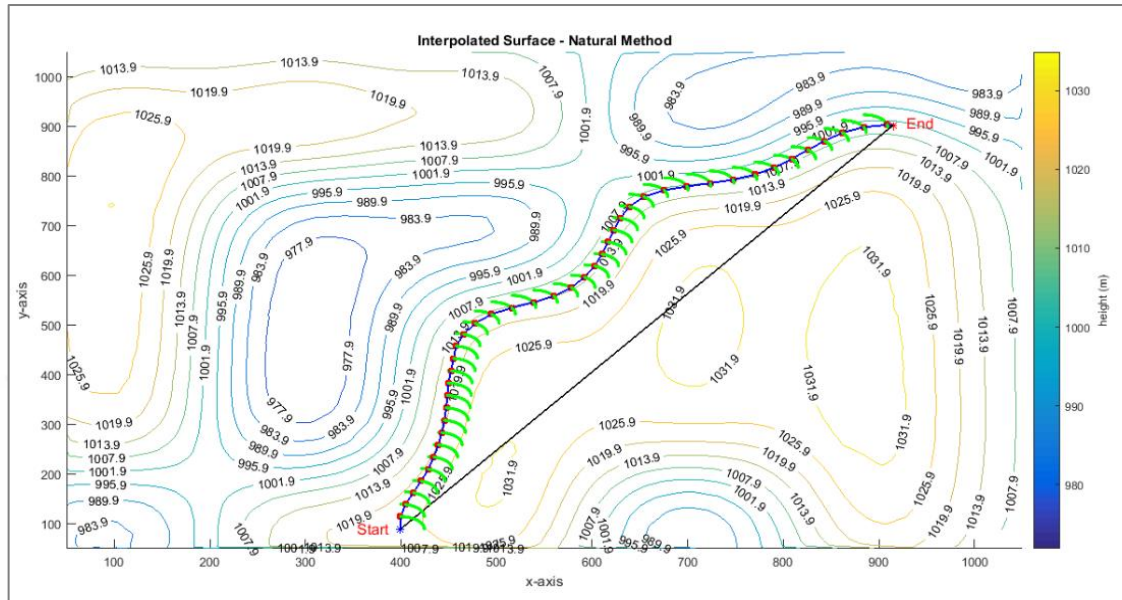


Figure 4.4 Optimal horizontal alignment on contour map case (2)

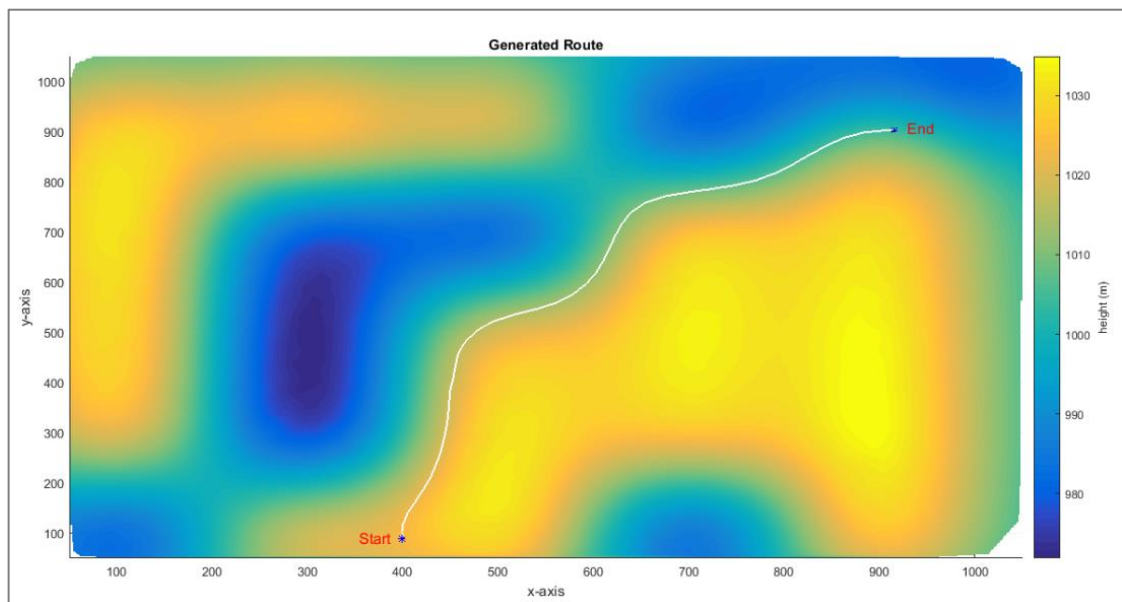


Figure 4.5 Optimal horizontal alignment on DTM case (2)

Furthermore, Table 4.8 shows the residuals values (Diff. h) of the differences in height between the optimal points (Optimal. P. h) and the calculated points from the original slope (Default. P. h).

Table 4.8 Differences in height case (2)

ID	Default. P. h	Optimal. P. h	Diff. h
1	1022.94430	1023.00166	0.05736
2	1022.48040	1022.52255	0.04215
3	1022.01650	1022.04712	0.03062
4	1021.55259	1021.59320	0.04061
5	1021.08869	1021.15112	0.06243
6	1020.62479	1020.65835	0.03357
7	1020.16089	1020.16615	0.00527
8	1019.69698	1019.71608	0.01910
9	1019.23308	1019.28625	0.05317
10	1018.76918	1018.79222	0.02304
11	1018.30528	1018.35356	0.04829
12	1017.84137	1017.87409	0.03271
13	1017.37747	1017.40247	0.02500
14	1016.91357	1016.95695	0.04338
15	1016.44967	1016.46796	0.01829
16	1015.98576	1015.97881	-0.00695
17	1015.52186	1015.50633	-0.01553
18	1015.05796	1015.05863	0.00068
19	1014.59406	1014.59583	0.00177
20	1014.13015	1014.12274	-0.00741
21	1013.66625	1013.63994	-0.02631
22	1013.20235	1013.15503	-0.04732
23	1012.73845	1012.70165	-0.03679
24	1012.27454	1012.26583	-0.00871
25	1011.81064	1011.82317	0.01253
26	1011.34674	1011.32975	-0.01699
27	1010.88284	1010.87181	-0.01103
28	1010.41893	1010.41041	-0.00852
29	1009.95503	1009.94040	-0.01463

Table 4.8 (cont'd)

30	1009.49113	1009.47285	-0.01828
31	1009.02723	1009.01281	-0.01442
32	1008.56332	1008.55510	-0.00822
33	1008.09942	1008.07289	-0.02653
34	1007.63552	1007.61481	-0.02071
35	1007.17162	1007.15776	-0.01385
36	1006.70771	1006.70578	-0.00194
37	1006.24381	1006.22956	-0.01425
38	1005.77991	1005.76658	-0.01333
39	1005.31601	1005.28455	-0.03145
40	1004.85210	1004.83498	-0.01712
41	1004.38820	1004.37390	-0.01430
42	1003.92430	1003.91819	-0.00611

Then, mean of the differences in height are calculated and shown together with vertical alignment (Profile) in Figure 4.6 as residuals. The Elapsed time for this case example is 5.408161 seconds.

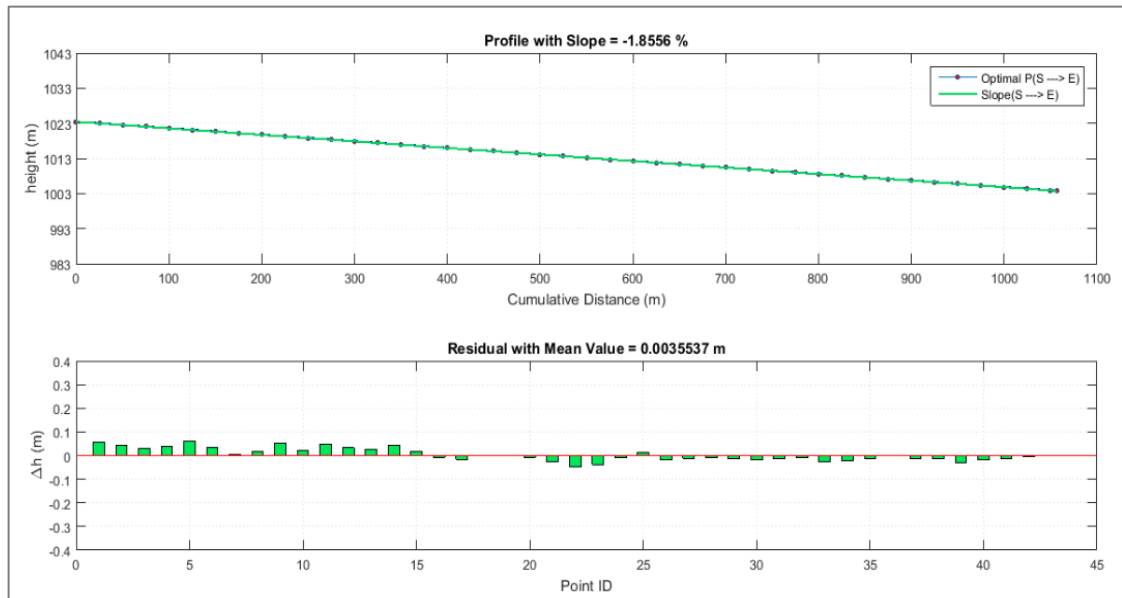


Figure 4.6 Optimal vertical alignment and residuals case (2)

4.3 Case3: Problematic Area

When more than one slope or additional one or more assist points are required to circumvent some restricted or forbidden lands with respect to the terrain topography and conservation the conditions of the free flow, a problematic area are selected on the simulated terrain to clarify this situation through the proposed approach.

After the problematic area is defined on the terrain for free flow case and Start, Intermediate and End points are selected as a preliminary solution for the required area, the three selected points exported and saved in an Excel worksheet to read them directly through the algorithm (Table 4.9 shows the coordinates for each component). After the algorithm is started, an automatically calculating options is selected for the first and second slopes determinations to calculate the all required data to select the optimal route between the two end points with the assistance of the intermediate point (Table 4.10 display these elements).

Table 4.9 Start, Intermediate, and End points coordinates case (3)

Point	x (m)	y (m)	h (m)
Start	496.42454	166.40535	1032.69805
Intermediate	448.42454	504.80535	1009.16187
End	934.42454	886.40535	1005.73751

Table 4.10 Important parameter and elements to find the optimal route case (3)

No. of Observation : 4250
x-min : 50.03454 x-max : 1049.83499
y-min : 50.01534 y-max : 1049.83565
h-min : 971.86246 h-max : 1034.88388
Start-P _(x, y, h) = 496.42454 , 166.40535 , 1032.69805
Intermediate-P _(x, y, h) = 448.42454 , 504.80535 , 1009.16187
End-P _(x, y, h) = 934.42454 , 886.40535 , 1005.73751
T-Dist _(Start ==> I.P) = 375.96603
T-Dist _(I.P ==> End) = 679.70260
Slope1= -6.26019 %

Table 4.10 (cont'd)

Slope2 = -0.50380 %
Azi (Start ==> I.P) = 351.92680
Azi (I.P ==> End) = 51.86152
Step interval = 25

Then, the program starts the calculations of the optimal points coordinates with the slopes for each determined point (between start, intermediate and end points) from the previous point through the calculation process. Thus, totally 7240 searched points are generated (181 point at each iteration) and among them 40 points are selected as optimal points based on the given criteria (16 points for first alignment and 26 points for the second alignment both with space interval 25m). The 3-D coordinates for these points with slopes on the first and second alignment tabulated in the Table 4.11, 4.12 respectively.

Table 4.11 Optimal points coordinates on 1st alignment case (3)

ID	x (m)	y (m)	h (m)	Slope1
1	471.63842	169.66850	1031.13181	-5.69541%
2	463.49922	193.30646	1029.57696	-5.65401%
3	461.53774	218.22940	1027.99212	-5.76305%
4	459.79383	243.16850	1026.44382	-5.63020%
5	458.04992	268.10760	1024.86775	-5.73118%
6	456.52370	293.06097	1023.31392	-5.65028%
7	454.77979	318.00007	1021.74058	-5.72123%
8	452.60090	342.90494	1020.15242	-5.77513%
9	449.98769	367.76799	1018.60369	-5.63176%
10	448.02621	392.69092	1017.04434	-5.67035%
11	447.58990	417.68711	1015.44848	-5.80313%
12	445.41101	442.59198	1013.85519	-5.79376%
13	445.41101	467.59198	1012.26263	-5.79113%
14	448.24109	492.43128	1010.68254	-5.74580%

Table 4.12 Optimal points coordinates 2nd alignment case (3)

ID	x (m)	y (m)	h (m)	Slope2
1	462.04052	525.77211	1009.05470	-0.38970%
2	479.87178	543.29484	1008.90656	-0.53871%
3	501.84221	555.22381	1008.79269	-0.41405%
4	524.59124	565.59114	1008.64096	-0.55177%
5	546.86640	576.94090	1008.48854	-0.55424%
6	566.56667	592.33244	1008.33618	-0.55404%
7	582.12954	611.89764	1008.18385	-0.55393%
8	593.28448	634.27100	1008.07913	-0.38080%
9	602.24368	657.61051	1007.96211	-0.42553%
10	609.13462	681.64206	1007.80931	-0.55565%
11	615.39412	705.84575	1007.68738	-0.44337%
12	623.11954	729.62216	1007.58712	-0.36459%
13	634.07882	752.09201	1007.47940	-0.39169%
14	652.51075	768.98177	1007.35243	-0.46174%
15	675.16845	779.54722	1007.23306	-0.43406%
16	699.52770	785.17100	1007.10867	-0.45232%
17	724.10907	789.72689	1007.00168	-0.38905%
18	748.31276	795.98639	1006.87798	-0.44982%
19	771.57320	805.14892	1006.77064	-0.39032%
20	792.53997	818.76489	1006.65171	-0.43251%
21	811.40771	835.16637	1006.53693	-0.41738%
22	829.23897	852.68910	1006.42570	-0.40447%
23	847.96286	869.25460	1006.32471	-0.36721%
24	868.44166	883.59401	1006.21894	-0.38463%
25	891.78117	892.55321	1006.08786	-0.47666%
26	916.77736	892.11690	1005.96530	-0.44567%

Then, the horizontal alignment on the contour map (with contour interval equal to 6m) as a blue line connecting the optimal points (for the first and second alignments) with the two ends, and the generated pipeline route on the DTM as a white line after the all points are connected are presented in Figures 4.7, 4.8 respectively.

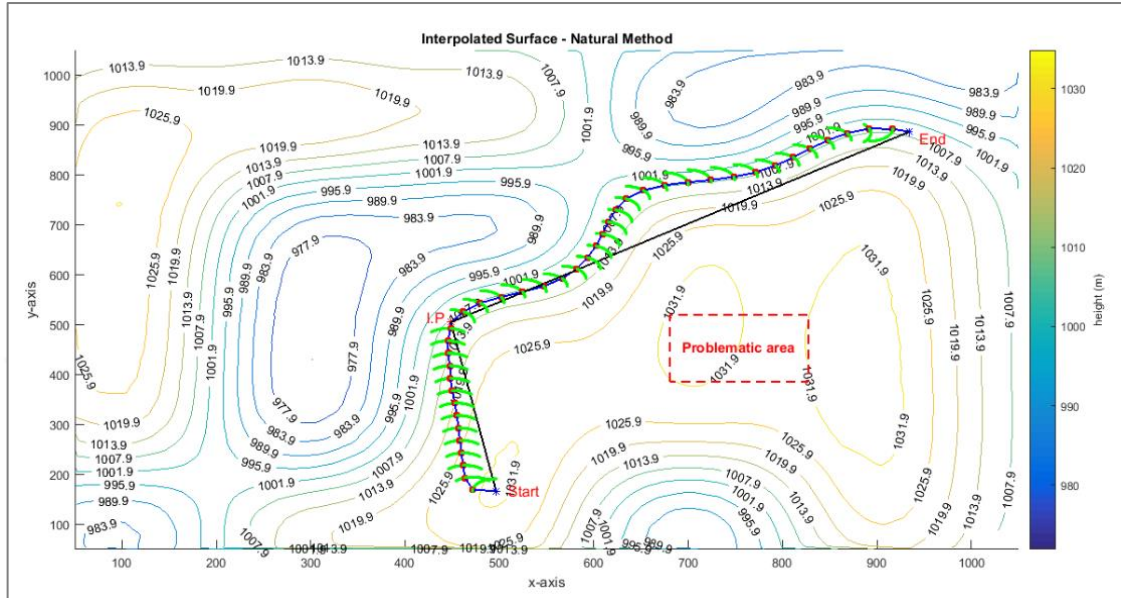


Figure 4.7 Optimal horizontal alignment on contour map case (3)

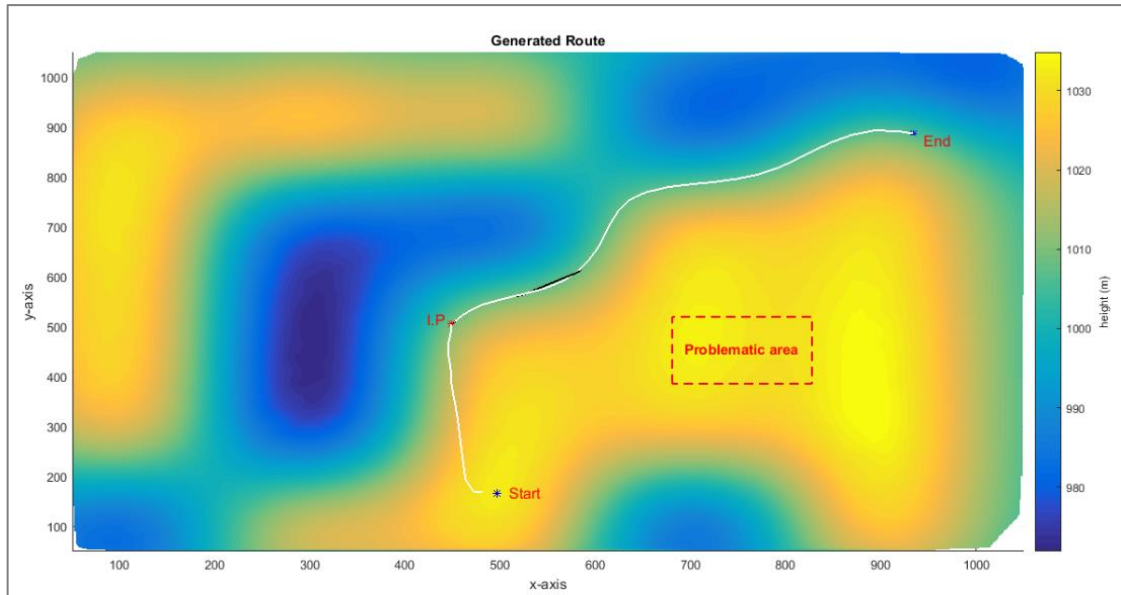


Figure 4.8 Optimal horizontal alignment on DTM case (3)

Table 4.13, 4.14 illustrates the residuals values of the differences in height between optimal points (Optimal. P. h) and the calculated points from the original slope (Default. P. h) for the both alignments respectively.

Table 4.13 Differences in height 1st alignment case (3)

ID	Default. P. h	Optimal. P. h	Diff. h
1	1031.13301	1031.13181	-0.00119
2	1029.56796	1029.57696	0.00900
3	1028.00291	1027.99212	-0.01079
4	1026.43786	1026.44382	0.00596
5	1024.87282	1024.86774	-0.00507
6	1023.30777	1023.31392	0.00615
7	1021.74272	1021.74058	-0.00214
8	1020.17767	1020.15242	-0.02525
9	1018.61263	1018.60369	-0.00894
10	1017.04758	1017.04434	-0.00324
11	1015.48253	1015.44848	-0.03405
12	1013.91748	1013.85519	-0.06229
13	1012.35244	1012.26263	-0.08980
14	1010.78739	1010.68254	-0.10485

Table 4.14 Differences in height 2nd alignment case (3)

ID	Default. P. h	Optimal. P. h	Diff. h
1	1009.03592	1009.05470	0.01878
2	1008.90997	1008.90656	-0.00341
3	1008.78402	1008.79269	0.00868
4	1008.65806	1008.64096	-0.01711
5	1008.53211	1008.48854	-0.04357
6	1008.40616	1008.33618	-0.06998
7	1008.28021	1008.18385	-0.09636

Table 4.14 (cont'd)

8	1008.15426	1008.07913	-0.07513
9	1008.02831	1007.96211	-0.06620
10	1007.90236	1007.80931	-0.09305
11	1007.77641	1007.68738	-0.08903
12	1007.65046	1007.58712	-0.06334
13	1007.52451	1007.47940	-0.04511
14	1007.39856	1007.35243	-0.04613
15	1007.27261	1007.23306	-0.03955
16	1007.14666	1007.10867	-0.03799
17	1007.02071	1007.00168	-0.01902
18	1006.89476	1006.87798	-0.01677
19	1006.76881	1006.77064	0.00184
20	1006.64286	1006.65170	0.00885
21	1006.51690	1006.53693	0.02002
22	1006.39095	1006.42570	0.03474
23	1006.26500	1006.32471	0.05971
24	1006.13905	1006.21894	0.07989
25	1006.01310	1006.08786	0.07476
26	1005.88715	1005.96530	0.07815

While the mean of these values with the vertical alignment (Profile) shown together in the Figures 4.9 and 4.10 for the first and second alignments respectively. The Elapsed time for this case is 10.180504 seconds.

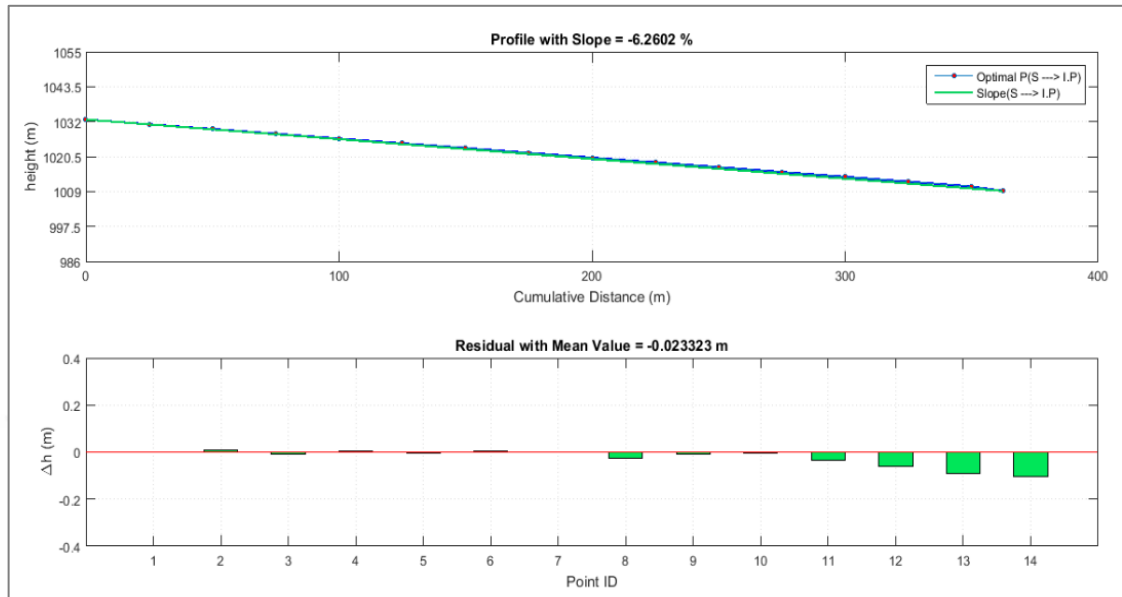


Figure 4.9 Optimal vertical alignment and residuals case (3) 1st alignment

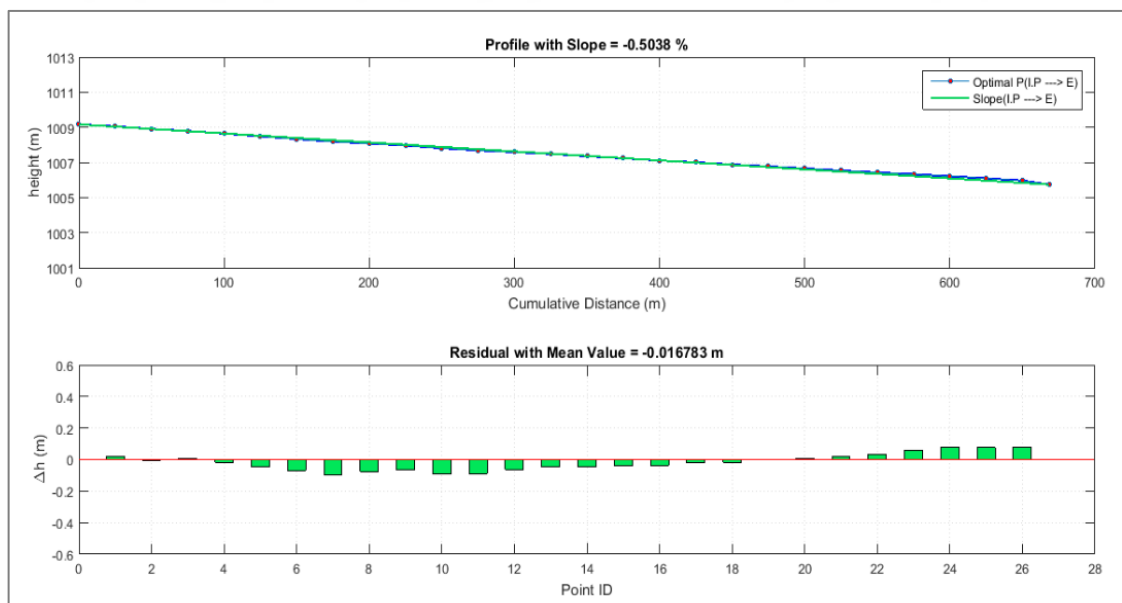


Figure 4.10 Optimal vertical alignment and residuals case (3) 2nd alignment

RESULTS AND DISCUSSION

Water supply facilities are crucial for human lives as a common life source. With regard to this, water transmission studies should be done carefully to ensure the transportation of the water from the source to the treatment plant and to the area of distribution. As classified before at this study, the facility may be realized in three ways, as free-flow (gravity flow), pressurized pipelines (pumping systems) and a combination of them depending on the conditions of the topography, where the pipeline passes through and in terms of the subsequent complex hydraulic processes. Among them, free-flow conduits (canals, aqueducts, and tunnels) are preferred in hilly areas or in areas where the required slope of the conduit more or less coincides with the slope of the terrain. In the free-flow system, the water reservoir placed in the higher elevation of a hill is taken and transmitted to the required place such as residential areas. According to this, this study investigates geometric design of free-flow pipelines with regard to zero-line approach. The method applied in this thesis has a simple search algorithm and represents iterative approach for optimum solution. Regarding the longitudinal slopes appropriate for the topography where the pipeline route passes, the algorithm provides acceptable solutions when compared with the computed slopes. The methodology depends on vertical alignment of the pipeline design which enables to transmission of the water. One point that also important for the geometric design is the conjunction angle of the pipes. In this study, this is taken into consideration by limitation of the search angles. Consequently, the resulting pipeline route is non-backtracking, smooth, close to the zero-line and the assigned slope, and the shortest path between two ends depending on given criteria's. Moreover, the algorithm uses topographical features of the terrain data, in addition to these data and in the purpose of developing the algorithm, more options, different constraints and conditions can be added to it for determining the intermediate points besides these three

criteria's especially for the problematic area and restricted regions (i.e. geotechnical properties, property status, etc.).



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APPENDIX-A

PIPELINES LENGTH AND AVAILABILITIES IN COUNTRIES

In Table A.1 (summarized from [53]), the total length, rank and percentages of the pipelines in the 124 countries around the world constructed for different purposes are listed, started with the United States at the first rank with 2,225,032.00 km total length of pipelines and ended with Liberia at the end of this list with 4.00 km.

Table A.1 Classification of the countries depending on the pipelines availability

Rank	Country	Pipeline (km)	Percentages %
1	United States	2,225,032.00	50.2778%
2	China	828,606.00	18.7235%
3	Russia	251,800.00	5.6898%
4	Canada	110,000.00	2.4856%
5	Hungary	91,542.00	2.0685%
6	Ukraine	45,597.00	1.0303%
7	Argentina	39,850.00	0.9005%
8	United Kingdom	39,778.00	0.8988%
9	Iran	38,906.00	0.8791%
10	Mexico	37,008.00	0.8362%
11	Slovakia	36,081.00	0.8153%
12	India	35,676.00	0.8062%
13	Australia	34,722.00	0.7846%
14	Germany	34,335.00	0.7758%
15	Kazakhstan	30,297.00	0.6846%
16	Algeria	29,642.00	0.6698%

Table A.1 (cont'd)

17	Brazil	27,468.00	0.6207%
18	France	23,345.00	0.5275%
19	Italy	23,190.00	0.5240%
20	Indonesia	21,704.00	0.4904%
21	Netherlands	19,500.00	0.4406%
22	Poland	16,349.00	0.3694%
23	Pakistan	16,309.00	0.3685%
24	Venezuela	16,288.00	0.3681%
25	Egypt	15,725.00	0.3553%
26	Turkey	15,641.00	0.3534%
27	Colombia	15,216.00	0.3438%
28	Uzbekistan	14,644.00	0.3309%
29	Spain	14,558.00	0.3290%
30	Nigeria	12,714.00	0.2873%
31	Libya	11,630.00	0.2628%
32	Saudi Arabia	10,600.00	0.2395%
33	Iraq	10,437.00	0.2358%
34	Norway	9,824.00	0.2220%
35	Bolivia	9,646.00	0.2180%
36	Malaysia	9,068.00	0.2049%
37	Turkmenistan	9,001.00	0.2034%
38	Belarus	8,705.00	0.1967%
39	Oman	8,185.00	0.1850%
40	Czechia	7,790.00	0.1760%
41	United Arab Emirates	7,738.00	0.1749%
42	Thailand	7,085.00	0.1601%
43	Azerbaijan	6,425.00	0.1452%
44	Romania	6,177.00	0.1396%
45	Sudan	5,839.00	0.1319%
46	Chile	5,648.00	0.1276%

Table A.1 (cont'd)

47	Syria	5,199.00	0.1175%
48	Burma	5,060.00	0.1143%
49	Tunisia	5,013.00	0.1133%
50	Japan	4,734.00	0.1070%
51	Korea, South	4,695.00	0.1061%
52	Singapore	4,350.00	0.0983%
53	Ecuador	4,265.00	0.0964%
54	Peru	4,039.00	0.0913%
55	South Africa	3,839.00	0.0867%
56	Armenia	3,838.00	0.0867%
57	Qatar	3,830.00	0.0865%
58	Belgium	3,828.00	0.0865%
59	Kyrgyzstan	3,582.00	0.0809%
60	Bulgaria	3,489.00	0.0788%
61	New Zealand	3,489.00	0.0788%
62	Finland	3,264.00	0.0738%
63	Croatia	3,020.00	0.0682%
64	Bangladesh	2,950.00	0.0667%
65	Georgia	2,771.00	0.0626%
66	Austria	2,639.00	0.0596%
67	Gabon	2,449.00	0.0553%
68	Trinidad and Tobago	2,422.00	0.0547%
69	Estonia	2,360.00	0.0533%
70	Ireland	2,147.00	0.0485%
71	Lithuania	2,042.00	0.0461%
72	Yemen	2,033.00	0.0459%
73	Moldova	1,916.00	0.0433%
74	Switzerland	1,901.00	0.0430%
75	Denmark	1,866.00	0.0422%
76	Vietnam	1,805.00	0.0408%

Table A.1 (cont'd)

77	Sweden	1,626.00	0.0367%
78	Portugal	1,543.00	0.0349%
79	Angola	1,507.00	0.0341%
80	Israel	1,466.00	0.0331%
81	Greece	1,423.00	0.0322%
82	Morocco	1,389.00	0.0314%
83	Latvia	1,343.00	0.0303%
84	Mozambique	1,250.00	0.0282%
85	Brunei	1,239.00	0.0280%
86	Republic of the Congo	1,218.00	0.0275%
87	Tanzania	1,210.00	0.0273%
88	Cameroon	1,200.00	0.0271%
89	Taiwan	1,068.00	0.0241%
90	Kenya	932.00	0.0211%
91	The Democratic Republic of Congo	895.00	0.0202%
92	Kuwait	858.00	0.0194%
93	Philippines	853.00	0.0193%
94	Slovenia	849.00	0.0192%
95	Ghana	775.00	0.0175%
96	Zambia	771.00	0.0174%
97	Albania	747.00	0.0169%
98	Costa Rica	662.00	0.0150%
99	Tajikistan	587.00	0.0133%
100	Chad	582.00	0.0132%
101	Laos	540.00	0.0122%
102	Jordan	522.00	0.0118%
103	Cote d'Ivoire	487.00	0.0110%
104	Guatemala	480.00	0.0108%
105	Afghanistan	466.00	0.0105%

Table A.1 (cont'd)

106	Uruguay	417.00	0.0094%
107	Macedonia	382.00	0.0086%
108	Cuba	271.00	0.0061%
109	Zimbabwe	270.00	0.0061%
110	Papua New Guinea	264.00	0.0060%
111	Equatorial Guinea	197.00	0.0045%
112	Luxembourg	169.00	0.0038%
113	Bosnia and Herzegovina	156.00	0.0035%
114	Dominican Republic	130.00	0.0029%
115	Panama	128.00	0.0029%
116	Barbados	103.00	0.0023%
117	Lebanon	88.00	0.0020%
118	Bahrain	74.00	0.0017%
119	Nicaragua	54.00	0.0012%
120	Senegal	51.00	0.0012%
121	Suriname	50.00	0.0011%
122	Liechtenstein	20.00	0.0005%
123	Korea, North	6.00	0.0001%
124	Liberia	4.00	0.0001%
	Total length (km)	4,425,478.00	100%

CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname : Mohammed Sahran K. KHORSHEED
Date of birth and place : 19.08.1991 Iraq – Kirkuk
Foreign Languages : Arabic – Turkish – English
E-mail : mafa850@gmail.com

EDUCATION

Degree	Department	University	Date of Graduation
Undergraduate	Surveying Engineering	Kirkuk Technical College	2013
High School	Secondary School	Türkmen Evi	2009

WORK EXPERIENCE

Year	Corporation/Institute	Enrollment
2015 – 09 2014 – 09	Jurmat Group	Surveying Engineer
2014 – 06 2013 – 09	Kirkuk Technical College, Surveying Engineering Department.	Lecturer

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