Automating Offshore Pipeline Routing

Final Report

Tiana Gallo
Alex Moss
Mira Rayson

May 23, 2024

GDAA 3000 Major Analytics Project

COGS
Centre of Geographic Sciences
nscc

ABSTRACT

The offshore energy sector relies heavily on efficient and cost-effective underwater pipeline routing to ensure the safe transportation of resources. Since the first offshore pipeline was built in 1954, manual routing has been the dependable industry method for routing underwater pipelines. This project's significance lies in its potential to delve into the world of automated pipeline routing using GIS-based tools, which offers a more efficient and informed decision-making tool for industry professionals. The GIS-based automation not only accelerates the route selection process but also introduces a new level of sophistication by balancing engineering requirements with cost-sensitive geohazard considerations. This project is poised to contribute to the advancement of geospatial data analytics in the energy sector, providing a practical solution for optimizing underwater pipeline routing and addressing the complex interplay between engineering constraints and economic factors. The outcomes are anticipated to provide the industry with a valuable tool for strategic decision-making, fostering sustainable and resilient offshore energy infrastructure.

1 BACKGROUND

In the past few decades, offshore pipelines have been constructed globally - with development expected to persist into the future as worldwide oil demand continues to boast a persistent growth rate in the modern day (International Energy Agency (IEA), 2024). In 2018, over 80% of crude production and about two-thirds of the natural gas supply in the US Gulf of Mexico Outer Continental Shelf (OCS) was produced in water depths greater than 400 feet (Kaiser, M., Narra, S., 2019). Given the considerable expenses associated with these projects, and the stringent environmental standards they must adhere to, the significance of designing cost-effective pipelines cannot be overstated. An optimal route selection can be extremely beneficial as it minimizes not only the cost of construction and maintenance of a pipeline but its failure probability as well (Makrakis et al., 2020).

Geographic Information System (GIS) technologies can significantly impact subsea pipeline mapping by providing advanced tools and capabilities for managing, analyzing, and visualizing spatial data. Spatial information has played an important role in the pipeline route selection process where an effective route will directly impact the pipeline life cycle from design and planning to construction and operation (Gamarra, 2015). It is also crucial to take factors such as cost, scheduling, and social and environmental aspects into consideration when planning a pipeline route. As GIS technologies advance, they will be able to aid in the planning of pipeline route options by integrating geologic, existing infrastructure and bathymetric data.

2 INTRODUCTION

A least-cost path is a planned route that travels from a destination to a source and is guaranteed to be the cheapest route relative to cost units that are defined by a user in a weighted-distance tool. Least cost path analysis is a versatile tool that can be adapted to various fields and provides insights and solutions for spatial planning and decision-making. This application can be used for subsea pipeline routing to minimize construction and operational costs while also considering impact and regulatory compliance. Offshore pipelines are used to transport oil and gas between countries, to deliver offshore production to market, and to develop fields. Pipeline routing on the Gulf of Mexico shelf is simple as the seafloor is flat and featureless, but in deepwater, seafloor topography is complex, water gradients increase and geohazards arise (Kaiser, M., Narra, S., 2019).

Geosyntec Consultants proposed a project idea to automate their subsea pipeline routing system and develop a sophisticated GIS-based tool. This tool aims to speed up the labor-intensive process of delineating subsea pipeline routes by automating it through a Python Toolbox. The script incorporates a hierarchical analysis of geohazards and least-cost pathways, paving the way for future adaptability and scalability.

3 OBJECTIVES & ADJUSTMENTS

The primary aim of this project is to develop a GIS-based tool to automate the labor-intensive process of subsea pipeline routing. Initially, the project proposal outlined the integration of this tool as an add-on module or extension for Global Mapper. However, after careful deliberation, our team decided to pivot towards developing a Python script within ArcGIS Pro. This adjustment allows us to work in a more familiar environment which works well with our limited time frame for project completion.

Originally, the secondary objective involved implementing geocosting to assess the engineering parameters and geohazards within the protraction area. However, as the project progressed, the team realized that geocosting was not required when looking at the project's scope. The engineering parameters and geohazards only required varied offset distances for compliance, but it is required to avoid them 100 percent of the time, therefore, our team phased out the idea of geocosting. While that particular idea was removed from the project, the team still incorporated a custom toolbox that allows users to input weights for certain criteria and slope classification based on their specific project goals.

4 METHODS

4.1 STUDY AREA

The study area for this project is in the Gulf of Mexico (GoM), covering approximately 657,202.9 km^2 of seafloor. The federal waters of the GoM are administered by the US Department of the Interior's Bureau of Ocean Energy Management (BOEM) and Bureau of Safety and Environmental Enforcement (BSEE) - and are described in terms of three administrative areas, referred to as the Western, Central and Eastern planning areas (Kaiser, M., Narra, S., 2019). This region's oil and gas industry is one of the most developed in the world, having over 26,000 miles of pipeline on the seafloor (National Oceanic and Atmospheric Administration, 2011).

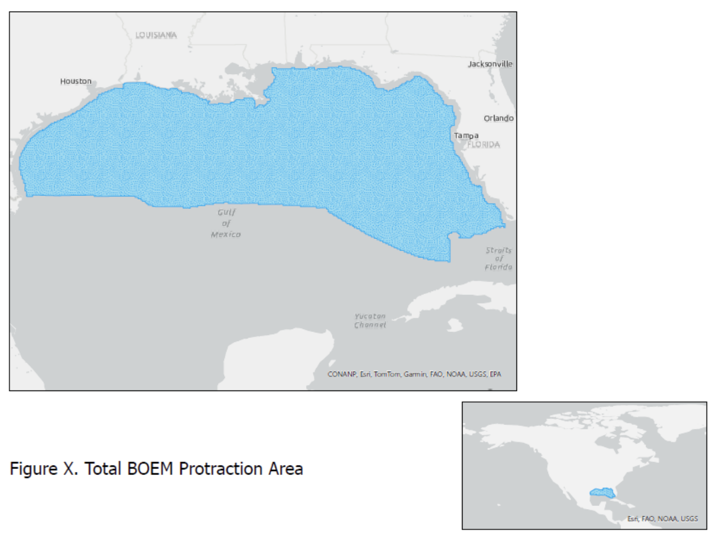


Figure X. Total BOEM Protraction Area

4.2 METHODOLOGY

The GIS tool and Python script alike allow inputs for routing criteria in the form of engineering requirements and constraints. Said engineering factors include start and end coordinates, bathymetric grids, slope gradients, existing subsea infrastructure, and BOEM-identified seabed anomalies. The route selection must be automated to avoid factors such as infrastructure, anomalies, and steep gradients.

4.2.1 ArcGIS Model Builder

Our first step in our methodology was to build a model using Model Builder within ArcGIS to create a least-cost path with the input data that was provided by Geosyntec. A slope raster was derived from the bathymetry data, which was further reclassified to reflect the necessary parameters to avoid slopes greater than 30°. Lower cost values were allocated to shallow slopes, and the cost values increased as slope increased. For example, a slope between 0° and 6° would have a cost of 1 whereas a slope between 6° and 12° would have a cost of 2. Slopes exceeding 30° incurred a significantly elevated cost of 100, due to the impossibility of constructing a pipeline on such steep terrain.

The second phase involved incorporating features that require avoidance at all costs, including existing BOEM platforms, wells, pipelines, and various oceanic anomalies such as mud volcanoes and coral reefs. Geosyntec supplied corresponding avoidance distances for each feature, which were integrated using buffer operations tailored to their specific parameters. Anomalies and wells are to have a buffer of 500 feet, platforms have a corresponding buffer of 500 meters, and lastly, existing pipelines require a buffer of 200 feet. Following the buffer application, a union operation was used to merge all avoidance features and subsequently convert them into a raster representation through the feature-to-raster tool. This raster was then reclassified to uniformly assign a cost value of 100 across all avoidable features.

Further refinement of the final cost raster involved using the raster calculator for two pivotal tasks. First, within the feature raster all values outside the avoidable features were set to zero, effectively delineating two layers within the raster: one representing the entire area with a cost of zero, and the other overlaying avoidable features with a cost of 100. Finally, the raster calculator combined the feature and slope rasters, creating the final cost raster for further utilization in the least cost path analyses.

During the development of the model, a restricted subset of the bathymetry dataset was utilized to have the tools run in a timelier fashion. Within this designated test area, two points were arbitrarily selected to serve as source and destination points. Using the final cost raster, and the source point as inputs for the cost distance tool, both a cost distance and backlink raster were created. These two new outputs combined with the destination point were then used as inputs for the cost path tool. The output raster created from that tool was then used as an input for the raster to polyline tool, which is our final output of the model.

4.2.2 Python Toolbox

The next step in our project was to create a Python toolbox within ArcGIS that would automate the pipeline routing process and allow users to input their own parameters depending on their project goals. We took the output Python script generated through the development of our model and created five separate scripts from them with Visual Studio Code, which correspond to the five tools within our toolbox.

Our first tool is called “Slope Raster Reclassification” and allows users to input elevation data, name their output reclassified slope layer, and reclassify different ranges of slopes to their desired values. The resulting output is a reclassified slope raster layer that is now added to the user’s map.

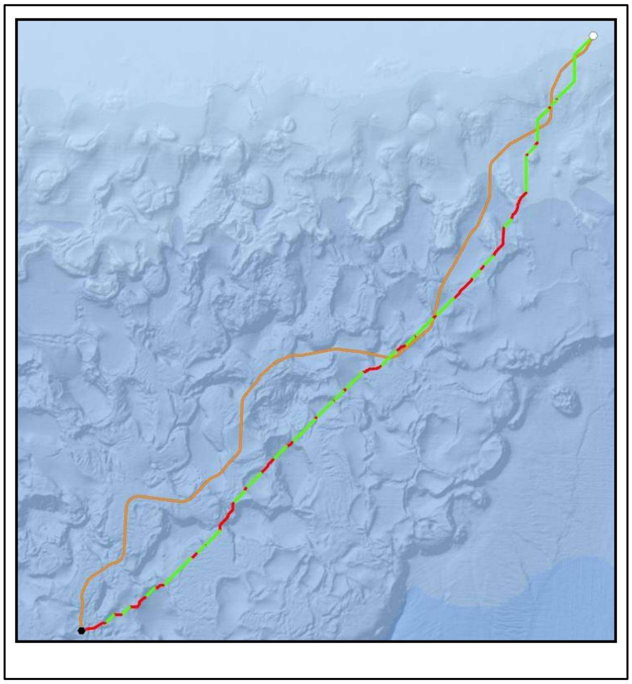
The second tool is called “Avoidance Raster Reclassification” which allows users to input multiple layers and assign each of them a corresponding buffer. The buffer parameter was added to this tool using Linear Unit as its datatype, allowing the user to choose different units of measurement from a drop-down menu. The buffered layers will then be combined into one layer using the Union tool and added to the map as a new avoidance raster.

The third tool is labeled “Least Cost Path” and allows the user to choose multiple raster layers as inputs that will be combined into a new raster. There is also an optional parameter allowing users to assign weights to those rasters depending on their importance, but this is not necessary for the tool to run. Next, the user can choose their start and end points from either the drop-down menu or by clicking the folder icons beside the “Source Point” and “Destination Point” parameters. The last parameter is called “Smoothing Tolerance” and uses the Polynomial Approximation with Exponential Kernel (PAEK) algorithm to apply a smoothing factor to the least cost path. This will create a smoother path as a separate output, lending its hand to curvature consideration. Finally, the user can name and choose the workspace for the output for the least cost path, which is then added to their map.

Geosyntec also recommended two additional parameters for the construction of new pipelines. The first involves maintaining an optimal distance of two miles between curves, and the second ensures that turns have a minimum curvature radius of 10,000 feet and a maximum of 15,000 feet. Despite our efforts to automate the integration of these parameters into new toolboxes, we encountered challenges within the given time frame. We were able to create scripts that adhered to both the minimum straight distance and minimum turn radius. However, upon running these tools, we noticed that the newly created routes which adhered to the new parameters were now ignoring the cost raster. With three different test areas, the routes always seemed to pass through either anomalies, infrastructure, or steep slopes. Given the time frame of the project, this issue was not properly solved, resulting in those parameters being left out of the final project. Consequently, we opted to divide the proposed routes generated by the least-cost path toolbox into segments. This approach allowed us to utilize the symbology in ArcGIS and colour-code the segments, highlighting areas of concern along the route for further investigation by the user. This toolbox is called “Route Segmentation” and allows users to choose their input polyline and output a new segmented polyline. Once the new segmented path is created, the user can modify the layers’ symbology by changing it from Natural Breaks with five classes, to Manual Interval with two classes. The number of classes can be changed depending on how the user would like to visualize the segments. By changing the symbology to Manual Intervals, the user can then specify different lengths of segments and assign them a colour. For our purpose, we assigned any segments longer than two miles the colour green to indicate that these adhere to the specifications provided, and any segments shorter than two miles were assigned the colour red to indicate that these segments may need user intervention.

Our fifth and final tool is called “Report Creation” and allows the user to output a summary report of the least-cost path. The report includes information such as the length of the polyline, the start and end coordinates, and the coordinate reference system that the map has. If the user chooses to include a layout within ArcGIS Pro, this image will also be saved to the report. If no layout is in the project, the report will indicate that it was not found. Although the report is quite basic, we hope that as the tool is used and modified in the future, it will have more valuable insights into least-cost path analysis that will help users in their journey of optimizing these routes.

5 RESULTS



The tools ran successfully and created an output least-cost path that has start and end points that were provided to us by Geosyntec. The points are located along a pre-existing pipeline so that we could compare our results to and visualize any differences. The resulting segmented least-cost path is seen in Figure 2. represented by the red and green line, and the existing pipeline is shown in orange. One of the major differences is that the existing pipeline contains more broad turns compared to our path that has multiple, smaller, and sharper turns. This is most likely because we did not implement a minimum curve radius threshold or a minimum straight distance between curves in our toolbox due to time constraints. Other factors such as changes in environmental regulations, terrain changes, and data quality can all be reasons why our calculated path is different from the pipeline. Our path was still successful in avoiding steep slopes, seafloor anomalies, and existing infrastructure. There will always be a need for human intervention to fully optimize a potential route, but our toolbox is a great tool in building a foundation for subsea pipeline planning.

6 HARDWARE & SOFTWARE ENVIRONMENTS

The hardware used for this project is a computer equipped with a Windows Operating System capable of running various Geographic Information Systems. The software used is ArcGIS, including Model Builder. Additionally, the integrated development environment software used to run our Python code in conjunction with our toolbox is Visual Studio Code.

7 CHALLENGES

Outlined below are a few challenges we encountered throughout various stages of our project:

- Once in the Model Builder stages, our initial attempts were to run the model considering the whole area of the Gulf of Mexico. This proved time-consuming as the model would take a very long time to process all the data. It was decided to clip our provided data to a study area for the tools to run faster, which proved to be a much better method during this process.
- Integrating a minimum straight-line distance and curve radius into our least-cost path algorithm posed the greatest challenge. The least-cost path tool typically generates paths with closely spaced curves. Geosyntec has initially specified a preferred parameter that there should be at least a 2-mile distance between each pipeline turn, as well as the starting and end points. However, when we attempted to implement these constraints, the tool adhered to the new parameters, but disregarded the cost raster, resulting in paths that traversed anomalies. Despite exploring multiple

approaches to reconcile the minimum distance and minimum turn radius requirements with the cost considerations, we were unable to achieve a satisfactory solution. As described in the methods section above, we ultimately decided to segment the least-cost path to enable the use of a colour-coding tool that would highlight areas of concern. We hope that this challenge of disregard towards the cost raster upon introduction of new parameters will be overcome in the future, and that this toolbox will continuously be expanded upon.

8 DISCUSSION

Throughout this project, our team has gained valuable insights from intricate cost-distance analysis, building on the concepts we've explored in class throughout the last two semesters. Automating such workflows has proven to be a challenging yet fascinating endeavor, sparking a passion for using automation to make significant contributions in the field of Geomatics.

While automating the creation of least-cost pathways offers numerous benefits, human intervention remains crucial for managing real-world complexities and ensuring practical, tailored solutions for specific project needs. Algorithms depend on the quality of the data they process, and in our continuously changing environments, incomplete or outdated data can lead to suboptimal path suggestions. Therefore, human oversight is still essential for verifying and adjusting these paths. The goal for our project is not to replace human intervention, but to enhance the process, allowing more time to be spent on analyzing the optimization and practicality of potential paths.

We hope that this toolbox will be continuously expanded in the future to include more specific parameters, resulting in increasingly realistic outputs. Potential additions could include specifying a minimum straight distance for the path and ensuring that the curve radius of any turns meets the project's requirements. With more time dedicated to the toolbox, we believe it could be a momentous aid in the process of creating least-cost paths for various situations.

9 CONCLUSION

By utilizing the data obtained from the Gulf of Mexico provided by Geosyntec, as well as further research into application and technology, we have been successful in automating the pipeline routing process with the construction of Python toolboxes in ArcGIS Pro. We established a solid foundation in ModelBuilder that enabled us to further our understanding of the next steps that we took in Python. The Python toolbox we created is an integral part of geoprocessing and can be shared with other users to be utilized in future projects. Dividing the steps in numerical order makes the workflow user-friendly and easy to understand. The purpose of the toolbox is to create efficiency when building least cost pathways for potential subsea pipeline construction.

10 REFERENCES

Gamarra, A. (2015). GIS Suitability Modeling to Support a Pipeline Route Selection. Retrieved from https://www.researchgate.net/publication/281286278_GIS_Suitability_Modeling_to_Support_a_Pipeline_Route_Selection

International Energy Agency. (2024). Oil Market Report - May 2024. *IEA*, Paris. Retrieved from https://www.iea.org/reports/oil-market-report-may-2024

Kaiser, M.J., & Narra, S. (2019). The Offshore Pipeline Construction Industry and Activity Modeling in the US Gulf of Mexico. *Bureau of Ocean Energy Management.* Retrieved from https://www.sciencedirect.com/book/9780128202883/the-offshore-pipeline-construction-industry

Makrakis et al., (2020). Route Optimization of Offshore Lifelines Taking Into Account Potential Earthquake-Related Geohazards. *Frontiers in Built Environment.* Retrieved from https://www.frontiersin.org/articles/10.3389/fbuil.2020.00112