GIS-based Methodology and Software Tools for Oil Pipeline Routing Planning

A case study of an hypothetical connection between Valencia and Alicante

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INTRODUCTION

The European Union has been dedicated to a profound energy transition. However, a significant challenge arises from the intermittent nature of renewable energy sources, as their operational efficiency is contingent upon prevailing weather conditions. In response to this intermittency, two principal avenues have emerged as essential complements to bolster green energy solutions: nuclear energy and gas/oil. Nuclear energy found limited favor in Germany's strategic energy plan, with the nation instead emphasizing gas-based alternatives and sourcing gas from Russia. However, this energy arrangement ended when Russia invaded Ukraine on the 24th of February 2022. This geopolitical development prompted Germany and numerous other central EU nations that relied on Russian gas imports to seek alternative energy supply routes and sources promptly. The implementation of these energy alternatives necessitates meticulous planning and extensive infrastructure development, particularly involving establishing new grid systems and pipeline connections. At this juncture, the present thesis assumes significance and relevance as it aims to develop a GIS-based methodology and software tools to be integrated into Pathfinder to to enhance the efficacy and performance of optimal pipeline routing. This thesis combines GIS with optimization problems, all in one tool.

METHODOLOGY

DATA COLLECTION → MODEL DEFINITION → SW DEVELOPMENT

DATA COLLECTION

- **Data sources**
  - BDN
  - ICV
  - IGN
  - OSM
- **Data sets**
  - Forest
  - Humid areas
  - Natural Parks
  - Protected areas
  - Protected landscapes
  - Etc (+25 layers)

SW USED

- Django
- PuLP
- GEOS
- GDAL
- HiGHS
- Kiwi TCMS
- Pathfinder
- SAGA

MODEL DEFINITION

The MILP problem is described as follows:

- Given:
  - The elevation along the pipeline route
  - The available size, price per unit length, and pipeline design pressure
  - The available pump operational plan
  - The construction cost of pump stations and the pressure reduction station
  - The flow rate of the pipeline
- Determine:
  - The inner diameter of the pipeline in each segment
  - The locations of the pump stations and the pressure reduction stations
  - The pump operational plan of the pump stations

The problem presented is a constrained optimization problem. Therefore, an objective function to be maximized or minimized has to be defined:

$$\min f = \sum_{j \in \mathrm{L}_a} \sum_{g \in \mathrm{G}} \phi_j T_{\mathrm{P}_{j,g}} C_{\mathrm{UP}g} + \sum_{j \in \mathrm{L}_a} T_{\mathrm{D}j} C_{\mathrm{UD}} + \sum_{j \in \mathrm{L}_a} \sum_{y \in \mathrm{Y}} T_{\mathrm{Z}j,y} C_{\mathrm{UZ}}$$

Some constraints to limit the possible optimal values are defined too. For instance:

$$p_i - p_{i+1} - C_{\mathrm{F}_{j,a}} \geq M(T_{\mathrm{D}_j} - 1), \forall i \in N_a, j \in L_a, i = j$$

$$p_i - p_{i+1} - C_{\mathrm{F}_{j,a}} \leq M(T_{\mathrm{D}_j} - 1), \forall i \in N_a, j \in L_a, i = j$$

SW DEVELOPMENT

PROTOTYPE

Obtain a standalone script capable of achieving the most basic aspirations of the final tool. The main features were: a model-solving section, input and output for the geospatial data, and some visual outputs.

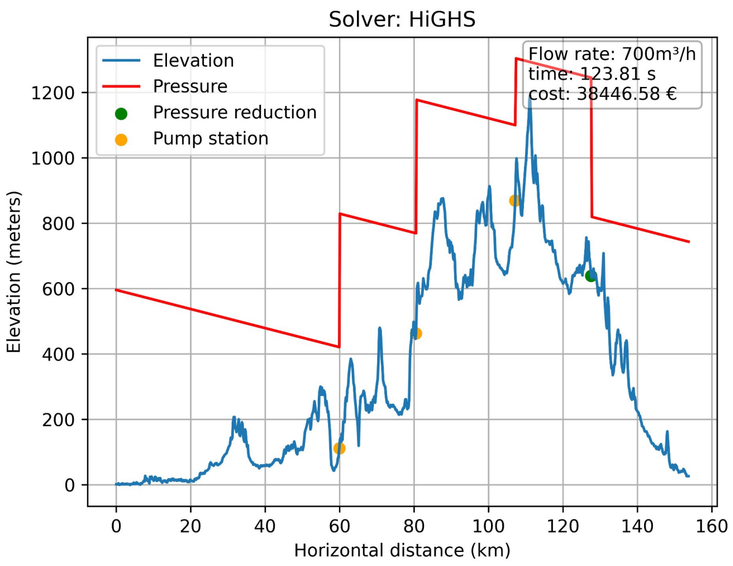
INTEGRATION

Libraries installation on real server, adapt the prototype to make use of Django framework and GEOS. Change the input/output workflow to fit the Pathfinder's Geoprocessing module.

TESTING

A test case was design to ensure the proper function of the tool periodically and check that the new features added to Pathfinder do not affect this part of the code.

RESULTS



The above chart was obtained during the prototyping phase. There it is possible to see how the solver adjusts the pressure to be close to the path elevation, the location of the pump and pressure reduction stations, the selection of two different pumps with different power capacity and the pressure drop along the pipeline.

The tool and methodology developed in the project are applied to an hypothetical connection between Valencia and Alicante city.

VIDEO DEMONSTRATION

In the video, it is possible to see how the final integrated tool works in Pathfinder.

CONCLUSIONS

This study presents a comprehensive approach to pipeline optimization and routing using the developed geoprocessing tool. The tool successfully integrated various spatial layers, multi-criteria decision analysis (MCDA), and advanced algorithms to determine optimal paths for pipeline installation. The results from the case study demonstrated the tool's capability to provide feasible and efficient pipeline routes while considering multiple factors such as environmental, infrastructural, and terrain considerations.

- Enhancements
  - Commercial solver for faster results
  - 3D pipeline model for more realistic 3D map representation
- Future work
  - Network optimization scenarios not limited to point-to-point paths

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