Cartography M.Sc.

Master thesis

Multi Criteria Decision Analysis and Automatic Submarine Cable Routing

Daphné Tapia

Technical University of Munich

TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

TECHNISCHE UNIVERSITÄT DRESDEN

ITC UNIVERSITY OF TWENTE.

2020

Multi Criteria Decision Analysis and Automatic Submarine Cable Routing

Submitted for the academic degree of Master of Science (M.Sc.)
Thesis submitted to the Faculty of Geo-informatics and to the Institute of Cartography of the Technical University of Dresden in partial fulfilment of the requirements for the joint Master of Science in Cartography.

Author: Daphné Tapia
Study course: Cartography M.Sc.
Supervisor: Dr.-Ing. Stephan Mäs (TUD), Chair of Geoinformatics
Reviewer: Drs. Richard Knippers (UT), Department of Geo-information Processing and Faculty of Geo-information Science and Earth Observation

Cooperation: Alcatel Submarine Networks

Date of submission: 10.09.2020

Multi Criteria Decision Analysis and Automatic Submarine Cable Routing

Alcatel Submarine Networks, Nozay, France

ASN supervisor: Michele Barezzani

Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"Multi Criteria Decision Analysis and Automatic Submarine Cable Routing"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Paris, 10.09.2020 Daphné Tapia

Confidentiality Clause

Reproduction rights for this document are held by Alcatel Submarine Networks. Without the written consent of Alcatel Submarine Networks, provided by contract or any other form, this document may not be copied, printed or reproduced, in whole or in part. The contents of this document, as well as the methods and techniques described should not be communicated to any third party.

Acknowledgment

This thesis could not be possible without the participation and assistance from many people. First, I would like to express my sincere gratitude to my first supervisor Dr.-Ing. Stephan Mäs for the guidance through each discussion. Your comments and insights were always a great help. I would like to thank Prof. Dipl.-Phys. Dr.-Ing. habil. Dirk Burghardt and Drs. Richard Knippers for the insightful feedback during the research proposal and the midterm presentation. Thanks to Mr Mathias Gröbe for his availability and great help. Thanks also to Dr.Eva Hauthal and Mrs. Juliane Cron for their involvement throughout the program.

I would like to thank the Marine Business Development team from Alcatel Submarine Networks for being so gentle and welcoming. Thank you for teaching me and sharing with me your knowledge about the submarine cable industry and for turning this internship into such a meaningful experience. It was a true honor and pleasure to work with you, Michele Barezzani, François-Xavier Abrial and Alban Crusson.

I am grateful to my classmates from whom I have learned a lot. The two years of the master's program are a unique and unforgettable experience. Finally, I would like to thank my family for their unconditional love and support, my friends for being so faithful, and Michael, for whom no more words are needed because he knows how I feel towards him.

Abstract

Submarine cable routing is a critical phase in the definition of a new submarine cable system: this complex activity is traditionally performed manually. The aim of this master's thesis is to define methods and algorithms to automatically generate submarine cable paths on the sea bottom. The objective is to determine optimal routes in a time and cost-efficient manner. Tests were run on different geographic zones using the Least Cost Path Algorithm, while trying different cost functions.

Keywords: Multi Criteria Decision Analysis, Single Criteria, Least Cost Path, Automatic Submarine Cable Routing.

Acronyms

AC	Alter Course
ASN	Alcatel Submarine Networks
BMH	Beach ManHole
BU	Branching Unit
CRE	Cable Route Estimate
CSV	Comma-Separated Value
CZ	Contiguous Zones
DA	Double Armour
DB	DataBase
DTS	Desktop Study
EZ	Economic Zones
FZ	Fishing Zones
GIS	Geographic Information System
H-SEAS	High Seas
ICPC	International Cable Protection Committee
LCPA	Least Cost Path Analysis
LW	LightWeigth
LWP	LightWeight Protected
MCDA	Multi Criteria Decision Analysis
NM	Nautical Miles
PFE	Power Feeding Equipment
ROADM	Reconfigurable Optical Add-Drop Multiplexer
ROV	Remotely Operate
RPL	Route Position List
SA	Single Armour
SE	Shore End
SOLAS	Safety Of Life At Sea
TR	Transition
TW	Territorial Waters
UNCLOS	United Nations Convention on the Law of the Sea
UXO	UneXploded Ordnance
WD	Water Depth

Table of Contents

1 Introduction 13
1.1 Motivation 13
1.2 Background 14
1.2.1 Alcatel Submarine Networks 14
1.2.2 Submarine Telecom Networks 15
1.3 Research Identification & Objectives 17
1.3.1 Research Questions 17
1.3.2 An innovative topic 18
1.4 Thesis Structure 19
2 State-of-the-art submarine cable routing 19
2.1 Cable Route Engineering 20
2.1.1 General Constraints and Obstacles 21
2.1.2 Manual Routing 23
2.1.3 Cable Installation 24
2.1.4 Cable Relative Cost 25
2.2 Very Rough Order of Magnitude 25
3 Research Methodology 27
3.1 Workflow: Apply GIS function to Cable Routing 28
3.1.1 Bathymetric data: the most important input to the cost raster 28
3.1.2 Chosen areas for test 28
3.2 Single Criteria Analysis 29
3.3 Multi Criteria Analysis 30
3.4 Analytical Hierarchy Process 30
4 Implementation and Software 32
4.1 Data description 32
4.1.1 Bathymetric and Coastal Data 32
4.1.2 Global Marine Cable Database 32
4.1.3 Maritime Boundaries 33
4.2 ArcMap 34
4.3 Data Preparation 36
4.3.1 The Land 36
4.3.2 The GEBCO Charts 36

4.3.3 The Beach Man Holes (BMH) 36
4.3.4 Determining adequate cost function 37
4.3.5 Cable crossings 39
5 Single & Multi Criteria Decision Analysis (MCDA) 39
5.1 Intelligent Phase and problem definition 40
5.1.1 Evaluation Criteria 41
5.1.2 Constraints 41
5.2 Design Phase 41
5.2.1 Decision Matrix 41
5.2.2 Alternatives 41
5.2.3 Decision Rules 42
5.3 Choice Phase 42
5.3.1 Sensitivity Analysis 42
5.3.2 Comparison 43
5.3.3- Recommendation & Conclusion 53
6 Analytical Hierarchy Process 53
6.1 Features 53
6.2 Implementation 56
6.3 Limits 58
7 Results 59
7.1 Definition of cable route assessment criteria 59
7.2 Strength, weaknesses and limitations of the proposed methodology 63
8 Discussion and future work 64
8.1 Answers to the research questions 64
8.2 Future Works 65
8.2.1 Implementing Slopes and Sediments Maps. 65
8.2.2 Introducing currents 66
8.2.3 Implementing Maritime Boundaries Data 66
8.2.4 BU: addition of a branch to a trunk link 66
8.2.5 Use of a “Genetic” approach to cable routing 67
8.2.6 Submarine Cable Routing in Arctic Waters 68
Conclusion 72
Bibliography 73

List of Figures

Figure 1 World Map of submarine cable systems 14
Figure 2 ASN equipment for marine operation 15
Figure 3.1 Point to point Figure 3.2 Point to multi-point 16
Figure 4 Submarine cable infrastructures....17
Figure 5 schema of thesis structure....19
Figure 6: Four major types of submarine cable 20
Figure 7 Angles for alter course 23
Figure 8 The different steps while creating and discussing contract 26
Figure 9 Schema of the overall methodology that was used 27
Figure 10 Single criteria analysis workflow....29
Figure 11 Workflow analytical hierarchy process 31
Figure 12 Buffer 0.001° corridor around the GMCD 33
Figure 13 Maritime boundaries 34
Figure 14 Sawtooth aspect on the LCPA 35
Figure 15 Smoothed aspect on the LCPA 35
Figure 16 1/-Z cost function....37
Figure 17 1/Log(-Z+1) cost function 38
Figure 18 $1/Z^{1/2}$ cost function 38
Figure 19 Cost functions comparison 38
Figure 20 Cost function according to cable cost criteria....39
Figure 21 The three phases (Intelligence, Design & Choice) of MCDA 40
Figure 22 GMCD between Barcelona and Port Said 43
Figure 23 Single & two-criteria route 44
Figure 24 Comparing the number of crossings....45
Figure 25 Zoom-in. 46
Figure 26 Influence of the slope raster chart on the MCDA 47
Figure 27 Results. 48
Figure 28 Raster chart of the GMCD....49
Figure 29 1/ Log (-Z+1) 50
Figure 30 Strait of Messina, the 1/Log(-Z+1) cost function 51
Figure 31 Hierarchical structure 53
Figure 32 Barcelona Port Said: AHP 57
Figure 33 Weights used for the AHP method....58
Figure 34.1 Graphs Barcelona Port Said.....Figure 34.2 Graphs Sesimbra Marseilles 61
Figure 35 The resolution of the GEBCO 2014 raster charts is 0.008° 64
Figure 36 Sediments 65
Figure 37 Maritime boundaries (EEZ) map 66
Figure 38 Branching Unit method 67
Figure 39 Genetic approach 68
Figure 40 Extension of the arctic sea ice in August 1984. 69
Figure 41 Extension of the arctic sea ice in August 2019. 69
Figure 42 Mosaic of overlapping sidescan sonographs showing a thoroughly ice-scoured sea floor beneath the Beaufort Sea ice-shear zone. 70
Figure 43 Drift trajectories for 50 icebergs released at each of three Greenland outlet glaciers 71
Figure 44 IBCAO chart of the arctic region 71

List of Tables

Table 1: Research objectives and questions 18
Table 3: Type of cable corresponding to the water depth 20
Table 2: Restricted zones 21
Table 4: Comparative costs of cable types 25
Table 5: Set of objectives 41
Table 6: Comparison of the number of crossings between three different roads 49
Table 7: System length (km) 49
Table 8: Normalized cable cost (%) 50
Table 9: Results obtained with the 1/Log(-Z+1) function (km and cost) 50
Table 10: Comparison between the two function (1/-Z) and LOG (-Z+1) over Barcelona Port Said going through the Strait of Messina 51
Table 11: Results in length (km) and cost (%) between the 5 different cost functions over Barcelona – Port Said without going through the strait of Messina 52
Table 12: Comparison of the three function over two different areas 52
Table 13: Comparison scale as used by Saaty (1995) 54
Table 14: Pairwise comparison matrix 54
Table 15: Normalized comparison matrix: 55
Table 16: Consistency check 56
Table 17: Comparing functions over Barcelona - Port Said 59
Table 18: Comparing functions over Sesimbra Marseilles 61

Bibliography

Alanbari, Mohammad Ali, Nadhir Al-Ansari, Hadeel Kareem Jasim, and Sven Knutsson. "Al-Mseiab Qadaa Landfill Site Selection Using GIS and Multicriteria Decision Analysis." *Engineering* 06, no. 09: 526–49, (2014). https://doi.org/10.4236/eng.2014.69055.

Bagli, Stefano, Davide Geneletti, and Francesco Orsi. "Routeing of Power Lines through Least-Cost Path Analysis and Multicriteria Evaluation to Minimise Environmental Impacts." *Environmental Impact Assessment Review* 31, no. 3: 234–39, (2011). https://doi.org/10.1016/j.eiar.2010.10.003.

Bansal, V. K., and Mahesh Pal. "Construction Projects Scheduling Using GIS Tools." *International Journal of Construction Management* 11, no. 1: 1–18, (2011). https://doi.org/10.1080/15623599.2011.10773158.

Bemmelen, Joost van, Wilko Quak, Marcel van Hekken, and Peter van Oosterom. "Vector vs. Raster-Based Algorithms for Cross Country Movement Planning," n.d., (2014).

Chang Kang-tsung "Introduction to Geographic Information Systems*", (*2012*).*

Coote, Ian S. "Handbook for Ocean Cable Engineering." *Unpublished Notes* 1, n.d., (2009).

Durmaz, Ali, Erdinç Ünal, and Cevdet Aydın. "Automatic Pipeline Route Design with Multi-Criteria Evaluation Based on Least-Cost Path Analysis and Line-Based Cartographic Simplification: A Case Study of the Mus Project in Turkey." *ISPRS International Journal of Geo-Information* 8, no. 4: 173, (2019). https://doi.org/10.3390/ijgi8040173.

Kang, Ju Young, and Byung Suk Lee. "Optimisation of Pipeline Route in the Presence of Obstacles Based on a Least Cost Path Algorithm and Laplacian Smoothing." *International Journal of Naval Architecture and Ocean Engineering* 9, no. 5: 492–98, (2017). https://doi.org/10.1016/j.ijnaoe.2017.02.001.

Macharis, Springael, Brucker, Verbeke. "PROMETHEE and AHP: the design of operational Synergies in multicriteria analysis: strengthening PROMETHEE with ideas of AHP". *European Journal of Operational Research,* no.153: 307-317, (2004). https://doi.org/10.1016/S0377-2217(03)00153-X

Malczewski, Jacek. "GIS-Based Multicriteria Decision Analysis: A Survey of the Literature". *International Journal of Geographical Information Science*, no. 20: 703-726, (2006). https://doi.org/10.1080/13658810600661508

Meng, Yunliang, Jacek Malczewski, and Soheil Boroushaki. “A GIS-Based Multicriteria Decision Analysis Approach for Mapping Accessibility Patterns of Housing Development Sites: A Case Study in Canmore, Alberta.” *Journal of Geographic Information System* 03, no. 01: 50–61, (2011). https://doi.org/10.4236/jgis.2011.31004.

Paski, "The TAT-8 undersea cable system." Optical Fiber Communication Conference *OSA Technical Digest Series (Optical Society of America*) 05, (1989).

“ROUTE ENGINEERING HANDBOOK ISSUE” n.d, (2016).

Saaty, T.L. “The Analytic Hierarchy Process.” *McGraw-Hill* 06, (1980).

Saida Saeedrashed, Younis. “An Experimental Comparison of Line Generalization Algorithms in GIS,” *International Journal of Advanced Remote Sensing and GIS edition*, (2014)

“Symbol and Abbreviations Used on Admiralty Charts.” In *UK Admiralty Charts and Publications*, (2008).

Wang et al. “Cost-Effective Path Planning for Submarine Cable”, n.d., (2019).

Wang, Qing, Jun Guo, Zengfu Wang, Elias Tahchi, Xinyu Wang, Bill Moran, and Moshe Zukerman. “Cost-Effective Path Planning for Submarine Cable Network Extension.” *IEEE Access* 7: 61883–95, (2019) https://doi.org/10.1109/ACCESS.2019.2915125.