J. Mt. Sci. (2020) XX(X): XXX-XXX

Trails network analysis and path optimization in the western Italian dolomites.

ZATELLI Paolo[1,*] http://orcid.org/0000-0003-3095-0472; e-mail: paolo.zatelli@unitn.it

FRONTUTO Vito[2] http://orcid.org/0000-0002-0627-9511; ✉ e-mail: vito.frontuto@unito.it

BESANA Angelo[3] http://orcid.org/0000-0002-1549-9591; e-mail: angelo.besana@unito.it

1 Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123, Trento, Italy

2 Department of Economics and Statistics "Cognetti de Martiis", University of Torino, Lungo Dora Siena, 100, 10153, Torino, Italy

3 Interuniversity Department of Regional and Urban Studies and Planning, Polytechnic and University of Torino, Castello del Valentino, Viale Mattioli, 39, 10125, Torino, Italy

Abstract: The purpose of this work is the development of an automatic procedure for the analysis and optimization of hiking paths. The paper verifies its application to the mountain trails network of the Trentino, alpin region of Italy, where the digital trail map of the Tridentine Alpinist Society (Società degli Alpinisti Tridentini, SAT) is available. The map is provided in the KML, SHP and GPX formats with Open Database License (OdbL) license. The availability of this map allows the analysis of the topological features and environmental aspects of the corresponding network graph. Moreover, it is possible to implement path optimization tools, selecting distance, walking time and upward slope as cost. The evaluation of the traveling times for each path is carried out according to the Schweizer Wanderwege formula, which links walking speed to the slope, but with the possibility of adding reductive coefficients of the speed as a function of the accidentality of the terrain. The estimated time for each trail has been verified by comparing it to the empirical travel time published by the SAT. After modifying the network topology by breaking lines at intersection points, it has been possible to compute the traveling time for each trail section.

Traveling times in the two directions, length and altitude difference has been associated to each trail section, to be used as “costs” in path minimization. Points of interest have been added to the network to be used as nodes, i.e. points of departure and / or arrival of routes or intermediate stop points. These points have been associated with relative "cost" values of the average stay times. Simulations have also been done on the network graph in order to identify the minimum paths: starting from a parking, touching some significant points (shelters, mountain huts, panoramic sites, ...) and returning to the initial parking lot. The whole procedure has been automated in GRASS GIS through a Python script. Estimated traveling times are in good agreement with empirical times and the network analysis and path minimization have shown that the minimum cost path can be very different depending on the cost choice. In particular, for mountain paths, shortest paths are different whether the distance, the traveling time or the total height difference is minimized.

Keywords: Hiking trails; Network; Graph analysis; Travelling salesman problem; Path optimization

Notation

e = *number of network edge;*
n = *number of network nodes;*
p = *number of isolated sub graphs;*
μ = *number of possible cycles;*
α = *connectivity index* α;

β = *connectivity index* β;
γ = *connectivity index* γ;

Introduction

Trentino, formally the Autonomous Province of Trento, is a region of Italy in the north east Alps. The area is currently investigated in the Trentinoland project (Gobbi et al., 2019a), which aims to build a comprehensive dataset describing the region landscape and ecology evolution through the analysis of historical maps (Zatelli et al., 2019) (Gobbi et al., 2019b) (Ferretti et al., 2018) and aerial images (Gobbi et al., 2018).

Mostly covered by mountains and forests, the region provides many opportunities for outdoor activities, such as mountain climbing, trekking and winter sports.

The Società degli Alpinisti Tridentini (Society of Tridentine Mountaineers, SAT) is the association that historically manages and maintains the official network of mountain trails and publishes on its website (SAT, 2018) a digital map of the Trentino mountain trail network. While the main use of this map is to provide guidance through the use of the paths in GPX format in hiking satellite navigators, the availability of the path map in digital format makes it possible to use this information in environmental models in a Geographic Information System GIS. It is also possible to use this map for analyzing the network and determining optimal routes.

Network analysis tools are useful for managers to study the network connectivity, identifying some critical components, such as the sections (arcs) that make up the so-called bridges, i.e. the connecting elements between different subnets otherwise isolated. These are arches which, due to their relative importance, must be safeguarded and subjected to more scrupulous maintenance.

The calculation of routes solves the classic optimization problems on a network: shorter route between two points, shorter route that passes through a given set of points and shorter ring route that passes through a given set of points. This last case constitutes the so-called "Traveling Salesman Problem, TSP" which requires the identification of the shortest route to reach all customers and return to the base. In operational terms, the solution to the problem involves the construction of a graph whose nodes represent the headquarter and the customers' venues of the traveling salesman, while the arcs correspond to the paths between the nodes, in order to identify a circular path that touches all the nodes minimizing the distance. The problem, however simple to describe, is somewhat complex to solve, since the number of its solutions grows very rapidly as the number of nodes increases (Reinelt, 1994). The optimal route is determined by minimizing a "cost", which usually corresponds to the geometric distance between two points. Often, however, depending on the field of application, it may be advisable to use other quantities as an element of "cost": in particular, for mountain routes, due to the strong altimetric variations, it can be more significant to minimize the travel time or the total height difference.

This paper describes the topological analysis of the Trentino mountain trail network maintained by the SAT, with particular respect to its connectivity and redundancy. Moreover, the network connectivity and centrality is evaluated also with respect to SAT's alpine huts.

Finally, an application of the network analysis methods for the optimization of routes on alpine paths with minimization of: distance, travel time, altitude difference in uphill is presented for a sub network in the north west part of the region. The analysis of the actual network is necessarily preceded by the correction of its topology. The calculation of the walking times of the paths and the difference in height uphill on each stretch has been performed using a custom algorithm.

1 Materials and methods

The area of the Trentino region is about 6200 km^2, mostly covered of forests, with elevation ranging from 64 m.a.s.l. (Valle del Sarca) to 3769 m.a.s.l. (Monte Cevedale).

The SAT trail network[1] includes 858 alpine trails, 123 equipped alpine trails and 70 *vie ferrate* (protected climbing routes) (Table 1).

Type of trail	**Number**	**Length [m]**	**Equipment length [m]**
Alpine trails	858	4,376,280	436
Equipped alpine trails	123	866,990	8,364
Vie ferrate	70	265,090	19,956
Total	1,051	5,508,360	28,756

Table 1 *– SAT trail network features on 31/12/2018.*

A vector map of the trail is available in KML, SHP and GPX formats with Open Database License (OdbL) license (Database Contents License v1.0, 2018). This license allows the free use of the map and its derivatives also in commercial applications.

The list of the alpine refuges managed by the SAT is available as a spreadsheet[2], which includes the coordinates of the refuges in different datums and map projections. A vector map for the refuges has been created in the ETRS89/UTM32N (EPSG 25832) datum.

Elevation, elevation changes and slope has been evaluated using the Digital Terrain Model (DTM) available on the Portale Geocartografico Trentino[3] with Creative Commons Attribuzione 3.0 Italia (CC BY 3.0 IT) license. The map is provided in the ETRS89/UTM32N (EPSG 25832) datum with 10 m resolution.

Map management and the network analysis has been carried out using GRASS GIS (GRASS Development Team, 2017), a Free and Open Source GIS widely used for research (Neteler et al., 2012) and education (Ciolli et al., 2017) in the geospatial field. GRASS GIS provides 16 modules for the management and analysis of networks.

2 Topological analysis of the trail network

For the determination of the optimal paths, the trail network is represented by a set of nodes and arcs that indicate their connections. Therefore, the possible paths between the nodes and their features can be evaluated.

The original vector map, in ESRI Shape format, does not provide the topology, which must therefore be reconstructed during the acquisition phase in a GIS system. The map contains the single trails as lines, the common sections between trails are reported either with overlapping segments or with close but separate lines. Moreover, intersections between trails do not correspond to nodes. This requires pre-processing the map to eliminate duplicate sections and break the lines of the trails at the intersections. The application of automatic tools for correcting the topology, which removed 163 duplicate lines and created 1625 nodes at the intersections, solved most of the problems but in some cases it was necessary to intervene manually, in particular where some trails intersected several times over a short distance.

---

[1] https://sentieri.sat.tn.it/?page_id=594

[2] https://www.sat.tn.it/rifugi/elenco-rifugi

[3] http://www.territorio.provincia.tn.it

Alpine refuges managed by the SAT have been added to the trail network as nodes, representing points of interest for hikers. Each node has been assigned a typical residence time, which can be used as the "crossing" cost of the node in determining the optimal routes.

2.1 Global connectivity evaluation

Global connectivity indexes have been evaluated following (Gattuso and Miriello, 2005) and (Taczanowska et al., 2014), based on connectivity indexes (Unwin, 1981) (Haggett and Chorley, 1969). Given the number of edges *e*, the number of nodes *n* and the number of isolated subgraphs *p*, it possible to define:

- $\mu = e - n + p$ number of cycles
- $\alpha = \mu / (2n - 5)$ which compares the number of cycles in a graph to the maximum number of possible cycles. High values of the index indicate a well-connected network with high redundancy;
- $\beta = e / n$ which expresses the level of connectivity in a graph by the ratio between the number of edges (*e*) over the number of nodes (*n*). The value of β is lower than 1 for simple networks and trees, it is 1 for a connected network with one cycle and has values higher than 1 for complex networks, with a large number of possible paths;
- $\gamma = n / (3(e - 2))$ which measures the connectivity through the relationship between the number of observed and possible links. Its value ranges between 0 and 1, with $\gamma = 1$ for completely connected networks.

After the creation of nodes at the intersections and the removal of duplicate lines, the SAT trail network has 2518 edges (*e*) and 2016 nodes (*n*) with 66 isolated subgraphs (*p*). Therefore, for this network μ=478, α=0.12, β=1.20 and γ=0.40. These values indicate a medium connectivity, with an average of 1.20 connections (edges) per node (β). The low value of α indicates a low number of possible cycles, while an intermediate value of γ denotes a medium connectivity. Altogether these values indicate a network structure between the core (tree) and the grid configuration.

For comparison, Kołodziejczyk (Kołodziejczyk, 2019) has evaluated the same quantities for two trail networks with roughly a tenth of edges and nodes. For the Krkonoše National Park (Czech Republic), with 358 sections and 194 nodes, the values μ=167, α=0.44, β=1.84 and γ= 0.61 correspond to a grid scheme, while for the Peneda-Gerês National Park (Portugal) with 177 sections and 124 nodes, the values μ=68, α=0.28, β=1.42 and γ=0.48 suggest a core/grid configuration.

Taczanowska et al. (Taczanowska et al., 2014) have found similar values for trail networks for a much smaller recreational area in Austria, comparing the results for the network taking into account all the used trails with those calculated when only the designated (marked) trails are considered. The complete network, with 405 edges and 268 nodes, α=0.25, β=1.51 and γ= 0.50, corresponds to a grid configuration. The sub network corresponding to designated (marked) trails has lower values β=0.61 and γ= 0.21, therefore it is closer to a core configuration.

The minimum spanning tree for the trail network (Fig.1), i. e. the sub network of minimum length connecting all the nodes, contains 2193 arcs out of the original 2681, for a total length of 3982.86 km instead of the original 5393.43 km. This means that only 81.80% of the arcs, corresponding to the 73.85% of the total trail network length, are needed to connect all the nodes.

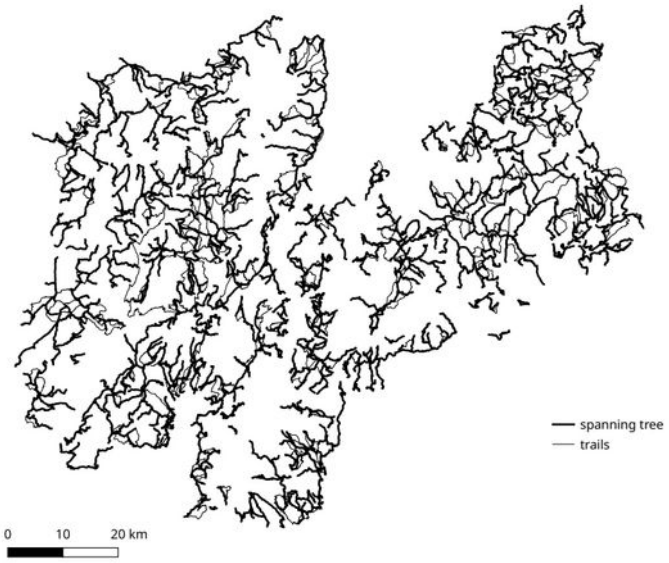

Figure 1 *- minimum spanning tree for the trail network.*

2.1 Local connectivity evaluation

Local measures of the connectivity have been evaluated to investigate possible differences in different parts of the network and to highlight local topological features.

The first analysis has determined the number and location of bridges and articulation points. Arcs are bridges if and only if they are not part of any cycle. The deletion of a bridge increases the network connectivity. Articulation points (cut points) are nodes belonging to every path between some pair of other nodes. The removal of articulation points increases the number of connected components. The SAT trail network contains 899 bridges (Fig. 2) and 793 articulation points (Fig. 3). Trail sections constituting a bridge need particular maintenance since they are the only path to an ending node. At the same time, nodes representing articulation points must be careful maintained because they connect sub networks.

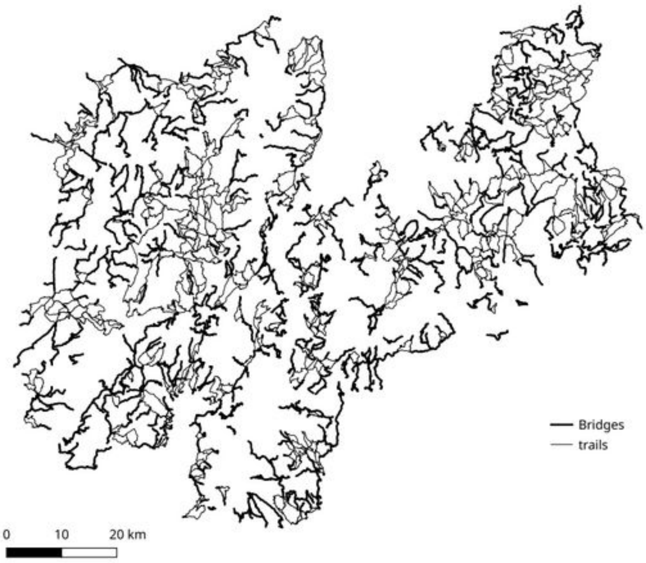

Figure 2 – Bridges (trail sections not part of any cycle) of the trail network.

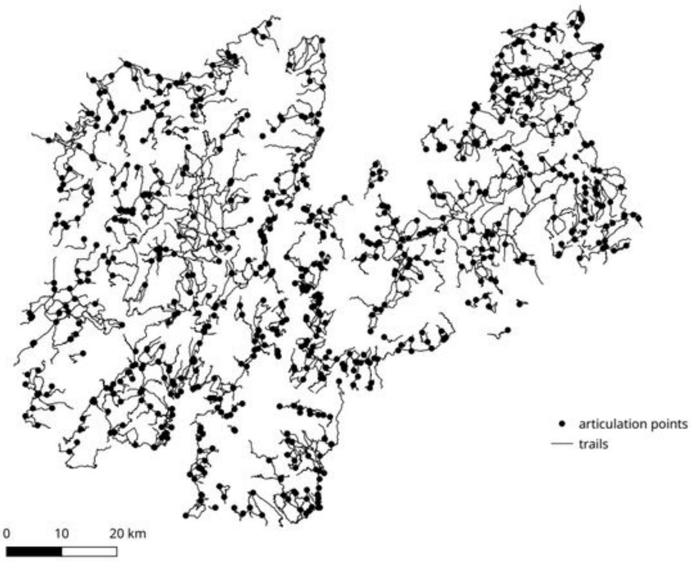

Figure 3 – Articulation points (nodes belonging to every path between some pair of other nodes) of the trail network.

The relative importance of nodes in a network can be assessed by computing their centrality measures (Borgatti and Everett, 2006):

- degree centrality, which is the number of edges connecting a node;
- closeness centrality, defined as the average length of the shortest path between a node and all the other nodes in the network; the more central a node is, the closer it is to all other nodes;
- betweeness centrality, measuring the average length of shortest paths between two any other nodes passing through the node; the value is 0 if no shortest path passes through the node;

- eigenvector centrality, which assesses the influence of a node on a network by its connections to other nodes with high eigenvector centrality.

Table 2 shows the main features of the four centrality indexes, their spatial distribution is mapped in Fig. 4, Fig. 5, Fig. 6 and Fig. 7.

	Degree	Closeness	Betweenness	Eigenvector
Average	2.39	28209.08	3015.33	0.001369
Std dev.	0.99	18901.51	10068.70	0.033921
Max	5.00	85633.16	99176.00	1.000000
Min	1.00	446.07	0.00	0.000000
Median	3.00	25761.63	242.50	0.000000

Table 2 - Degree centrality, closeness centrality [m], betweeness centrality [m] and eigenvalue centrality distribution parameters for the SAT (Società degli Alpinisti Tridentini) trail network.

Degree centrality ranges from 1 (a node connected by just one edge) and 5 (a node with 5 connections), Figure 4 shows that, as expected, the degree centrality is higher for nodes close to the centers of trails sub network. The median value of 3 indicates that more than half of the nodes can be reached using more than one trail.

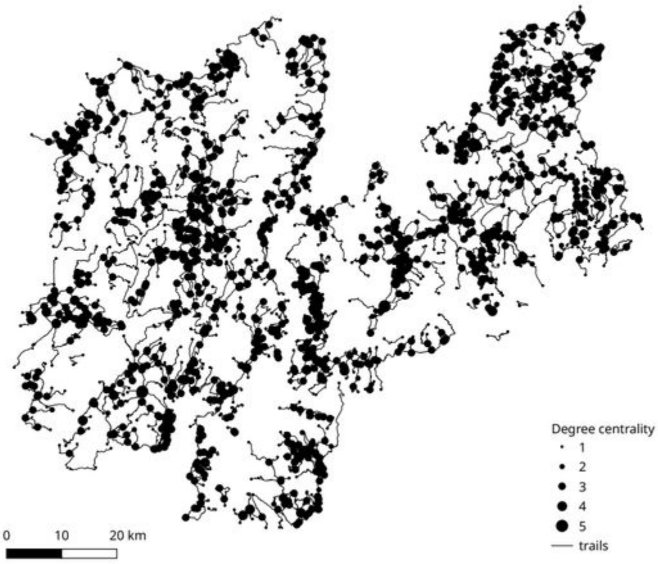

Figure 4 – Degree centrality (number of edges connecting a node) of the trail network nodes.

Closeness centrality, the average length of the shortest path between a node and all the other nodes in the network, has a mean value of 28209.08 m, with a high variability between 446.07 and 85633.16. Nodes with average short connections are located in the peripheral parts of the sub networks, while nodes of the north east part of the network correspond to higher values of closeness (Figure 5).

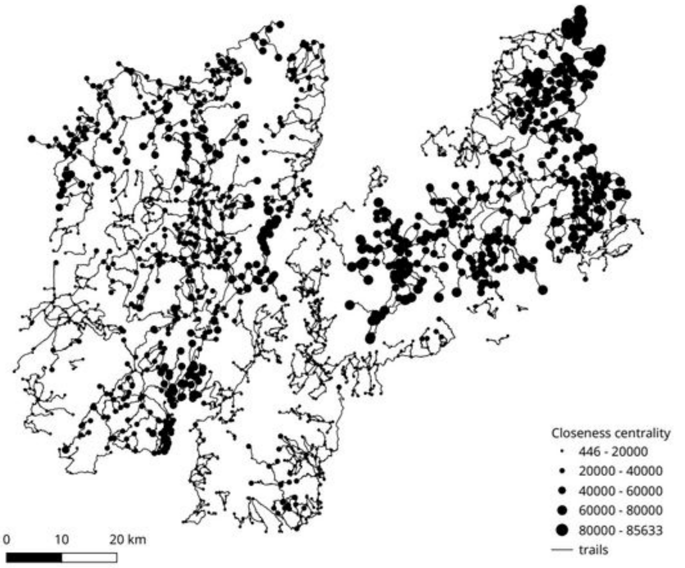

Figure 5 – Closeness centrality (average length of the shortest path between a node and all the other nodes in the network) of the trail network nodes.

Betweeness centrality has a maximum value of 99176.00 m, corresponding to a node in the north east extremity of the network (Figure 6). The distribution of the values is very heterogeneous, with very high values in the east part of the network.

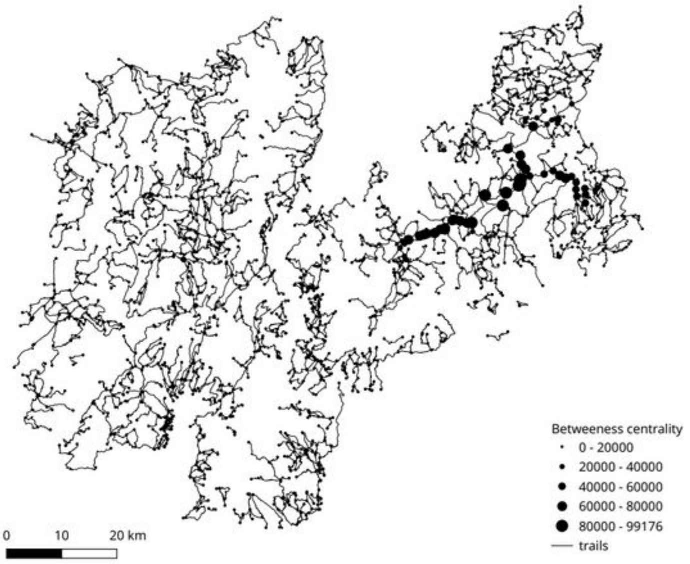

Figure 6 – Betweeness centrality (average length of shortest paths between two any other nodes passing through the node) of the trail network nodes.

Finally, eigenvector centrality, which ranks the nodes depending on their connection to well-connected nodes, is maximum for two nodes in the eastern part of the network, with a third high ranking node nearby (Figure 7).

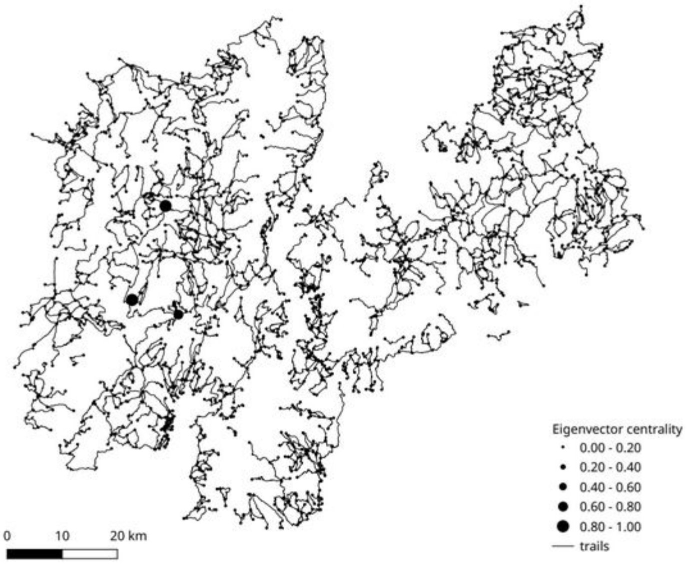

Figure 7 – Eigenvector centrality (influence of a node on the network) of the trail network nodes.

3 Paths optimization

The route optimization methods have been applied to a sub set of the trail network, in the north west part of the region. This area corresponds to the Brenta mountain group and includes 47 of the 1051 SAT trails, for a length of 119,975 meters, compared to 5,508,360 meters of the entire trail network, i.e. 2.2% of the total. 15 refuges, 2 huts (“baita” or “baito”) and 2 high mountain pasture huts (“malga”) have been added to the network, to be used as points of interest for path optimization.

The network thus prepared was used in GRASS GIS for the determination of the paths along the trails that minimize the quantities associated with each section of the path: planimetric distance, travel time and uphill altitude difference.

The entire procedure has been coded in a Python script in GRASS GIS 7.6, making the procedure automatic, requiring only a vector map containing the trail network and a Digital Terrain Model (DTM), for calculating slope and elevation changes, to evaluate travel times.

Point of interest	**Elev.**	**Point of interest**	**Elev.**
Baita Ciclamino	927	Rifugio Croz dell'Altissimo	1.441
Baito Brenta Alta	1.668	Rifugio Montanara	1.507
Malga Cavedago	1.852	Rifugio Pedrotti	2.500
Malga Spora	1.857	Rifugio Pradél	1.364
Rifugio Alberto e Maria ai Brentei	2.179	Rifugio Sella	2.282
Rifugio Alimonta	2.589	Rifugio Selvata	1.656
Rifugio Brenta	1.357	Rifugio Tosa	2.449
Rifugio Cacciatori di Spora	1.868	Rifugio Tuckett	2.270
Rifugio Casinei	1.825	Rifugio XII Apostoli	2.490

Table 3 *– Points of interest used as nodes for optimal paths determination and their elevation.*

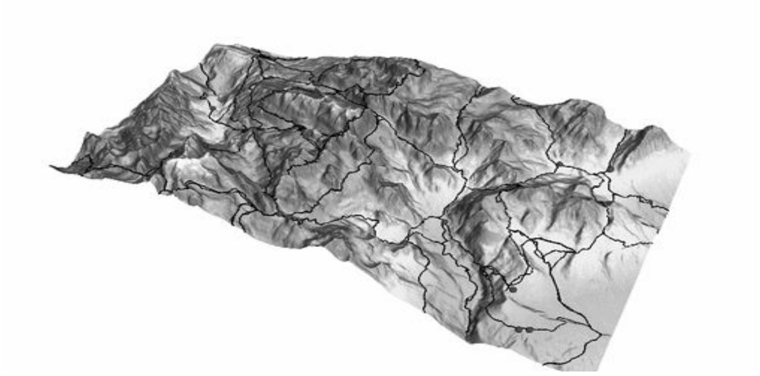

***Figure 8** – The trail sub network used for the paths optimization tests.*

The travel times of the individual sections of the paths have been assessed in the two directions using the indications of the Swiss Body Pro Sentieri (Schweizer Wanderwege, 2006), which relate the walking speed of a standard person (adult individual in good physical condition but without specific athletic skills) with the slope of the path. On the basis of this parameter, a relationship between travel speed and slope of the path was then formulated as a piecewise third degree polynomial (Ciolli et al., 2006a), as shown in Table 2.

It is possible to introduce penalizing coefficients according to the characteristics of the terrain (altitude, accidentalness of the terrain and density of the vegetation) and the person (gender, age and fitness) (Ciolli et al., 2006b; Ciolli et al., 2006c), but here the analysis refers to a standard person.

Slope interval [degrees]	Speed polynomial [Km/h]
[-90 ÷ -80]	0.05
(-80 ÷ -45]	$0.0002 p^2 + 0.0285 p + 1.162$
(-45 ÷ -7]	$0.0005 p^3 + 0.0067 p^2 + 0.3169 p + 5.8524$
(-7 ÷ 4]	$0.0012 p^3 - 0.0194 p^2 - 0.1559 p + 4.2097$
(4 ÷ 25]	$-0.00008 p^3 + 0.0091 p^2 - 0.3296 p + 4.5583$
(25 ÷ 80]	$0.0003 p^2 - 0.0437 p + 1.6718$
(80÷ 90]	0.05

***Table 4** – Polynomials for calculating the walking speed of the paths as a function of the slope p.*

The paths were discretized in sections of 10 m and for each section altitude, slope and travel speed were calculated in both directions. This is because the same stretch can have a significantly different cost depending on the direction of travel, due to its slope. For this reason, the graph and the implemented calculation model are asymmetric.

The altitude is obtained from a digital terrain model (DTM) with a resolution of 10 m. Tests previously conducted on some trails in another area in central Trentino, in the Vigolana mountain group, have shown that using DTMs with higher resolution leads to a significant difference in the assessment of travel times only for short and winding paths.

Cat	Time forward [h]	Time backward [h]	Elev. change. forward [m]	Elev. change. backward [m]
3	0.033	0.026	6.588	0
11	0.008	0.005	2.485	0
13	0.058	0.035	20.479	0
15	0.086	0.071	12.765	0
20	0.033	0.037	0	4.213
21	0.188	0.234	0	43.094

Table 5 *– Attributes associated with the path sections. The null value, in the height difference columns, indicates that the corresponding value of the other column must be used but with a negative sign.*

The calculated travel times were compared with the times reported by the SAT itself (an example is in Table 2): good agreements were found, with an underestimation of the times in some cases, also taking into account the fact that published times have typically a 15' resolution, while times are calculated with 1' resolution.

	Evaluated time		SAT tables times	
Trail num.	Forward	Backward	Forward	Backward
447	4:44h	2:59h	5:00h	3:45h
442	2:55h	1:46h	3:00h	2:00h
431	5:09h	3:14h	5:15h	4:00h
425	5:06h	4:12h	4:40h	4:00h

Table 6 *– Walking times of some paths in the Vigolana group.*

3 Results

For the tests, a ring route was studied, which starts from the Casinei refuge at an altitude of 1825 m and passes through the Tosa refuge (2449 m), the Montanara refuge (1506 m) and Malga Cavedago (1852 m), to return to the Casinei refuge. The optimal routes were determined in three different ways, using the planimetric distance, the travel time and the difference in altitude respectively as the cost to be minimized. Table 7 shows the distance, travel time and altitude difference for the three optimal routes.

Minimized cost	Distance [m]	%	Time [h]	%	Elev. change [m]	%
Distance	34.797	100,00	25,24	100,52	2.626,74	102,79
Time	35.398	101,73	25,11	100,00	2.815,55	110,18
Elevation change	41.927	120,49	31,80	126,64	2.555,52	100,00

Table 7 *– Distance, travel times and uphill gradients for the three routes determined by minimizing the three sizes and percentage of each cost with respect to its minimum value.*

A different choice of the quantity to be minimized determines optimal routes with significantly different characteristics, for example minimizing the difference in altitude increases the distance by about 20% compared to the shortest route and the walking time by about 27% compared to the fastest route. Figures 9 to 11 show the three minimum routes: it is possible to note that some sections are selected whatever the cost (distance, time or difference in altitude) that is minimized, while other sections change, especially in the eastern part of the map.

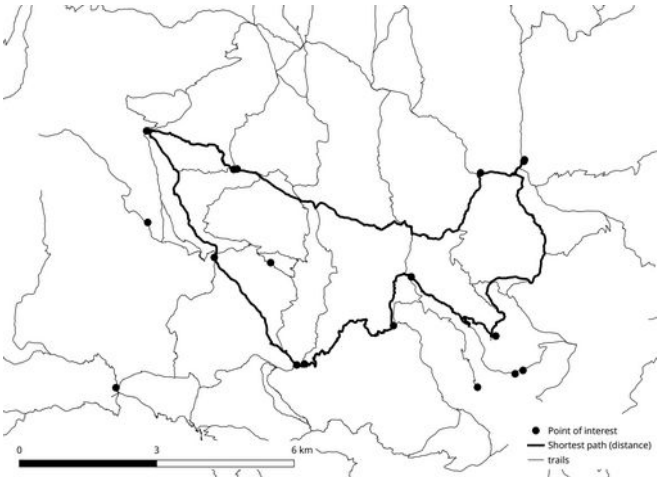

Figure 9 *– Path minimizing planimetric distance.*

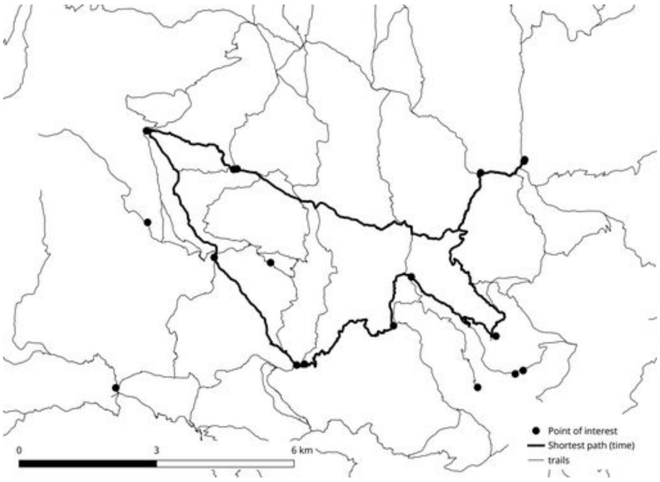

Figure 10 *– Path minimizing travel time.*

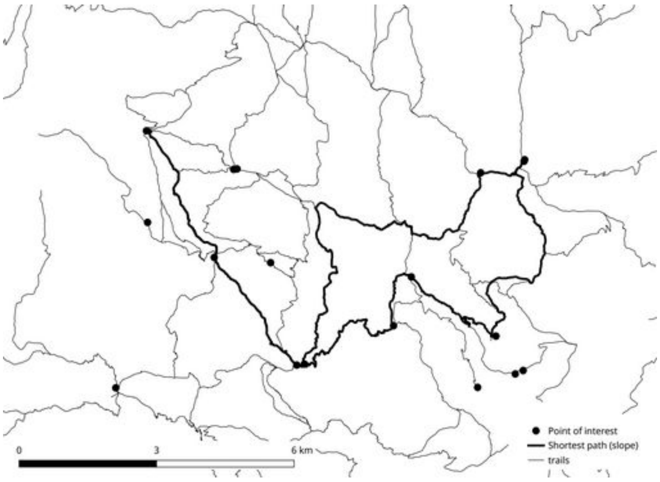

Figure 11 *– Path minimizing slope (uphill altitude difference).*

4 Conclusion

The availability of the digital SAT map with OdbL license opens the possibility of a wide range of interesting analyses, both for the network managers and for its users.

As a precondition for any analysis of this type, the topology of the map must be corrected, passing from a map corresponding to a simple collection of the lines representing the paths to a network configuration, without duplicate arcs and with nodes at each intersection.

The analysis of the trail network topology has indicated some interesting features, such as the heterogeneity of the centrality of the nodes, with few high ranking nodes with respect to the eigenvalue centrality. The automatic determination of the differences in height and the travel times of sections of paths allows to attribute differences in level and times to each arch of the network and therefore to use these quantities as costs to be minimized in the calculation of the routes. The test carried out has shown that a different choice of the optimization parameter leads to significantly different paths.

For final users the present study provides an efficient tool to customize the routes based on individual preferences with respect to points of interest, distance, slope and travel time. This type of service has the advantage to support individuals in maximizing the utility they derive from outdoor recreational activities in mountain areas. An increasing effort have been made to study preferences and demand of tourists and hikers for Cultural Ecosystem Services (CES) (Carvalho Ribeiro et al., 2013) and to map, globally and locally, the provision of these services (Albert et al., 2016). In fact, outdoor recreational activities are the result of the combination of attitudes of final users and the natural environment in which these activities are experienced. For this reason, the analyses provided in this study can be used to efficiently manage the trails networks in order to fully exploit the attractiveness of the mountain areas and to maximize the quality of tourism experiences (Bachi et al., 2020). Furthermore, it is widely recognized that the provision of CES generates a flow of benefits with a measurable, and significant, economic value (inter alia de Groot et al., 2012; Schirpke et al., 2016; Stålhammar and Pedersen, 2017) that should be taken into account in designing management plans.

For the network managers, the analyses presented in the previous sections could be an excellent tool to manage conflicting interests in use may potentially arise (Jacob and Schreyer, 1980). The literature on this topic has focused mainly on interpersonal conflict, i.e. when “another person's behaviour can actually alter the desired social or physical components of the recreation experience” (Jacob and Schreyer, 1980; p. 369). Examples of these conflicts are the ones rising between hunters and non-hunters (Vaske et al., 1995), hikers and mountain bikers (Carothers et al., 2001), alpine skiers and snowboarders (Vaske et al., 2000). Moreover, the management of trails network should take care of the unavoidable trade-off between conservation and recreation in natural environments (Tomczyk et al., 2017). Recreational activities can create revenues for conservation interventions and benefits for users in terms of personal satisfaction and well-being (Sandifer et al., 2015). However, recreational activities may interfere with the “natural” dynamics of the ecosystem causing negative impacts. In light of this, the present study aims to be the base to build up an instrument able to support managers in prioritising ordinary and extraordinary investments and in designing policies for conflicts reduction.

The study will continue with the analysis of the real use of the trail network by analyzing the available GPS tracks, in particular in terms of connectivity, following (Taczanowska et al., 2014). Other points of interest derived from an inter-visibility analysis for the automatic determination of the panoramic points could be added to the traditional points of interest, such as refuges, huts and car parks.

Acknowledgements

Data of table 4 is based on computations by Francesca Alba, Riccardo Bonanomi, and Simone Colli Tibaldi, some initial processing has been carried out by Gabriele Barile. The trail network map and the refuges' spreadsheet are © Società degli Alpinisti Tridentini (SAT), available under the Open Database License (OdbL) license (Database Contents License v1.0, 2018).

References

Albert, C., Bonn, A., Burkhard, N., Daube, S., Dietrich, K., Engels B., et al. (2016). Towards a national set of ecosystem service indicators : Insights from Germany, Ecological Indicators, 61, 38-48, ISSN 1470-160X, https://10.1016/j.ecolind.2015.08.050.

Bachi, L., Carvalho Ribeiro, S., Hermes, J., Saadi, A. (2020). Cultural Ecosystem Services (CES) in landscapes with a tourist vocation: Mapping and modeling the physical landscape components that bring benefits to people in a mountain tourist destination in southeastern Brazil, Tourism Management, 77, ISSN 0261-5177, https://doi.org/10.1016/j.tourman.2019.104017.

Borgatti, S., Everett M. (2006). A Graph-Theoretic Perspective on Centrality. Social Networks 28: 466-484. https://doi.org/10.1016/j.socnet.2005.11.005.

Carothers, P., Vaske, J.J., Donnelly, M.P. (2001). Social Values versus Interpersonal Conflict among Hikers and Mountain Bikers, Leisure Sciences, 23(1), 47-61, https://10.1080/01490400150502243.

Carvalho Ribeiro, S., Migliozzi, A., Incerti, G., Pinto Correia T. (2013), Placing land cover pattern preferences on the map: Bridging methodological approaches of landscape preference surveys and spatial pattern analysis, Landscape and Urban Planning, 114, 53-68, ISSN 0169-2046, https://10.1016/j.landurbplan.2013.02.011.

Ciolli M., Mengon L., Vitti A., Zatelli P., Zottele F. (2006a) A GIS-based FOSS decision support system for the management of SAR operations in mountain areas. In Proceedings of FOSS4G2006: 1–15, Losanna, 15 September 2006. OSGEO. http://2006.foss4g.org/conferenceOtherViews30f5.html, visited 22/12/2019.

Ciolli M., Mengon L., Vitti A., Zatelli P., Zottele F. (2006b) Un sistema di supporto alle decisioni per la gestione delle operazioni di ricerca e soccorso. In Atti del convegno ASITA (Federazione delle Associazioni Scientifiche per le Informazioni Territoriali e Ambientali), 1: 697–702, Bolzano, 17 novembre 2006. Asita.

Ciolli M., Mengon L., Vitti A., Zatelli P., Zottele F. (2006c) A GIS-based decision support system for the management of SAR operations in mountain areas. Geomatics Workbooks, 6:1–17.

Ciolli, M., Federici, B., Ferrando, I., Marzocchi, R., Sguerso, D., Tattoni, C., Vitti, A., and Zatelli, P. (2017). FOSS tools and applications for education in geospatial sciences. ISPRS International Journal of Geo-Information 6(7): 225. https://doi.org/10.3390/ijgi6070225

Database Contents License (DbCL) v1.0 (2018) https://opendatacommons.org/licenses/dbcl/1.0/, visited 8/8/2018.

De Groot, R.S., Wilson, M.A., Boumans, R.M.J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services Ecological Economics, 41(3), 393-408, ISSN 0921-8009, https://10.1016/S0921-8009(02)00089-7.

Ferretti, F., Sboarina, C., Tattoni, C., Vitti, A., Zatelli, P., Geri, F., Pompei E., Ciolli, M. (2018). The 1936 Italian Kingdom Forest Map reviewed: A dataset for landscape and ecological research. Annals of Silvicultural Research, 42(1), 3–19. https://doi.org/10.12899/asr-1411

Gattuso, D., Miriello, E. (2005) Compared Analysis of Metro Networks Supported by Graph Theory. Netw Spat Econ 5, 395–414. https://doi.org/10.1007/s11067-005-6210-5

Gobbi, S., Cantiani, M. G., Rocchini, D., Zatelli, P., Tattoni, C., La Porta, N., & Ciolli, M. (2019a). FINE SPATIAL SCALE MODELLING of TRENTINO PAST FOREST LANDSCAPE (TRENTINOLAND): A CASE STUDY of FOSS APPLICATION. In International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives (Vol. 42, pp. 71–78). International Society for Photogrammetry and Remote Sensing. https://doi.org/10.5194/isprs-archives-XLII-4-W14-71-2019

Gobbi, S., Ciolli, M., La Porta, N., Rocchini, D., Tattoni, C., & Zatelli, P. (2019b). New Tools for the Classification and Filtering of Historical Maps. ISPRS International Journal of Geo-Information, 8(10), 455. https://doi.org/10.3390/ijgi8100455

Gobbi, S., Maimeri, G., Tattoni, C., Cantiani, M. G., Rocchini, D., La Porta, N., Ciolli M., Zatelli, P. (2018). Orthorectification of a large dataset of historical aerial images: Procedure and precision assessment in an open source environment. In International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives (Vol. 42, pp. 53–59). International Society for Photogrammetry and Remote Sensing. https://doi.org/10.5194/isprs-archives-XLII-4-W8-53-2018

GRASS Development Team (2017). Geographic Resources Analysis Support System (GRASS) Software. Open Source Geospatial Foundation. 2017. Available online: grass.osgeo.org (accessed on 12 September 2019).

Hagget, P., Chorley R.J. (1974), Network analysis in geography, London: Arnold

Kołodziejczyk K (2019) Networks of hiking tourist trails in the Krkonoše (Czech Republic) and Peneda-Gerês (Portugal) national parks – comparative analysis. Journal of Mountain Science 16(4). https://doi.org/10.1007/s11629-018-5228-3

Jacob G.R. and Schreyer R., (1980). Conflict in Outdoor Recreation: A Theoretical Perspective, Journal of Leisure Research, 12(4), 368-380, https://10.1080/00222216.1980.11969462.

Neteler, M.; Bowman, M.; Landa, M.; Metz, M. (2012). GRASS GIS: A multi-purpose Open Source GIS.

Environmental Modeling and Software (31): 124–130. https://doi.org/10.1016/j.envsoft.2011.11.014.

Pettebone, D., D'Antonio, A., Sisneros-Kidd, A., Monz C. (2019) Modeling visitor use on high elevation mountain trails: An example from Longs Peak in Rocky Mountain National Park, USA. J. Mt. Sci. 16: 2882–2893 (2019) https://doi.org/10.1007/s11629-019-5663-9

Reinelt G. (1994) The traveling salesman: computational solutions for TSP applications, Springer-Verlag.

Sandifer, P.A., Sutton-Grier, A.E., Ward B.P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: opportunities to enhance health and biodiversity conservation, Ecosystem Services, 12, 1-15, ISSN 2212-0416, https://doi.org/10.1016/j.ecoser.2014.12.007.

Schirpke, U., Timmermann, F., Tappeiner, U., Tasser, E. (2016). Cultural ecosystem services of mountain regions: Modelling the aesthetic value, Ecological Indicators, 69, 78-90, ISSN 1470-160X, https://doi.org/10.1016/j.ecolind.2016.04.001.

Schweizer Wanderwege (Ente Svizzero Pro Sentieri) (2006) Walking time estimate for trails. CH-4125 Riehen.

Società degli Alpinisti Tridentini (SAT) (2018), web site http://www.sat.tn.it, visited 5/8/2018.

Stålhammar, S., Pedersen, E. (2017). Recreational cultural ecosystem services: How do people describe the value ?, Ecosystem Services, 26, 1-9, ISSN 2212-0416, https://10.1016/j.ecoser.2017.05.010.

Taczanowska K., González L.M., Garcia-Massó X., Muhar A., Brandenburg C., Toca-Herrera J.L. (2014) Evaluating the structure and use of hiking trails in recreational areas using a mixed GPS tracking and graph theory approach,Applied Geography, 55: 184-192. https://doi.org/10.1016/j.apgeog.2014.09.011.

Tomczyk, A. M., Ewertowski, M.W., White, P.C.L., Kasprzak, L. (2017). A new framework for prioritising decisions on recreational trail management, Landscape and Urban Planning, 167, 1-13, ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2017.05.009.

Unwin, D. J. (1981) Introductory Spatial Analysis, Methuen &Co. Ltd; London

Vaske, J.J., Donnelly, M., Wittmann, K., Laidlaw, S. (1995). Interpersonal versus social-values conflict. Leisure Sciences, Leisure Science, 17, 205-222, https://10.1080/01490409509513257.

Vaske, J.J., Carothers, P., Donnelly, M.P., Baird, B. (2000) Recreation Conflict among Skiers and Snowboarders, Leisure Sciences, 22(4), 297-313, https://10.1080/01490409950202311

Zatelli, P., Gobbi, S., Tattoni, C., La Porta, N., & Ciolli, M. (2019). OBJECT-BASED IMAGE ANALYSIS for HISTORIC MAPS CLASSIFICATION. In International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives (Vol. 42, pp. 247–254). International Society for Photogrammetry and Remote Sensing. https://doi.org/10.5194/isprs-archives-XLII-4-W14-247-2019