Optimal Trail Routing for Recreational Management Through Visual Quality Values

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Abstract: Tourism in forested landscape is one of the cultural ecosystem services with a continuous increase in demand by the public. Its importance has been recognized through recreational activities in forested landscapes closer to large urban centers with high population density. In this paper, we focus on visual quality values of forest sites as one of the ecosystem benefits in a forested landscape, and seek an optimal trail routing for recreational management based on visual quality values. We assume that tourists will visit sites in order to maximize the sum of visual quality values of the sites on their routing. We formulate the problem within the framework of the travel salesman problem (TSP), using an agroforestry site in Southern Portugal. Our computational experiments showed that TSP can be applied to search for optimal recreational route in a forested landscape with forest stands showing diverse visual quality levels.

Keywords: aesthetic quality, trail routing, spatial planning, optimization model, recreational management

1. Introduction

Since 2010 majority of world’s human population (i.e. 50.46%) have lived in urban centres. It is projected that 68.7% of world’s population will live in urban centres by 2050 (WUP, 2009). With growing urbanization of society and changing life style, the demand for outdoor recreation in forests or countryside will continue to increase, especially in developed countries (Koch and Rasmussen, 2000). Consequently, rural recreation will become a strong attraction for many urban dwellers. Forestry and agricultural lands are expected to provide a wide range of ecosystem services, including opportunities for tourism, recreation, leisure and the closeness of society to nature.

Traditional rural economies are experiencing destructuralization towards sector diversification with the aim of gaining higher stability and security (e.g. Marsden, 1998). Tourism is one of the principal areas for economic development targeted by rural development policies (e.g. EC, 2005). This marketable service from forests and agricultural lands will continue to contribute to the direct income of landowners.

A review of literature shows that the demand for outdoor recreation has been increasing (e.g. White et al., 2016). As a result of the increasing demand for outdoor recreation and the potential conflict it may pose with other resource use, the social functions of forests warrant much more attention than before. The increase in attention and awareness of recreational activities requires an interdisciplinary approach from researchers, policy makers, spatial planners and designers involved in the management of specific areas (Sievanen et al., 2008).

Areas outside urban centres play an important role in outdoor physical activities, such as walking, hiking, and biking. People use these areas for physical activities mainly to recreate and exercise (Abraham et al., 2010). The aim of management of tourism and recreation is to match the local resources to visitors’ expectations by delivering the most satisfactory experiences, regardless of who uses the resource, e.g. farmers, forest owners or tourism agencies (Chetri et al., 2004). One of the most valued characteristics of landscape in the eyes of local residents and visitors is the aesthetic quality of the landscape. In order to be perceived as an option for physical activity, landscapes must be aesthetically appealing to their users (Pretty et al., 2005). The study by Mellander et al. (2011) reveals that for many local residents, the beauty of a landscape is more important in deciding where to live than the local economic conditions or individual’s income. Therefore, considering aesthetic aspects in spatial planning through trail routing in recreational areas can contribute to the wellbeing of landscape users.

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Careful establishment of recreational trails provides better opportunities for visitors to realize the social and ecological values of forests, as revealed by European regulation (Council Regulation 1257/1999). It also protects valuable landscapes (ECL, 2000). A suitable methodology is therefore needed to assign values for visual quality for forest sites over space, considering general knowledge of landscape aesthetics, characteristics of local traditional forests and users’ preferences. When these aspects are appropriately translated into the visual values for a specific forest type, the value of visual forest quality (the aesthetic value) can be mapped out over a forest area (e.g. Surová et al., 2013). This sets the stage for the use of an appropriate methodology such as using an optimization technique to achieve optimal or efficient trail routing on local forest areas for tourism or recreational management.

Although several studies have been carried out on mapping place suitability for recreation (e.g. Kienast et al., 2012), there are limited or no studies that have used optimization techniques in managing the establishment of an efficient or optimal trail routing in specific areas. Even with spatial mapping of visual quality across forest area, seeking an efficient trail routing through connected forest parcels (sites), is necessary for managers to make recreational plans, while offering a level of aesthetic experience in forest and/or a local forest experience within a specified time period. That is, allocation of trails in an area is one of the basic recreational infrastructures in any forested landscape.

Mathematical programming techniques play an important role in finding an efficient or optimal trail routing on local forest maps subject to specific restrictions. Our optimal trail routing problem can be described as a type of traveling salesman problem (TSP). The general assignment of TSP is to seek an optimal route to visit each site only once, by minimizing traveling costs or other factors, given site location. Application of TSP can be found in many discrete optimization problems such as transportation and logistics. Our problem of seeking optimal recreational trail routing is similar, but differs in a sense that we are selecting the optimal set of sites to be visited, e.g. the number of sites for the salesman to visit is not fixed (the number of sites in final solution is unknown). In this study, site means forest parcels (sites). In order to solve our problem, we apply the same framework of TSP under a recursive approach to change the number of sites to be visited, as TSP can only be solved for the fixed number of sites (nodes). In such a case, by changing the number of sites, we are able to investigate how the optimal solution subject to traveling time, changes with a change in the number of sites to be visited. The main objective of this paper is to present an application of mathematical programming framework for developing touristic (recreational) routes in forest areas on the basis of maximum expected visual quality, given a specific travel time. We apply the proposed mathematical programming problem to our study area in Southern Portugal.

2. Materials and Methods

2.1. Problem specification for optimal routing and visits

In what follows, we elaborate our optimization problem within a mathematical programming framework. Let $x_i$ be the binary decision variable to specify if the $i$-th site is visited.

$$x_i = \begin{cases} 
1 & \text{if the } i\text{-th site is visited} \\
0 & \text{otherwise}
\end{cases}$$

Also, let $y_{ij}$ be the binary decision variable for the directed arc from the $i$-th to $j$-th site. If a visitor moves from the $i$-th to $j$-th site, it takes on a value of one, otherwise zero.

$$y_{ij} = \begin{cases} 
1 & \text{if move from the } i\text{-th to } j\text{-th site} \\
0 & \text{otherwise}
\end{cases}$$

Furthermore, let $u_i$ be the possible ordered number of the $i$-th site for a visitor. This general non-negative integer variable is necessary to eliminate subtours in the searching process. Given $c_i$ as the aesthetic value of visual quality for the $i$-th site, the objective of our problem is to maximize the accumulated sum of the aesthetic values by visiting sites through a visitor’s route.
Optimal Trail Routing for Recreational Management

\[ J = \max \sum_{i=1}^{m} c_i \cdot x_i \]

where \( m \) is the total number of sites in the target forested area. Constraints are as follows.

i). Requirement for the number of sites visited. Visitors have to visit the required number of sites.

\[ \sum_{i=1}^{m} x_i = n \]

where \( n \) is the given number of sites to be visited. Exactly \( n \) sites have to be visited.

ii). No round trip for one arc unless there is only one neighbor adjacency. The constraint ensures that there will be only one passing from one site to the neighboring one, moving back in the same direction is not allowed.

\[ y_{ij} + y_{ji} \leq 1, \quad \forall i, j (i \neq j) \]

iii). Inflow and outflow constraints for the gate (the \( i^* \) site). Visitors have to enter and exit from the gate site.

\[ \sum_{j=1}^{m} a_{i^* j} \cdot y_{i^* j} = 1, \quad \sum_{j=1}^{m} a_{j i^*} \cdot y_{j i^*} = 1 \]

where \( a_{ij} \) is the \( i \)-th row and \( j \)-th column element of the adjacency matrix among sites. This constraint allows (and ensures) that the selected site will be used as initial or starting site.

iv). Inflow and outflow constraints for every site, except the gate. Each site which is visited must also be exited (the arc for entering and arc for exiting of the site must be activated together).

\[ \sum_{j=1}^{m} a_{ij} \cdot y_{ij} = \sum_{j=1}^{m} a_{ji} \cdot y_{ji}, \quad \forall i (\neq i^*) \]

v). Subtour elimination constraints. We choose subtour elimination constraint formulations as described in Sherali and Driscoll (2002)

\[ u_i - u_j + (n - 1)y_{ij} + (n - 3)y_{ji} \leq (n - 2), \quad \forall i, j (i \neq j) \]

This is to avoid subtours or loop trips in the solution.

vi). Edge-arc constraints. Once a site is visited, then there should be inflow to the site.

\[ x_i \leq \sum_{j=1}^{m} a_{ji} \cdot y_{ji}, \quad \forall i (\neq j) \]
vii). Edge-ordered number constraints. Once a site is visited, then the order should be allocated for the visit (a supporting constraint for Eq.[6])

\[ x_i \leq u_i \leq n \quad \forall i \]

viii). Travel time constrains.

\[ \sum_{i=1}^{m} \sum_{j \leq i}^{m} b_{ij} \cdot y_{ij} \leq B \]

where \( b_{ij} \) is the travel time from the \( i \)-th to \( j \)-th site and \( B \) is the limited time for traveling. Note that we used a large value for \( B \) in order to seek the optimal set of visits without the time constraint. Given the above specification, we solved our problem using the optimization software called Gurobi 5.0 (Gurobi Optimization, www.gurobi.com)

2.2. Study area

The holm oak system is a traditional agro-silvo pastoral system in Southern Portugal dominated by tree species Quercus Ilex subsp. Rotundifolia Lam. The study area included areas covered by both pure and mixed holm oak forest stands. Holm oak is a drought tolerant medium-size tree, 20–25 m tall with finely square-fissured blackish bark and leathery evergreen leaves. The climate in the area is Mediterranean, with dry and hot summers, and rainy winters with moderate temperatures. The rainfall season starts from autumn till spring (Lionello, 2012). The soil has a maximum depth of around 1 m and a low water retention capacity, overlying granite bedrock. Holm oak forests are dominant on the Iberian Peninsula as well as within the Mediterranean basin as a whole. They are managed mainly for the production of acorns to feed livestock. Holm oak is mainly concentrated in the drier, eastern inland regions of Portugal as opposed to Cork oak (Quercus suber L.), which is concentrated more in the western part of the country, influenced by oceanic climate. Natural distribution of holm oak forests has been severely impacted by human transformation. Today, there is 20,000–30,000 km\(^2\) of holm oak forests on the Iberian Peninsula (Blanco et al., 1997). In the lowlands of southern Portugal and of Central Spain, a distinct kind of land management led to the transformation of dense natural forests into extensive “park-like” landscapes. These “park-like” areas called “montado” in Portugal and “dehesas” in Spain, are distinguished in terms of their systematic combination of agricultural, pastoral, and forestry uses. Today, most areas are abandoned for crop cultivation, but maintained by regular clearing shrubs. The main products of holm oak trees are fruits and acorn for animal feed and the fuel wood. The montado land use system with holm oak produces also livestock for meat.

Montado land use system is of large importance for conserving globally endangered species, which have been included in European Union directive 92/43 as natural habitat type of community-wide interest. That is designation for special areas of conservation. Moreover, it is important to maintain the regional identity for the preservation of natural resources including soil and water, the regional production of corn and livestock, and its suitability for different forms of leisure activities. The montado land use system produces a large landscape of ecological and cultural significance. According to the survey results, walking has been identified as the most popular recreational activity in the montado area (Surova and Pinto-Correia, 2009).

Tourism is one of the important economic activities in Portugal. The 2008 Report on Competitiveness of Travel and Tourism, ranked Portugal 15\(^{th}\) from a list of 130 countries in terms of tourism industry competitiveness. Inclusion of local natural and cultural resources as part of tourism management has a clear positive impact on the competitiveness of southern European destinations and thus contributes to their sustainability (Romao et al., 2013).

From the visual quality point of view, the holm oak montado area represents a mosaic of sites with different visual quality levels, as shown in our previous study (Surova et al., 2013). Identification of the visual quality of forest stands was based on theoretical aesthetic indicators and results from local studies were about landscape preferences and landscape changes. Derived visual indicators
were subsequently applied in the analyses of aerial photographs. The resulting mapping data in Figure 1 shows forest stands’ visual quality in Évora municipality in Southern Portugal. This was used as a base for testing our proposed approach. On the map, the value of visual quality attributed to each forest stand varies from 1 to 9. The value 1 is designated to areas with lowest visual quality, while the value of 9 on the other extreme represents the areas with highest visual quality.

3. Results

Two scenarios were considered in this study. The first scenario seeks an optimal solution by maximizing accumulated sum of the visual values for establishing an efficient recreational management plan for visitors, while the second scenario seeks an optimal solution with a minimization objective function to investigate which connected sites need to be improved to achieve a better visual quality for the area. The difference between the two scenarios is that one has a maximization objective function and the other has a minimization objective function. They both have the same constraints. The proposed mathematical programming formulation was applied to the montado area in Southern Portugal as follows.

Time needed for trail routing is associated with the speed of movement. It differs depending on transportation methods: walking, horse riding, bicycle, or terrain car. In our case study, we set the average speed of walking to be 5 km/hr. As an example, we defined total time constrained to be less than or equal to two hours for trail routing. The objective was assumed to maximize the accumulated sum of visual values.

Figure 2 shows changes in the objective function value and travel time for routing with respect to the number of polygons (sites) constrained. The travel time less than or equal to two hours, assured feasibility of the solution subject to other constraints. Given two hour limit, the number of polygons visited was changed from 4 by 1, resulting in infeasibility when the number of site was greater than or equal to 37. The decision may be taken by finding the maximum objective function value, or to accept any of the feasible solutions. The best solution for this problem is displayed in Figure 3. Points on the line represent the approximate centers of the site and their connection. Hence, the “real” route is considered to be walking over the entire site. We define the site’s length as square root of the area. It needs to be stressed that the resulted route option did not consider existing roads in the area, rather it uses the proposed routes that in future can be transformed into real routes or serve as a virtual guideline (using GPS coordinates) for forest visitors.

The objective of forest visit could also be to see the places with the “worst” visual aspect. These places can be of interest to researchers or landowners in order to further assess their different
Figure 2. Change in the value of objective function with respect to the number of polygons (sites) and corresponding travel time for the route.

Figure 3. Optimal route for 33 sites with the objective value of 225, the travel time of 2 hours. (Aesthetic value of sites: lightest one represents the highest aesthetic value; darkest one represents the lowest aesthetic value, empty circle indicates the gate).
functions and services. An example can be biodiversity issues. The optimization of visitors’ trip with this kind of objective allows visual overview of problematic areas, given a time constraint. This is especially relevant for land use types occupying vast areas with network of recreational trails, like our study area, the montado in Southern Portugal. The same optimization technique for positive route can be used for the negative route. The objective function was constructed using minimization formulation or inverting the values of individual sites. We used the inverted values for individual sites (the sites with values 9 became 1, those with 8 became 2 etc.). The results for different numbers of sites are displayed in Figure 4. Similarly to the case when positive objective is searched, a decision about trip allocation with greatest negative objective may be found by examining the objective curve on the graph showing optimization alternatives and selecting the point with maximum objective value. Figure 5 shows route for negative objective with 32 visited sites.

![Optimal Trail Routing for Recreational Management](image)

Figure 4. The objective function value with respect to the number of polygons (sites) and corresponding travel time for the route.

Different possibility for decision making process is to choose the route with maximum intensity of certain visual experience per unit time. In that case, the algorithm searches for route with specific aesthetic value (e.g. maximum or minimum visual quality) of adjacent forest stands independent of the travel time. In order words, the mathematical algorithm compares reasonable number of possible options, and the suitable location of route’s starting point, as defined previously. The algorithm compares all possible routes from defined point and chooses the best option under the given constraints. Figure 6 displays the intensity per hour for positive (left) and negative (right) route. Figure 7 displays the intensity per site for various numbers of sites for positive and negative route. Table 1 summarizes the objective function values and the corresponding number of sites and travel time (time spent on each route), for a given set of sites. For the positive objective function, the optimal solution is 225 with 33 corresponding sites and a travel time of 2.00 hours, and for the negative objective function, the optimal solution is 136 with 32 corresponding sites and a travel time of 2.00 hours.

In our demonstrative example, the starting point lies in the middle of the negative site, so the maximum intensity per hour for positive route will be achieved with longer routes when the visitor leaves the bad area. On the other hand, the intensity for negative route is highest for the short time routes. The best solution for positive case is the same as in Figure 1 and the best solution for negative case is shown on Figure 8.
Figure 5. Optimal route for 33 sites with the objective value of 136 and the travel time of 2 hours (Empty circle indicates the gate).

Figure 6. Intensity per hour for positive route (left), and for negative route (right).

Figure 7. Intensity per site for positive route (left), and for negative route (right).
Table 1. The values of objective function and the corresponding travel time spent on route for various numbers of sites.

| Positive objective | Negative objective |
|--------------------|--------------------|
| sites | objective | time | sites | objective | time |
| 4     | 16       | 0.42 | 4     | 26       | 0.29 |
| 5     | 25       | 0.44 | 5     | 31       | 0.31 |
| 6     | 31       | 0.60 | 6     | 40       | 0.38 |
| 7     | 40       | 0.67 | 7     | 49       | 0.43 |
| 8     | 49       | 0.77 | 8     | 50       | 0.52 |
| 9     | 58       | 0.82 | 9     | 51       | 0.52 |
| 10    | 67       | 0.94 | 10    | 51       | 0.54 |
| 11    | 73       | 1.00 | 11    | 55       | 0.82 |
| 12    | 82       | 1.13 | 12    | 60       | 0.90 |
| 13    | 91       | 1.20 | 13    | 64       | 1.00 |
| 14    | 97       | 1.25 | 14    | 66       | 1.06 |
| 15    | 106      | 1.31 | 15    | 71       | 1.05 |
| 16    | 115      | 1.44 | 16    | 76       | 0.95 |
| 17    | 121      | 1.47 | 17    | 81       | 1.24 |
| 18    | 130      | 1.59 | 18    | 85       | 1.32 |
| 19    | 136      | 1.62 | 19    | 89       | 1.37 |
| 20    | 145      | 1.75 | 20    | 94       | 1.37 |
| 21    | 151      | 1.80 | 21    | 98       | 1.45 |
| 22    | 159      | 1.86 | 22    | 102      | 1.51 |
| 23    | 166      | 1.91 | 23    | 106      | 1.60 |
| 24    | 174      | 2.00 | 24    | 110      | 1.62 |
| 25    | 180      | 2.00 | 25    | 114      | 1.64 |
| 26    | 186      | 2.00 | 26    | 118      | 1.76 |
| 27    | 193      | 1.95 | 27    | 122      | 1.77 |
| 28    | 199      | 1.97 | 28    | 126      | 1.83 |
| 29    | 205      | 1.99 | 29    | 130      | 1.91 |
| 30    | 211      | 2.00 | 30    | 134      | 1.99 |
| 31    | 216      | 1.99 | 31    | 135      | 1.99 |
| 32    | 221      | 1.97 | 32    | 136      | 2.00 |
| 33    | 225      | 2.00 | 33    | 135      | 1.98 |
| 34    | 224      | 1.99 | 34    | 132      | 1.99 |
| 35    | 216      | 2.00 | 35    | 131      | 1.98 |
| 36    | 209      | 1.99 | 36    | 128      | 1.99 |
| 37    | inf.     |     | 37    | inf.     |     |
4. Discussion

Traveling salesman problem is suitable for searching optimal routes across certain territory with sites representing different values of any characteristic. In this study we showed how the mathematical framework of TSP can be applied to solve a forest tourism and recreation optimization problem. This mathematical framework was applied for searching optimal recreational route in forested landscape with forest stands of diverse visual quality levels. Two main constraints were considered in the TSP framework application: the time for a trip (travel time) and the level of visual quality of visited stands.

The optimal decision for visited sites is useful to decide which sites should be included in a visit for the given constraints. It can be used to visit the places with the highest visual quality value in order to optimize positive visual impact of a visit to the forest landscape. On the other hand when the sum of sites is minimized, it can be used to visit the places with the worst visual quality value.

The list of applied constraints to the framework can be different and also shorter or longer than the one demonstrated in this paper. One of the additional constraints can be the relief accessibility. This constraint was not included in the study as the relief morphology of study area was nearly plain, and thus not so relevant in this case. The walking speed of the movement was set to 5 km/hr in this demonstrative example due to the popularity of this activity. However, it can be changed in the algorithm before running the optimization calculation according to mode of travel (e.g. running, biking, horse riding, four-wheeled motorcycle driving etc.) across the forest. One of the future research goals in this field can be a search for optimal solutions for specific recreational activity using social media to communicate findings to recreational managers, planners or to forest landscape users to plan trips that meet their own needs.

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