A GIS-dynamic segmentation approach to planning travel routes on forest trail networks in Central Taiwan

Chyi-Rong Chiou, Wei-Lun Tsai, Yu-Fai Leung

Abstract

Information about park infrastructure such as trail networks is not only useful for visitors to plan trips that meet their own needs, but it is also important for park and open space managers to monitor their assets and direct trail use patterns to achieve management objectives. This study aims at applying and evaluating dynamic segmentation and network analysis techniques in a GIS to gather elevation data on trail routes and generate travel time and energy consumption information. The method was applied to a network of 16 trails in a well-visited forest recreational area in central Taiwan Island. Results show that it is feasible and efficient to use GIS methods to integrate multiple data sets and derive advanced trail information. Optimal routes based on the least time cost and the most energy cost were identified. Combining indoor, GIS-based and outdoor field work of trail surveys is likely to produce information that is reliable and useful for visitors and managers to make travel and management decisions.

1. Introduction

1.1. Trail information

Forests and other natural areas contain rich natural resources that offer various environmental services to our society. As sustainable management of natural resources has become a significant concern, outdoor recreation is widely regarded as one of the more environmentally benign and socially appropriate uses of natural areas, potentially contributing to the long-term sustainability of these important resources (Fuhrer, 2000). In the past, many road systems in forested and natural areas were developed to provide access for resource extraction and transportation purposes, such as timber transportation, hunting, and tribal connections (Janowsky and Becker, 2003). However, renewable use and environmental services of natural area resources are now emphasized, resulting in much less road development. Meanwhile, more trail networks are being developed or converted from old road systems in forested and natural areas to provide access for nature-based tourism and recreation activities such as hiking, camping and wildlife viewing (Gray et al., 2003; Jeon et al., 1994).

Indeed, a trail system is the basic recreational infrastructure in any forest, park or protected area where visitors experience nature and improve their physical fitness. A well-planned park is expected to provide visitors with information about its trail system relevant to recreation experience and management objectives, including length, type of permitted use, type of surfacing, difficulty level, general ecology, and location of scenic spots and interesting resources. Such information helps visitors select optimal trail travel routes based on their motivation, benefits sought, and time availability (Huffman and Williams, 1985). As governments and health organizations in different countries, especially those in developed nations, are increasingly concerned about physical inactivity of their populations and associated chronic diseases and health care costs, they are collaborating with researchers in multiple disciplines in finding ways to promote physical activity (Forestry Commission Scotland, 2009; Parks Forum, 2008; Pretty, 2006; Sallis et al., 2006; USDHS, 2000). Forests, natural areas and parks are prime locations where many physical activities take place and therefore have an important role to play in addressing this societal concern (Bedimo-Rung et al., 2005). Providing trail information relevant to physical activity is a step toward this goal by promoting the physical health objective of trail use (Rosegard, 2004).

From the park and forest managers’ perspective, a formal trail network is an indispensable management tool for guiding visitors to particular areas of aesthetic or educational value while diverting them away from sensitive resources and safety hazards (Marion and Leung, 2004). Therefore, trail information is equally important for managers to provide visitor services and achieve management objectives (Li et al., 2005; Lynn and Brown, 2003), especially in parks and recreation areas with high visitation levels, such as those in East Asia.
Analysis of trail systems as linear features and attractions as point attributes is important in generating accurate and effective trail information for visitors and managers. Determining optimum routes is a common research topic in the transportation literature (Ahn and Rakha, 2008; Jahn et al., 2005). In order to manage traffic conditions and provide accurate information for drivers, many transportation studies have emphasized the use of commuting time and cost in finding the shortest road distance. While optimal routing is relatively less studied on pedestrian routes, techniques developed in the transportation literature may inform a similar endeavor for recreational trails.

Recognizing the potential of GIS in trail route planning and yet a paucity of documented applications in parks, this study aims at applying and evaluating a GIS-based methodology for determining optimal recreational trail routes using key information items based on estimates of time cost and energy consumption.

1.2. Overview of route analysis

Routes are defined as extended linear features, such as streets, roads, trails and rivers, whereas events are point features (e.g., trailhead signs) or short linear features (e.g., trail segments on a boardwalk) that are referenced based on distance to each other or to known points. Route analysis as applied in transportation research consists of two parts: dynamic segmentation and network analysis. Dynamic segmentation is an efficient method for gathering information along linear corridors (Wing and Johnson, 2001), while network analysis is a common way to find the shortest paths or closest facilities based on impedance. In this study we employ the dynamic segmentation method to gather physical attribute data of trail segments and utilize such data to derive information relevant to recreational opportunities and experiences. We also apply network analysis to find the optimal travel routes based on different travel scenarios.

1.2.1. Methods of gathering trail attribute information

Modeling linear data by dynamic segmentation has been shown to strengthen the use of data handling and manipulation (Chang, 2006; Choi and Jang, 2000; Guo and Kurt, 2004; Miller and Shaw, 2001). One main advantage is that a separate data file is created for each route, while different routes can be set on the same linear feature. Another advantage is that different events can reference the same linear measurement system stored with the route, enabling display, queries and analysis by linking events and routes in a dynamic manner. In transportation research, dynamic segmentation has been found useful in developing a transit network from the database that enabled modeling of transit solutions in response to demands (Choi and Jang, 2000; Davey et al., 1994; Guo and Kurt, 2004; Miller and Shaw, 2001). Conceivably, a travel path similar to a transit network can also be built on the same-trail network. Each travel path can have a start and an end point, and dynamic segmentation can provide relevant data for travel-demand modeling (Chang, 2006).

Linear events are the focus of this study as the primary visitor-related variables of interest are walking time and energy consumption. In this context, different events referencing the same trail routes and the line features can be displayed depending on different information required.

1.2.2. Methods of calculating trail travel costs

Certain trail properties are linked to travel costs, as trail visitors negotiate with the physical challenges posed by nature. These properties can be calculated from attributes such as trail length, time required to walk the trail, walking speed, and energy consumption.

Researchers have explored methods for quantifying trail travel costs. A specific area of interest is the effects of rough and uneven terrains on travel time and costs (Davey et al., 1994; Norman, 2004; Rees, 2004; Scarf, 2007; Scarf and Grehan, 2005). Time cost depends on walking speed, especially in mountainous areas where the terrain changed with uphill and downhill slopes. Estimating time of walking on hilly terrains has been largely based on the ‘Naismith’s Rule’ developed in the early 19th century as shown in Fig. 1.

Rees (2004) recently proposed a function to quantify the relationship between slope and walking speed in mountainous areas. He used a digital elevation model (DEM) to extract slope data which were then converted into walking speed using the function (Eqs. (1)–(3)). Specifically, he simplified the function by omitting the first-order parameter without losing accuracy, and the function became more convenient to use by ignoring whether the slopes in question involved ascent or descent.

Besides time costs, energy consumption is another topic in trail route planning research. Researchers (Minetti, 1995; Minetti et al., 2002; Ohtaki et al., 2005) have developed ways to quantify the energy cost of activities in mountainous areas and examine the influence of topography. Minetti et al. (2002), for example, investigated energy consumption of the slope ranging from –45% to +45% using equipment in a laboratory setting. A standard open-circuit method was used to quantify energy consumption by measuring O2 consumption and CO2 output, and a fifth-order function was established to calculate energy consumption for different values of slope. This function directly links slope data with energy consumption in different terrains, representing a close relationship between slope and energy consumption (R-square approaching 0.99).

In summary, as the past research reveals, useful time and energy cost information can be obtained from slope data to support travel route decisions on trails. The increasing availability of digital elevation models (DEMs) provides an opportunity to examine the extent to which DEM-derived slope data are useful in generating such information.

2. Methods

2.1. Study approach and flow

Time and energy costs are calculated by functions using slope data as the key parameter. These functions require the DEM-derived slope data be expressed as percentages. In travel route...
planning, trails can be regarded as several segments diverging from each junction. Different travel routes having the same starting point and terminal stop can be used to identify optimal route for different travel purposes. Optimal route selection is based on the concept of dynamic programming as implemented in ArcGIS’s network analysis functionality.

The optimal route was obtained through three main steps (Fig. 2). The slope data of each trail route were first obtained using publicly accessible DEMs. Slope data were then integrated with the travel cost functions based on previous research. The final step was to determine through network analysis the optimal route to best suit the purpose of proposed travel scenarios.

2.2. Study area and GIS layers

This study took place in a 22 km² zone within the Sitou Nature Education Area (SNEA) located in central Taiwan Island. SNEA is bordered by mountains (800–2000 m in altitudes) on the east, west and south, resulting in a concave-shaped terrain with a gap to the north. Because of its outstanding quality of natural resources, SNEA was designated in 1971 as a forest recreation area, the first of its kind in Taiwan. Its popularity as a nature-based tourism destination has sustained over the past decades, receiving no fewer than one million visitors every year according to visitor statistics of Taiwan Tourism Bureau. The trail network of SNEA extends approximately 30 km in total length connecting visitors to all major scenic spots and is composed of roads (mainly for car use) and trails (mainly for pedestrian use). The study zone included sixteen trails ranging from 182 m to 8145 m in length.

The profile of each trail was derived from trail feature data and a 5-m DEM which was produced by the Aerial Survey Office of Taiwanese Government’s Forest Bureau. Trail features were in shapefile format measured and digitized by National Taiwan University Experimental Forest. The trail profile and elevation data were employed to calculate slope along the trails using the surface function. The elevation data for every 1 m of horizontal distance were interpolated from the input DEM and the slope was calculated by two adjacent points (Fig. 3).

2.3. Time cost calculation

Time cost of walking on each trail in the study zone was derived from a quadratic function in which an algorithm calculates the cost of walking from one DEM cell to another. Walking speed $v$ was maintained on a surface slope $m$. The slope $m$ was defined as $dh/dx$ where $h$ was height and $x$ was the horizontal distance, $d$ was the walking distance, which was the distance actually walked or the

Fig. 3. The trail system of Sitou Nature Education Area (SNEA). Sixteen trails were included in the study zone (labeled A to P).
surface length (i.e., the hypotenuse of the triangle of which h is the height and x is the base), K was the time cost (Eq. (2)), and the coefficients for the function were determined by collecting data from ten separate walks with a total of 100 km in length (Rees, 2004). Time cost function (K) can also be regarded as the walking distance divided by the walking speed. The functions used in this study are specified below as Eq. (1) to Eq. (3).

\[ 1/v = a + bm + cm^2 \]  
\[ K = ad + c h^2/d. \]  
\[ 1/v = 0.75 + 14.6m^2; K = d/v. \] 

### 2.4. Energy cost calculation

The energy function developed by Minetti et al. (2002) was selected in this study due to its simplicity of use. Energy cost here is referred to the consumption of physical activity. Energy cost was calculated by a fifth-order function, and the function used the gradient \( i \) as a parameter. The gradient \( i \) represented slope defined as \( dh/dx \) where \( h \) was the height and \( x \) was the walking distance. The function describing the relationship between \( C_w \) (Unit: Joule Kilogram\(^{-1}\)-meter\(^{-1}\)) and gradient \( i \) at slope ranging from \(-45\% \) to \(+45\% \) was performed as

\[ C_w = 280.5i^2 - 58.7i^4 - 76.8i^3 + 51.9i^2 + 19.6i + 2.5(R^2 = 0.99) (4) \]

As the gradient of the energy cost function ranged from \(-45\% \) to \(+45\% \), extrapolation was used in this study to estimate the value excluded from the study range. The extrapolation postulated conservatively that the relationship between the gradient and energy cost that was below \(-45\% \) or over \(+45\% \) became a linear function, and the slope values of two linear functions were the same as the slope value of the range from \(-40\% \) to \(-45\% \) \( (S_{-0.40-0.45}, \text{ for the slope } \leq -45\%) \) and the range from \(+40\% \) to \(+45\% \) \( (S_{+0.40-0.45}, \text{ for the slope } > +45\%) \), respectively. The functions used for the value below \(-45\% \) and over \(+45\% \) were performed as \( C_w' \) and \( C_w'' \), respectively. The \( C_w' \) and \( C_w'' \) functions were described as

\[ C_w' = (i + 0.45) \times S_{-0.40-0.45} + C_w_{-0.45} \]  
\[ C_w'' = (i - 0.45) \times S_{+0.40-0.45} + C_w_{+0.45} \] 

where \( i \) was the gradient below \(-45\% \) or over \(+45\% \), \( S_{-0.40-0.45} \) is \(-2.018 \) (the slope between \(-40\% \) and \(-45\% \)), \( S_{+0.40-0.45} \) was \(0.038 \) (the slope between \(+40\% \) and \(+45\% \)), \( C_w_{-0.45} \) was \(3.605 \) (the energy cost at the gradient \(-45\% \)), and \( C_w_{+0.45} \) was \(17.600 \) (the energy cost at the gradient \(+45\% \)).

Since the unit of the energy cost (Joule-Kilogram\(^{-1}\)-meter\(^{-1}\)) is not easy to interpret, this study presents the total energy expenditure in kJ per track for a walker weighting 60 kg.

#### 2.5. The optimal planning routes

Important travel information and optimal trail travel routes were obtained after the topographic profile of each trail had been derived from slope data structured using dynamic segmentation. Travel routes with the same starting point and the same terminal stop were chosen to compare travel restrictions such as time and energy cost in association with travel purposes. In this research, links refer to the trails, and sixteen trails diverge at each junction to 116 links. Link impedance is a restriction in travel planning, and time cost and energy cost are the restrictions in this study. In terms of link impedance in this study, energy cost is directional. Thus, the measure of energy cost in the network was calculated based on a specific travel direction, and the cost of each segment was assigned to the value for that direction. As for time cost, both directions of each route had the same value because the first-order parameter of time cost function was omitted as suggested by Rees (2004). Two scenarios, the least time cost and the highest energy cost, were chosen to illustrate the optimal routing method. Information about the highest energy cost is useful for trail users who are engaged in physical exercise and for recreation areas where physical activity is promoted. However, there are other scenarios in which other users may find trail routes with medium or low energy cost to be optimal.

### 3. Results

#### 3.1. Slope data

Elevation data of every 1 m of horizontal distance were obtained. The difference between two adjacent points determined the slope, and the slope value was classified into one of the eight categories based on the slope classification scheme by Taiwan’s Council of Agriculture (Table 1). The terrain that has a slope value less than 5% is regarded as flat (Level 1), and a slope value more than 30% is regarded as hill (Level 6). Most trail slopes in the study area fall
Table 1
Slope range of each category. Slope value is reclassified into 8 categories, and the higher level refers to as steeper terrain. Generally slope value less than 5% is regarded as flat, and the value more than 30% is regarded as hill. Thus, the category level between 2 and 5 is referred to gentle terrain (Council of Agriculture in Taiwan URL: http://eng.coa.gov.tw).

<table>
<thead>
<tr>
<th>Slope range</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5%</td>
<td>1</td>
</tr>
<tr>
<td>5–10%</td>
<td>2</td>
</tr>
<tr>
<td>10–15%</td>
<td>3</td>
</tr>
<tr>
<td>15–20%</td>
<td>4</td>
</tr>
<tr>
<td>20–30%</td>
<td>5</td>
</tr>
<tr>
<td>30–40%</td>
<td>6</td>
</tr>
<tr>
<td>40–50%</td>
<td>7</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>8</td>
</tr>
</tbody>
</table>

between level 4 and level 5, meaning that the terrain was gently sloped. Some trails located on the hillside exhibit higher slope levels that are often associated with a more complex terrain. The trails were draped on a three-dimensional terrain model (Fig. 4) to better visualize that steeper trails are located on the mountain hills on the east, west and south sides of SNEA. In contrast, trails in the central part of the SNEA are flatter.

3.2. Time cost

Slope data were used to calculate the time cost and surface length of each trail based on DEMs. The results illustrate that whereas time cost is proportional to trail length when slope is constant, it is nonlinearly dependent on slope (based on Eq. (3)) (Table 2). For instance, Trail G (1387 m) and Trail J (1334 m) have a similar length, but the time cost of Trail J (88.2 min) is almost three times higher than that of Trail G (30.3 min). This variation reflects the difference in the slope values of these trails (31.9% for Trail J; 16.3% for Trail G). This example also illustrates the non-linear nature of the slope-time cost relationship—that time cost escalates more rapidly as the slope increases incrementally.

3.3. Energy cost

In terms of two different walking directions, the ascent/descendent segment becomes the reverse when walking in the opposite direction. In this study, we defined walking direction 1 by comparing the elevation of two nodes, and it is walking from the node that has a lower elevation to the other node of the same trail with a higher elevation. Walking direction 2 is the inverse direction of walking direction 1. The energy cost of each trail is shown in Table 2. As expected, the results show that walking with direction 1 (i.e., toward higher elevations) incurs more energy cost than walking with direction 2 (toward lower elevations). The difference is as little as 36 kJ per 60 kg on Trail M to 1467 kJ per 60 kg on Trail N (Table 2).

3.4. The optimal travel route

As shown in Fig. 5, stop 1 is the start node (top end of the route) and stop 2 is the end node (bottom end of the route) of our route selection scenario. The optimal routes based on the least time cost and the highest energy cost were identified in GIS, respectively (Fig. 5(a) and (b)). Key attributes of these selected routes are shown in Table 3. The difference between the two optimal routes is that the trail segments chosen for the purpose of least time cost are much flatter than the trail segments chosen for the purpose of highest energy consumption. A comparison between these two travel routes reveals that the average slope of the highest energy consumption route (24.8%) is much greater than that of the least time cost route (14.2%).

4. Discussion and implications

Travel planning encompasses a range of considerations and it is an important part of recreation experience, providing sufficient information to visitors is an essential task for park and open space managers. In this study, we utilized easily accessible spatial data such as DEM and the trail system and applied dynamic segmentation and network analysis techniques to generate visitor-relevant information in a GIS environment.

4.1. GIS analysis

Dynamic segmentation is a common technique used in GIS analysis in the transportation field but is still under-utilized in recreation and park applications. In this study, we identified the distribution of slope by dynamic segmentation and found that it is an effective way to gather and store data. For expanded applications in the future, more information such as landform type, facilities, scenic spots, safety hazards and resource condition can be linked to the trail data, facilitating decision-making by visitors as well as managers. For example, if each facility is coded and linked to a trail

Table 2
Travel information of each trail.

<table>
<thead>
<tr>
<th>Trail</th>
<th>Surface length (m)</th>
<th>Average of slope (%)</th>
<th>Average of walking speed (km/h)</th>
<th>Time cost* (min)</th>
<th>Energy cost** of direction 1 (kJ per 60 kg)</th>
<th>Energy cost** of direction 2 (kJ per 60 kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1403</td>
<td>19.1</td>
<td>3.2</td>
<td>117.2</td>
<td>698</td>
<td>311</td>
</tr>
<tr>
<td>B</td>
<td>752</td>
<td>13.4</td>
<td>3.7</td>
<td>27.8</td>
<td>248</td>
<td>126</td>
</tr>
<tr>
<td>C</td>
<td>925</td>
<td>18.5</td>
<td>3.1</td>
<td>23.6</td>
<td>316</td>
<td>194</td>
</tr>
<tr>
<td>D</td>
<td>461</td>
<td>16.4</td>
<td>3.3</td>
<td>10.6</td>
<td>188</td>
<td>41</td>
</tr>
<tr>
<td>E</td>
<td>3271</td>
<td>23.9</td>
<td>2.8</td>
<td>123.3</td>
<td>1550</td>
<td>805</td>
</tr>
<tr>
<td>F</td>
<td>340</td>
<td>37.0</td>
<td>2.0</td>
<td>24.2</td>
<td>288</td>
<td>104</td>
</tr>
<tr>
<td>G</td>
<td>1387</td>
<td>16.3</td>
<td>3.3</td>
<td>30.3</td>
<td>557</td>
<td>116</td>
</tr>
<tr>
<td>H</td>
<td>1459</td>
<td>15.3</td>
<td>3.3</td>
<td>30.5</td>
<td>543</td>
<td>131</td>
</tr>
<tr>
<td>I</td>
<td>576</td>
<td>17.5</td>
<td>3.4</td>
<td>17.2</td>
<td>218</td>
<td>121</td>
</tr>
<tr>
<td>J</td>
<td>1334</td>
<td>31.9</td>
<td>2.2</td>
<td>88.2</td>
<td>904</td>
<td>416</td>
</tr>
<tr>
<td>K</td>
<td>864</td>
<td>46.9</td>
<td>1.3</td>
<td>68.2</td>
<td>1006</td>
<td>187</td>
</tr>
<tr>
<td>L</td>
<td>370</td>
<td>18.7</td>
<td>3.0</td>
<td>9.6</td>
<td>124</td>
<td>84</td>
</tr>
<tr>
<td>M</td>
<td>182</td>
<td>11.6</td>
<td>3.8</td>
<td>3.3</td>
<td>55</td>
<td>19</td>
</tr>
<tr>
<td>N</td>
<td>8145</td>
<td>12.7</td>
<td>3.7</td>
<td>153.0</td>
<td>2395</td>
<td>928</td>
</tr>
<tr>
<td>O</td>
<td>1832</td>
<td>11.9</td>
<td>3.7</td>
<td>48.0</td>
<td>264</td>
<td>55</td>
</tr>
<tr>
<td>P</td>
<td>5542</td>
<td>18.0</td>
<td>3.2</td>
<td>150.3</td>
<td>2095</td>
<td>998</td>
</tr>
</tbody>
</table>

* Time cost is derived from Eqs. (1)–(3), which were developed by Rees (2004).
** Energy cost is derived from Eq. (4), which was developed by Minetti et al. (2002).
GIS using dynamic segmentation, visitors could report their facility code to manager immediately following an accident, and manager would be able to pinpoint the facility and plan rescue operations promptly. This approach can sometimes be more reliable and efficient than reporting GPS coordinates from visitors' GPS units or GPS-capable mobile phones. Network analysis is found to be helpful for users (visitors or managers) to select the optimal routes easily through the mathematical calculation of dynamic programming (Boulaxis and Papadopoulos, 2002; Monteiro et al., 2005). The combined use of dynamic segmentation and network analysis in GIS, as applied in this study, is an effective way to utilize park and trail data in facilitating recreation choices and management efficiency. This approach saves researchers or managers substantial amount of time and labor as compared to collecting slope and travel costs data in the field.

4.2. Time cost

Time cost is a function of walking speed, which is strongly dependent on slope. Walking distance is often considered as the main factor of time cost, but it is not absolute, especially in a mountainous area (Minetti et al., 2002). For instance, Trail F is 340 m in length and Trail L is 370 m in length, but the time cost of Trail F (24.2 min) is much greater than Trail L (9.6 min). The method used in this study to derive walking speed and time cost from DEM-based slope values was adopted from the past research (Rees, 2004). However, this study utilized a 5 m × 5 m DEM, which is at much higher resolution than those used in previous studies, such as the 50 m × 50 m DEM used by Rees (2004). Thus, time and energy costs of each trail calculated in this study should have a higher degree of accuracy, resulting in better-quality information conveyed to visitors and managers.

4.3. Energy cost

According to Minetti et al. (2002), the energy cost at the slope value of +20% is about seven-fold more than at the slope value of −20%. Each segment has two energy cost values, and in general, the direction that has more uphill components has a higher energy cost. Since the investigating range of the energy cost in Minetti et al. (2002)'s study was from −45% to +45%, extrapolation was needed for this study area with wider range of trail slopes. In order to obtain more precise values of energy cost, empirical testing can be used to determine the energy cost at the outer range as illustrated in this study. Similar approach can be applied in future research.

4.4. The optimal travel route

The optimal routes were selected using the concept of dynamic segmentation that assigns useful information to trail segment via network analysis function in the ArcGIS software package. The optimal route was calculated by analyzing the lowest cost of the route, and the cost depends on the different purposes we set. Because the process of selecting optimal routes is about finding the least amount of value, the reciprocal value of energy cost is used to select the highest cost travel route. The routes selected for least time cost and highest energy cost in this study demonstrate that one route cannot suit all purposes. The route chosen for the highest energy cost takes triple amount of walking distance than the route with the least time cost, but it takes 6.5 times longer to walk than the route with the least time cost. Furthermore, the route with the highest energy cost takes 5 times more energy than the route with the least energy cost. The equation of energy cost in this study also considered the difference of uphill and downhill. These results point out that neither time cost nor energy cost increases at an equal rate to walking distance (Minetti et al., 2002; Rees, 2004). Whereas walking time and energy cost are proportional to walking distance in a flat area, the results illustrate that track slope has a significant influence on both variables in mountainous zones. This study demonstrates the significant influence of slope on walking in a mountainous area.

4.5. Limitations and research implications

While this study demonstrates the utility of a GIS-dynamic segmentation approach to selecting optimal travel routes, there are

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Basic information for optimal routes for the least time cost and the maximum energy cost.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking distance</td>
<td>1586 (m)</td>
</tr>
<tr>
<td>Average of slope</td>
<td>14.2 (%)</td>
</tr>
<tr>
<td>Time cost</td>
<td>33 (min)</td>
</tr>
<tr>
<td>Energy cost</td>
<td>400 (kJ per 60 kg)</td>
</tr>
</tbody>
</table>
several limitations in our study that require attention if the utility of this approach is to be further expanded.

The first limitation is related to the use of DEMs, which have become an important data source for extracting terrain attributes and generating time and energy cost information. However, DEMs alone do not contain some trail design attributes that may influence walking behavior. For instance, trails may be built as simple linear routes, steps and/or staircases based on local terrains. Visitors may have different speed, strides or body movement when walking on different trail designs. Similarly, some trails are unsurpassed (underlain by soil) while others are surfaced with different materials. When walking on slippery surfaces, for example, visitors may slow down to seek safer footing, resulting in higher time and associated energy costs. In SNEA, some trails are surfaced with asphalt, cement, wood chips, cobble and granite slabs. Visitors may walk easily on the trails surfaced with asphalt, but walk slowly and carefully on those trails surfaced with cobble. Similarly, trails with different resource conditions (e.g., presence of ruts, mud or exposed tree roots) may have influenced walking behavior. Some SNEA trails could be slippery as they are easily splashed by the nearby river.

In order to develop more realistic applications and more accurate cost estimates, current knowledge about how surface conditions influence walking behavior should be assessed for its integration into the time cost and energy cost models. To this end field work may still be necessary to collect trail attribute data such as the ones mentioned above. Appropriate correction factor is then needed for most common trail surfacing materials, conditions, and forms. For example, using asphalt as the standard, gravel could be assigned by 1.2 as it is a more rugged surface. Indeed, some technology already exists that may help researchers in identifying suitable correcting factors for different trail characteristics. For example, the vibration of three-axis (i.e., x, y and z) on body movement will change differently when people walk. The up and down vibration of body movement has higher value when walking on stairs than line-routes. These changes of movement can be measured by a tri-axial accelerometer (e.g., RT3, Stayhealthy Inc.). Thus, combining indoor and outdoor work of trail survey can likely provide more accurate visitor-related information.

The second limitation is related to the optimal route selection. In this study, only one purpose could be considered at a time as the condition for travel planning using ArcGIS, but real-life visitors may consider multiple purposes in trip planning. Although dynamic programming can find the best solution for multiple purposes, network analysis in ArcGIS software can currently address and solve only one factor simultaneously. Solving multiple purposes in ArcGIS software is possible only by giving weighted value to each factor, but there are difficulties in determining a weight value for each factor. A good way to decide the weight values is based on user input, which was unavailable in this study. A recreational Web site, for example, could be developed that is linked to a complete park and trail database. A potential visitor could specify the relative importance of his/her individual purpose(s) and constraints of a hiking event. Examples of purposes include physical exercise, learning about Nature (geology, wildlife, trees, etc.) and sightseeing at natural attractions (waterfalls, panoramic views, etc.), whereas constraints may include time, length, elevation change and handi-cap accessible trail surfaces. The system could then assign weight values to the models based on the visitor’s input, resulting in an output of the optimal route displayed on the Web site that meets the individual’s needs. A fruitful avenue for future research is therefore to develop more intelligent and interactive travel planning systems that account for a combination of purposes and determine multipurpose routes, probably supported by powerful computing and well-designed Web interfaces.

5. Conclusion

In the past, trail length, type of use and surfacing materials are the most common pieces of trail information communicated to park and open space visitors. In this study, additional time and energy cost information can be generated to benefit both visitors and managers. For example, managers can better define difficulty of each trail based on energy cost instead of merely trail length. The energy cost is based on both trail length and slope and therefore more accurately represents the actual degree of physical challenge for walkers. In this paper we were able to illustrate two scenarios in which walkers were interested in the least time and highest energy cost of the hike, but this methodological approach can conceivably be extended to other trip purposes, some of which are described in the preceding section. The time and energy cost information portrayed in this study, or other information meaningful to visitors and consistent with management objectives, would help visitors plan their trips based on their motivation and constraints, likely resulting in recreation experiences of higher quality.

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References


