A Connection of Optimum Logistic and Energy Consumption in Hiking

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Abstrak

Dalam karya ini, kami bertujuan untuk memberikan hubungan antara konsumsi energi selama pendakian dan hubungannya dengan persiapan logistik yang optimal dalam wisata berbasis pendakian gunung. Konsumsi energi tersebut dihitung berdasarkan data dari profil jalur pendakian dan detak jantung orang yang mengikuti jalur tersebut. Ini kemudian digunakan sebagai masukan untuk memecahkan masalah optimasi dalam hal persiapan logistik. Di sini, kami mendemonstrasikan hubungan tersebut berdasarkan kondisi aktual jalur pendakian di Gunung Sindoro, Jawa Tengah, Indonesia.

Keywords: *jalur pendakian; konsumsi energi; detak jantung; optimalisasi logistik; Gunung Sindoro*

Abstract

In this work, we aim to provide a connection between energy consumption during hiking and its relation to optimum logistic preparations in mountaineering-based tourism. Such energy consumption is calculated based on data from hiking track profiles and heart rate of persons taking the track. It is then used as input to solve optimization problems in term of the logistic preparations. Here, we demonstrate such connection based on the actual condition of hiking track in the Mount of Sindoro, Central Java, Indonesia.

Keywords: *hiking track; energy consumption; heart rate; logistic optimization; Mount Sindoro*

1. Introduction

The impacts of online information systems in mountaineering activities are considerably high in particular by providing tourists with frequent updated tracking conditions and online booking systems. In the major mountaineering destinations, one can find extensive studies on such impacts in many previous works such as in [1]-[3]. On the other hand, in major mountaineering destinations in Indonesia, there have been also vast implementation of the online information systems [4]-[6]. Unfortunately, none of such information systems have provided tourists with recommendations on necessary logistic preparation based on preferable hiking tracks.

Mountaineering activities are normally more risky than ordinary outdoor activities, e.g. walking and jogging, due to several factors such as uncertain weather conditions and steep walking tracks. Hence, demand on more energy consumed is essential and needs appropriate preparation on logistics to maintain fitness and focus. In general, more logistics prepared are good but they will give additional weights and consume more energy to transport during hiking. Recently, calculation of energy expenditure (EE) and logistic demand in mountaineering tourism have been available, for instance, in [7]-[13]. Unfortunately, none of them have not used optimization procedures based on actual hiking track profiles and heart rate.

As a contribution, we aim in this work to develop such optimization procedure to build a possible connection between energy expenditure and required logistics. We present the connection with a demonstration by using the Kledung based hiking track in the Mount of Sindoro, Central Java, Indonesia. We choose the hiking track because it is considered as popular destination for mountaineering due to its strategic position, i.e. surrounded by several mountains such as Sumbing, Merbabu, and Merapi. Its position offers very attractive panoramic view in particular during sunrise and sunset as described for instance in [14]. Although information on hiking tracks to the summit of Mount Sindoro has been available such given by [15] and [16], none of them has provided information related to proper logistic preparation in connection with energy expenditure for their corresponding hiking tracks.

All data used in this work were taken from actual conditions on the corresponding track mentioned before. We started by simultaneously measuring coordinate and elevation for the Mount Sindoro hiking track by using global position system (GPS) receiver. The track is located from the Kledung Village, Temanggung Regency, Central Java, Indonesia. The global coordinate in X and Y as well as elevation of the track given by the GPS measurements were used to compute total distances accomplished and gradient of the track for EE calculations. With additional data related to time required to travel between two corresponding GPS measurement points, we can compute the EE by with the help of empirical formulation given, for instance, by [17]. Moreover, we also measured heart rate from the persons who were involved during the GPS measurements. In this case, we aim to obtain EE by using the empirical equations proposed by [18] and [19].

With the values of EE in hand, we can compute energy consumption E_c required to travel at specific distance on the track which will be used to determine proper logistic to take the track up-down. For an example, we use available foods in local market around the track to create logistic preparation sets to fulfil the required E_c. An optimization procedure is conducted to find the optimum number of logistic items in each set by considering E_c in the objective function.

We present our works here into four sections including this part. The next section presents with coordinate, elevation, and heart rate measurement results on hiking track of the Mount Sindoro. Determination of optimum number of logistic items to fit the required E_c for taking the track is done in the third section and discussed as well. Finally, we summarize our work in the last section.

2. Method

2.1. Coordinate, Elevation and Heart Rate Measurements

In this part, we present our activities to measure coordinate, elevation, and heart rate in the Mount Sindoro hiking track that start from its base camp in Kledung, Temanggung, Indonesia up to the elevation of approximately 2000 m above sea level as shown in Figure 1. We digitalize the track in that figure with the help of OpenStreetMap (OSM) [20], i.e. a free wiki word map. We did not go for further elevation due to weather condition where the measurements would be very difficult and quite dangerous. Moreover, the precise global location of the base camp is given in the decimal number as ($X = -7.339$, $Y = 110.032$). There were 5 persons involved where they were split into the following tasks. While two persons were responsible each for recording all measured data and performing the GPS measurements, two other persons were the objects for the heart rate measurements as shown in Figure 2a. Here, the equipments used were a GPS receiver, a stopwatch, and a pulse meter as given in Figure 2b.

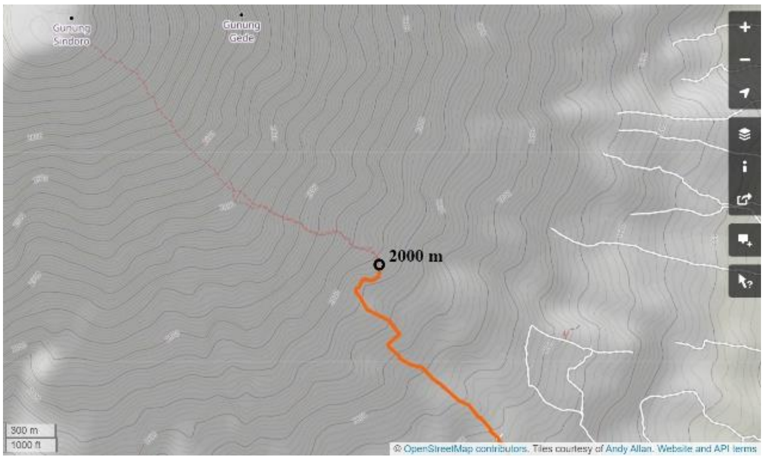


Figure 1. Path of the track up to the elevation approximately 2000 meter above sea level (see in [21] for detail).

(a)

(b)

Figure 2. Measurement activities (a) and equipments used (b) consisting of a stopwatch, a pulse meter, and a GPS receiver, respectively, from left to right.

All the measurements were done as follows. The hiking track coordinate and elevation were measured manually by using the GPS receiver step-by-step along the track with the base camp coordinate as the reference point. All data from the measurements are presented in Figure 3 where the basecamp is located at point 0. The variables h (m) and S (m) denote the total vertical distance travelled. It is important to note that according the contour map shown in Figure 1 our measurements on the elevation is very close to the contour line on the map up to the elevation of 2000 m above sea level.

Meanwhile, the measurements of heart rate v_h in beats per minute (bpm) were performed simultaneously with the GPS measurements to facilitate comparison of EE given later. Thus, we required to guarantee that the location of GPS measurements coincided with time and heart rate measurements. We used two persons with different ages, i.e. 33 and 51 years old, as subjects of the heart rate measurements. Their body weights were 64 kg and 70 kg.

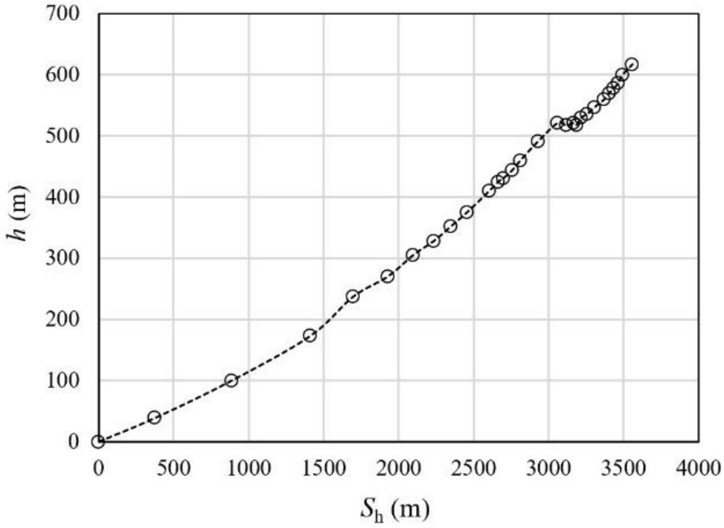


Figure 3. Elevation of the Sindoro hiking track from our GPS measurement points (o).

for the younger and the older one, respectively. We measured heart rate after the subjects stopped from walking and took a rest for 1-2 minutes. We did that because, in trial tests, direct measurements of heart rate suddenly after the subject stopped yields unstable measurement results. We present the heart rate measurement results in Figure 4 where, surprisingly, the average lines of the data from both ages coincide each other.

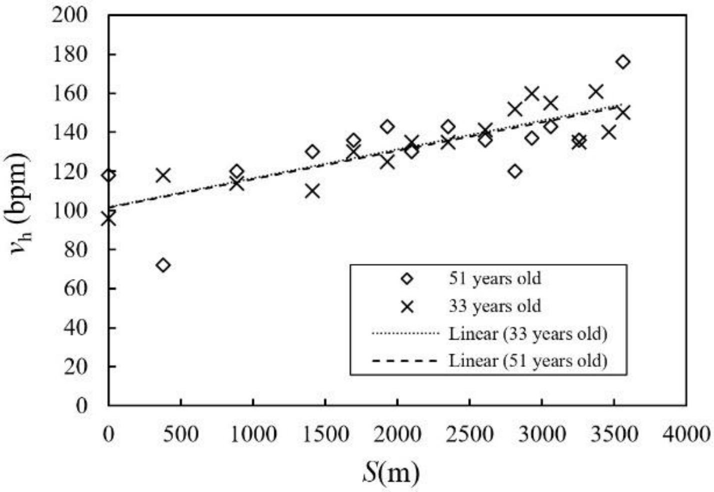


Figure 4. Heart rate measurement results.

Furthermore, we choose the EE models not only as a function of hiking track profile but also hear rate. First, according to [17], the EE model based mainly on hiking track profile can be obtained by using the empirical formula (in Watt.gram^{-1}) as

$$EE_{\mathrm{T}} = 1.44 + 1.94S^{0.43} + 0.24S^{4} + 0.34\,S\,G\left(1 - 1.05^{1-1.1^{G+32}}\right) \tag{1}$$

where S and G are the speed (in m.s^{-1}) and the surface grade (in %), respectively. On the other hand, we can also compute EE directly from the heat rate v_h by using the formulation proposed by [18] as

$$\begin{aligned} EE_{\mathrm{W}} = {} & g_W\left(-55.0969 + 0.6309v_h + 0.1988W_p + 0.2017A_g\right) \\ & + (1-g)\left(-20.4022 + 0.4472v_h - 0.1263W + 0.74A_g\right) \end{aligned} \tag{2}$$

given (in kJ.min^{-1}) with g_W, W_p, and A_g denoting gender (1 for men, 0 for women), the person weight (in kg), and the person age in years, respectively. Finally, based also from heart rate measurement, Soleman in [19] has proposed a simple EE model measured (in kcal.min^{-1}) namely

$$EE_{\mathrm{A}} = 1.8 - 0.022v_h + 0.000471v_h^2 \tag{3}$$

To convert the values of EE from each equations to E_c in kilocalorie (kcal), we depend on particular unit conversions of each formulation given in Equations 1 to 3.

All models presented above have their own advantages and drawbacks. In Equation 1, one can distinguish energy released by our body in different track gradients or slopes. Moreover, Equation 1 can be used to predict EE once hiking track profiles have been identified. However, it cannot represent track conditions and difficulties, e.g. wet or dry, which can only be captured well by using Equations 2 and 3. Instead, slippery-wet tracks may produce more v_h than its corresponding dry conditions. Additionally, it is also difficult in practice to measure wavy track trajectories using GPS because, in mountainous area, that will need a huge number of measurement points. Based on such drawbacks, the measurement of v_h to obtain EE will be more convenient since one needs only to record the response of human heart with respect to hiking tracks regardless the track conditions and geometries. Unfortunately, by using the EE model based on heart rate, one needs to consider heart rate dependencies not only with respect to age or weight but also other factors such as gender, ambient temperature, and emotional condition. To capture well such dependencies, one needs to use statistically acceptable number of measurement subjects.

2.2. Logistic sets

To design logistic preparation for the obtained E_c, we conduct online surveys to identify logistic items, i.e. drinking and foods, which are often used for hiking and are available in stores and markets relatively close to the basecamp. The logistic items will be considered here are not in a generic form because they can vary depending on local weather and social-cultural aspects.

Figure 5. Examples of logistic sets A (a) and B (b) with item numbering based on existing food and drinks on markets around to the basecamp.

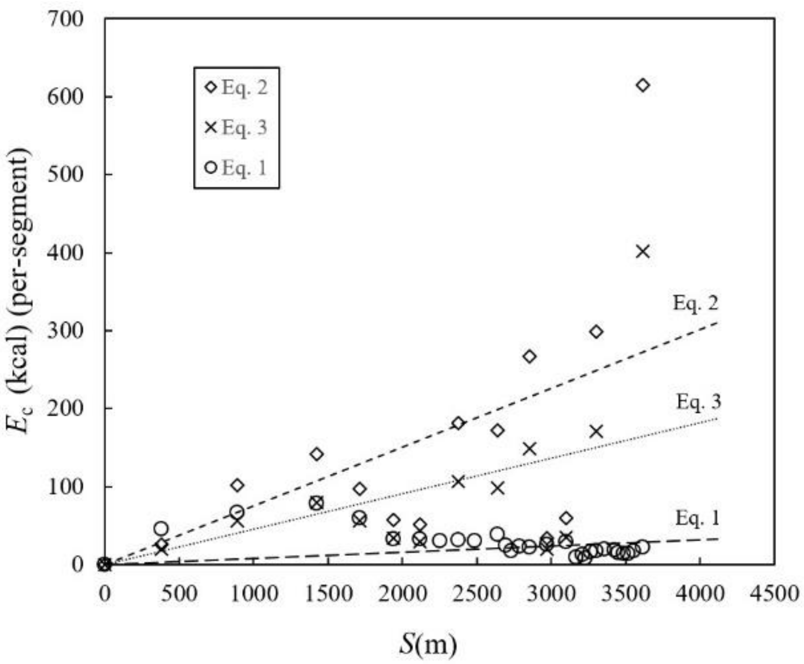
From the identified items, we construct two demonstrator sets as shown in Figures 5 from the items which consist each with food and drinking water with each energy content $E_{s,i}$ as presented in Table 1. In this case, we do not consider freedom choice yet, which needs advanced optimization algorithms, to focus more on the connection of logistic and E_c. We assume that the calorific values shown in Table 1 are given as the basis data from the complete sets of food-drink combinations.

Now, we consider a logistic optimization problem based on a simple target namely to compensate E_c required during hiking. In this case, we perform a simple optimization procedure to find a minimum value of $r(x_i, E_{s,i}, E_c(x_i))$ due to contribution of each number of logistic items x_i, simultaneously constrained by their total weights and volumes. The procedure can be expressed mathematically as

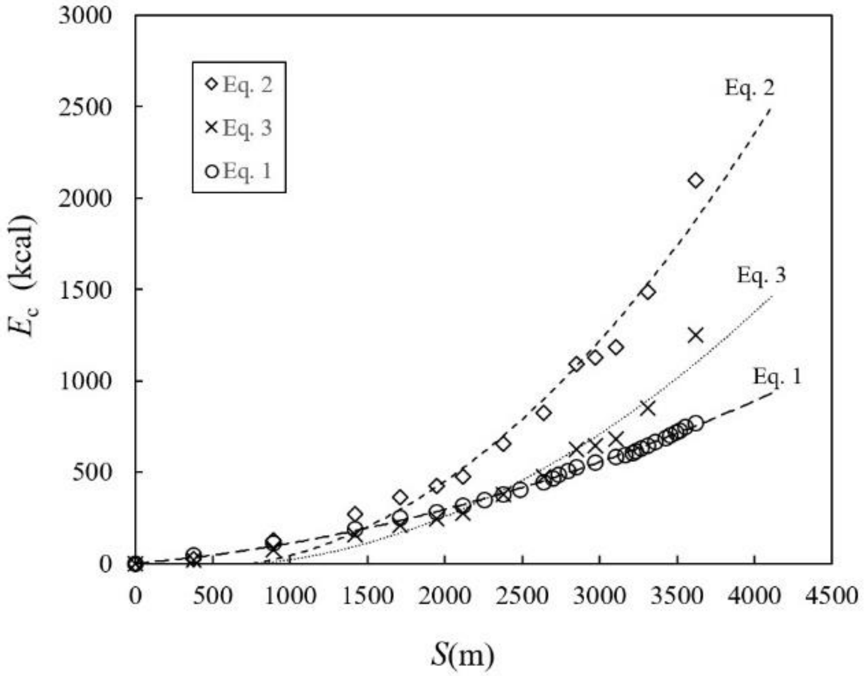
$$\begin{aligned} &\min\ r = \min\left[\sum_{i=1}^{4} E_{s,i} x_i - E_c(x_i)\right] \\ &\qquad x_i \le x_{i,\max} \\ &\qquad x_i \ge x_{i,\min} \end{aligned} \tag{4}$$

with $x_{i,\max}$ and $x_{i,\min}$ representing the maximum and minimum number of items, respectively, according to demand. Moreover, by defining the function $E_c(x_i)$, the total weight corresponding to $x_i m_i$ during the optimization process is coupled with Equations 1 to (3). The objective function $r(x_i, E_{s,i}, E_c(x_i))$ is set to be minimum since it compute the differences between energy required by a specific hiking track and produced by the logistic items. The constraints in Equation 4 shall be defined in case a logistic item more important than others.

The optimization procedure given in Equation 4 is dedicated to our simple one-day hiking activities described before. For more complex situations, e.g. overnight or multiple days hiking, additional data must be defined where it will be done for our next research objective.



(a)



(b)

Figure 6. Energy consumption E_c for the older person computed from Equations 1 to 3 presented in per-segment (a) and cumulative amounts (b) with their corresponding trendlines.

Table 1. Energy supplied $E_{s,i}$ (kcal), weight m_i (gram), and volume V_i (litre) for each logistic item in the particular set given in Figure 5. While each $E_{s,i}$ and m_i depicted here are obtained from [22], each of the volume V_i is measured.

	set A			set B		
item (i)	$E_{s,i}$	m_i	V_i	$E_{s,i}$	m_i	V_i
1	110	20	0.1	170	30	0.2
2	370	107	1.5	140	500	0.5
3	0.01	600	0.6	220	60	1.0
4	150	25	0.75	110	20	0.75

3. Results and Discussion

We calculate first the energy consumption E_c in Figure 6 based on the data from Figures 3 and 4. There are 3 results in the figure from different formulations given by Equations (1) to (3). We present the calculation of E_c per-segment, and in cumulative amounts. While the calculations of E_c based on each segment, i.e. the location for either the GPS or the heart rate measurements in Figure 6a do not show quite clear behaviors shown by the unfitted linear trendlines, the results in Figure 6b give more predictable results as given by the good fit with non-linear trendlines.

Based on the results of E_c, one can observe clearly that there are significant gaps among the results of Equation (1) to (3). We propose explanations for those based on our experiences during all the measurements as follows. First, the gap between the results based the hiking track as represented by Equations (1) and based on the heart rate (in Equations (2) and (3)) may strongly be produced by actual conditions of the track. In fact, muddy tracks as found during our measurements have produced different heart rate than dry ground tracks for the same elevation and distance. Second, the gap between Equations (2) and (3) is produced due to different climate and persons as given in detail in their corresponding works from [18] and [19]. Instead of performing averaging or choosing only one model in Figure 6b, we decide here to use the lower bound, i.e. Equations (1), and the upper bound, i.e. Equations (2), to optimize the number of logistic items.

We use the Solver tool in the MS-Excel [23] where its evolutionary algorithm is applied to solve the optimization problem in Equation 4. All results are obtained by using the initial number of item x_i equal to 1. Since the targeted variables in each logistic set in Figure 5 has only 4 variables, the solver can produce results only after a couple of minutes.

From the results presented in Table 2 and Table 3, we have simulated if a tourist prefers to bring more logistic items than the others in one logistic set by activating the constraints in Equation (4). From the tables, the corresponding total logistic weight and volume are given as well. One can see in both tables that the optimization results give the best option for the number of each item in the sets A and B. For an example from Table 2, to fulfil the total energy $E_s = 4228.5$ kcal, one needs to prepare a backpack with the minimum total volume of $V = 17.7$ litre for the corresponding total weight $m = 1.93$ kg. Meanwhile, by defining the constraints $x_{3,\max} = 2$ and $x_{2,\max} = 2$, i.e. correspond to drinking water, respectively, for the sets A and B, we mean that a tourist does not need to bring too much water. Moreover, the optimum number of items are presented in numerical value to adapt with the Solver where, to convert them to real number of logistic items, one can simply round it to the closer-higher integer, e.g. x_1 in Table 3 for Equation (1) converted to 3 instead of 2.2.

Table 2. The number of items predicted by the optimization based on the different set of logistic set A in Figure 5a for the total given E_c up and down from the last data point shown in Figure 6b.

item i	Equation 1 (set A)				Equation 2 (set A)			
	x_i (-)	$x_i m_i$ (g)	$x_i V_i$ (litre)	$x_i E_{s,i}$ (kcal)	x_i (-)	$x_i m_i$ (g)	$x_i V_i$ (litre)	$x_i E_{s,i}$ (kcal)
1	4.5	90.2	0.5	496.4	3.8	76.0	0.4	417.9
2	1.7	182.5	2.6	631.2	7.5	807.7	11.3	2792.9
3	1.8	1059.1	1.1	0.02	1.5	873.3	0.9	0.01
4	2.9	73.2	2.2	439.4	6.8	169.6	5.1	1017.7
Total =	10.9	1405.1	6.3	1567.0	19.6	1926.6	17.7	4228.5

Table 3. The number of items predicted by the optimization based on the different set of logistic set B in Figure 5b for the total given E_c up and down from the last data point shown in Figure 6b.

item i	Equation 1 (set B)				Equation 2 (set B)			
	x_i (-)	$x_i m_i$ (g)	$x_i V_i$ (litre)	$x_i E_{s,i}$ (kcal)	x_i (-)	$x_i m_i$ (g)	$x_i V_i$ (litre)	$x_i E_{s,i}$ (kcal)
1	2.2	64.6	0.4	366.0	9.7	292.2	1.9	1656.1
2	1.6	797.5	0.8	223.3	1.3	674.2	0.7	188.8
3	2.2	133.0	2.2	487.7	9.4	561.5	9.4	2058.9
4	4.4	87.8	3.3	482.9	2.9	58.1	2.2	319.7
Total =	10.4	1082.9	6.7	1559.9	23.4	1586.1	14.2	4223.5

The optimum logistic items for each set serves as important information for tourists to better plan their hiking activities. Such a plan can be illustrated as follows. First, specific distances of the hiking track is selected by tourists based on their will. From the selected tracks, we obtain E_c by using Equations (1) and (2). Second, by using the values of E_c, we perform the optimization by using the logistic set given in Table 1 to determine each number of item in order to fulfill the corresponding E_c. The results of the optimization are given back to the tourist as a recommendation. Thus, we consider that all the steps and the calculations described here are generic because they can be used for different hiking tracks and logistic item sets. In a more complex situation such as multiple day adventures with more complex logistic items, one needs to modify the logistic sets demonstrated here, e.g. by additional camping tents.

Finally, it is important to note that the values of E_c from the logistic optimization are not directly related with real time energy consumed during hiking. It is because we normally consume energy produced from foods from the past. Therefore, our logistic preparation sets are dedicated to replace the energy earned during hiking.

4. Conclussion

A connection between energy consumption and optimum logistic during hiking has been proposed in this work. We demonstrate such connection by using hiking track in the Mount of Sindoro from the Kledung basecamp. Here, the energy consumption is calculated from the hiking track profile and the heart rate of the persons walking on the tracks. With that energy consumption in hand, we perform optimization to determine the optimum number of logistic items to match the consumed energy by considering weight and volume each item. Our work can be used by tourists as supporting information to better manage their hiking activities in the future.

Acknowledgments

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