2017 HiMcM
Ski Slope Design Summary Sheet

Team Control Number: 8124
Problem Chosen: B

Abstract:

As the 2018 Winter Olympics is approaching, skiing fans are excited and prompted to construct a new ski resorts in Wasatch Peaks Ranch. Upon their request, we construct 21 skiing routes with 1-2-2 difficulty level distribution and a total slope length over 160 kilometers.

In part 1, we simplify the problem by constructing a 13-by-13 0-1 matrix, seeking all the potential ski slopes as decision variables. To construct a topological structure for the routes, we find the nodes on the smooth terrains by comparing the normal vectors. We fill the matrix with 1 or 0 to show whether the node is used after optimizing the solution using Lingo. On top of that, we apply Cluster Analysis to group the peaks into different groups to find the typical peaks and bowls that can be applied to the Linear Programming (0-1 matrix) Model.

In part 2, we evaluate all the given data by employing multiple-criteria decision analysis. Our design of the resort is within the top 5 resorts among the given resorts. After processing the data, we go through an analytic hierarchy process to construct a clear criteria and apply it to our design. The major criteria include the total distance, skiable acres, vertical drop, number of runs, distribution of difficulty, number of lifts, and annual snowfall.

After building our model, we come up with specific solution and design to each question.

Keywords: 0-1 matrix, multiple-criteria decision analysis, optimal solution, analytical hierarchy process, pairwise comparison.

Contents

I. Letter to Ms. Mogul

Dear Ms. Mogul,

Thank you for your interest in the possibility of developing the Wasatch Peak Ranch into a ski resort. Over the past two days, our team has worked out a design solution of ski trails on the amount of available mountain land that we have that would fit not only the purposes of a ski resort, but also the potential future of a location hosting the Winter Olympics.

In the process of designing the trails, we took a variety of factors into consideration upon your request. By locating the nodes of the mountain, which are the most smooth and locally non-steep regions, we construct 5 ski lifts for skiers' convenience to ski again from the peaks. Other factors include difficulty levels of based on the rise and run ratio. To make the construction economic and less costly, we minimized the distance of the total distance of slopes. We arrived at our final design based on 0-1 Linear Programming, and designed 20 routes for skiers' choice.

Additionally, we ranked our design against other existing major North American ski resorts for quality evaluation. We confirmed that our design is very competitive to all other ski resorts around the world. Taking into account the size, variety of slopes, convenience, and quality of a ski resort, our design of Wasatch ski resort ranks the 6th against 15 other major ski resorts in North America. This proves our plan to be very cost-effective since we minimized cost in designing the resort.

Attached is an overview of our final ski trail design. Thank you again for your interest, and we look forward to your feedback!

Sincerely,
Team 8124

Attachment:
The specific location and distance of each skiing slope:

Route Numbe	Route Difficult	Route Start	Route End	Distance(km)	Connected No
1	Beginner	Peak3	Node 2	8.1363	2
2	Beginner	Peak3	Node 7	6.5458	7
3	Beginner	Peak1	Node 1	10.2203	7,1
4	Beginner	Peak1	Node 7	6.7554	7
5	Intermediate	Peak1	Node 2	8.0395	2
6	Intermediate	Peak1	Node 4	15.826	3,4
7	Intermediate	Peak3	Node 4	4.0482	4
8	Intermediate	Peak2	Node 2	12.4297	4,2
9	Intermediate	Peak3	Node 5	9.5394	5
10	Intermediate	Peak1	Node 5	9.8357	5
11	Intermediate	Peak2	Node 4	6.64776	7,4
12	Professional	Peak2	Node 3	9.8654	3
13	Professional	Peak3	Node 1	5.9584	9,1
14	Professional	Peak2	Node 7	6.5131	7
15	Professional	Peak1	Node 3	10.1468	3
16	Professional	Peak4	Node 7	6.5025	7
17	Professional	Peak4	Node 1	5.9588	9,1
18	Professional	Peak4	Node 5	9.4025	5
19	Professional	Peak4	Node 4	8.394	2,4
			Total Distance =	160.76556	

	Latitude	Longitude
Node1	41.10324286	-111.794379
Node2	41.08309418	-111.763068
Node3	41.07470168	-111.7451369
Node4	41.10324286	-111.8068769
Node5	41.07302318	-111.750279
Node7	41.09317186	-111.778944
Peak1	41.11194444	-111.8555278
Peak2	41.10830556	-111.8539444
Peak3	41.1065	-111.8549444
Peak4	41.10191667	-111.8555833

II. Introduction

A. Background

The upcoming Winter Olympics in South Korea excited every skiing fans. Over 55 ski-related events, including Cross-Country, Ski Jumping, and Snowboarding, will compete on the best ski resorts in February 2018. To satisfy the need of the winter sports fans, we design a math model to identify the ski trails in Wasatch Peaks Ranch, aiming to become a top ski resort in North America. The Ranch has large acres of land and a long ridgeline for the development of the ski slopes. In our design, there are a variety of trails of different levels- beginner, intermediate, and professional skiers- to make the resort an enjoyable resort for everyone. Furthermore, the resort also provides enough ski slopes- over 160 km in total -to avoid congestions. By using Linear Programming and 0-1 matrix, We also chose optimal locations for 5 bases with lifts to make it convenient to ski the trails again.

However, Wasatch Peaks Ranch does not only aim for completion and convenience, but also a potential Winter Olympics location. To adjust our design in making Wasatch Peaks Ranch more competitive, we evaluated other major ski areas in North America based on their resort size and slopes' design by employing multiple-criteria decision analysis. In general, the objective of our solution is to identify best ski slopes for different levels of skiers with convenience and efficiency and to qualify for potential Winter Olympics location.

B. Problem Restatement

The Wasatch Peaks Ranch is located in Peterson, Utah, USA, and because of its long ridgeline of 11 miles that includes 24 peaks, 15 bowls and cirques, the skiing fans are considering if they should buy the ranch and develop it into a ski resort. They also hope it will become competitive for Winter Olympics with other well-known resorts.

To make skiing in Wasatch Peaks Ranch an enjoyable experience for every skier, the skiing slopes should be long and vary in difficulty levels. However, the geography of the Ranch is very complex to design all the potential slopes precisely. Built according to existing topography, nodes can be set up on smooth terrains, serving as stations for ski lifts. If these nodes can be found, they can be connected to determine potential skiing slopes, and after a selection of these potential slopes, we can optimize the ski slopes.

Therefore, we need to construct and analyze two models for this problem- for both finding the nodes and needed slopes - using Linear Programming and Analytic Hierarchy in the following report.

III. Assumptions and Justifications

1. Assume the skiing slopes will not overlap;

Justification: The skiing slopes cannot overlap besides the node connections. That will cause confusion of the skiers during the skiing experience and unexpectedly ski on more difficult slopes than anticipated.

2. Assume the area within the ranch can construct a ski slope;

Justification: We assume that all area within the map can construct a ski slope, so we do not need to put limitations on the design of the ski slopes.

3. Assume the the data given are accurate and precise;

Justification: We assume that the data in the brochure are accurate so that we can build accurate model on top of that.

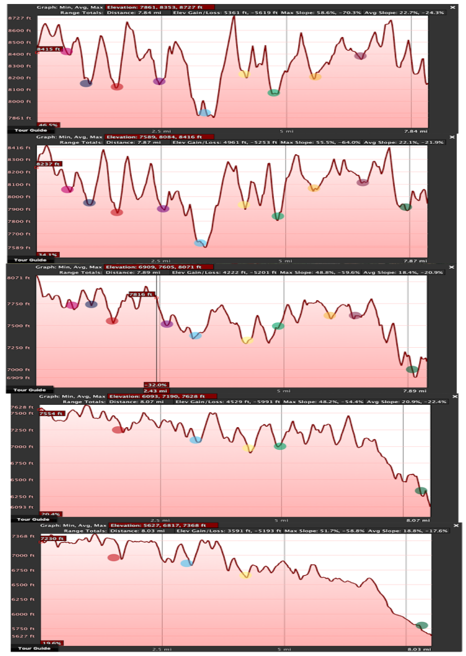
IV. Data Gathering

A. Finding Peaks and Bowls.

We were given that Wasatch Peak Ranch has a total of 24 peaks and 15 bowls. A holistic view of the mountain is rendered in Google Earth, where the ridgeline of the mountain is shown. In order to determine the locations of the 24 peaks on the mountain, we traced the ridgeline with the "path" function, and obtained an elevation graph of the points on the ridgeline:

(Figure 4.1)

By determining the local maximum of the the curve, we were able to locate the peaks' coordinates. The bowls, on the other hand, were discovered through a similar approach. By comparing the elevation graphs of the adjacent paths, we were able to find bowls, or areas on the mountain that have a relative lower elevation.



(Figure 4.2)

The exact location of the peaks and bowls are attached (See Appendix 1.1).

V. Mathematical Modeling

A.Parameters

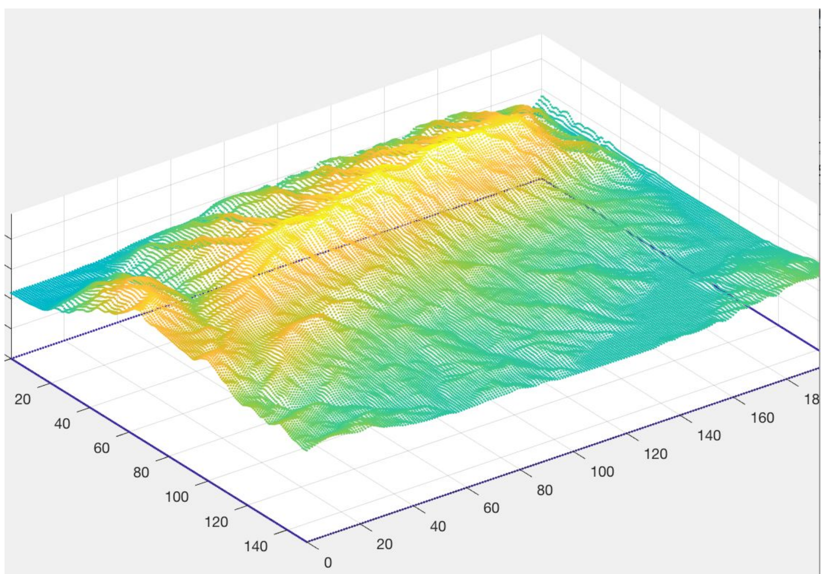
L_n	The length of the nth slope;
N_{total}	The number of slopes designed in total;
$C_n(Lat, Lng)$	The location of the nth nodes;
a_n	The altitude of a random point around the nth node;
$\overline{a}$	The average altitude within 1km*1km range of the nth node;
σ_n	The standard deviation of the altitudes of the nth node;
$S_n(Lat, Lng)$	The location of the start of the nth slope;
$E_n(Lat, Lng)$	The location of the end of the nth slope;

D_n	The difficulty level of the of the *nth* slope.

B. Plan for optimal node locations

1. Basic Description of our Model:
   In this model, we try to find the nodes within the area. The nodes are defined and determined to play two roles:
   (1) Locations that are suitable for construction of ski lifts;
   (2) Connecting the nodes to sketch the potential ski slopes;

2. Using Normal Vector to find smooth terrains:
   Upon research, we found that the 3D model of the Wasatch mountain ranch can be generated through the Terrain STL generator (Terrain2STL), which comes in as a point cloud form and can be rendered on Matlab:

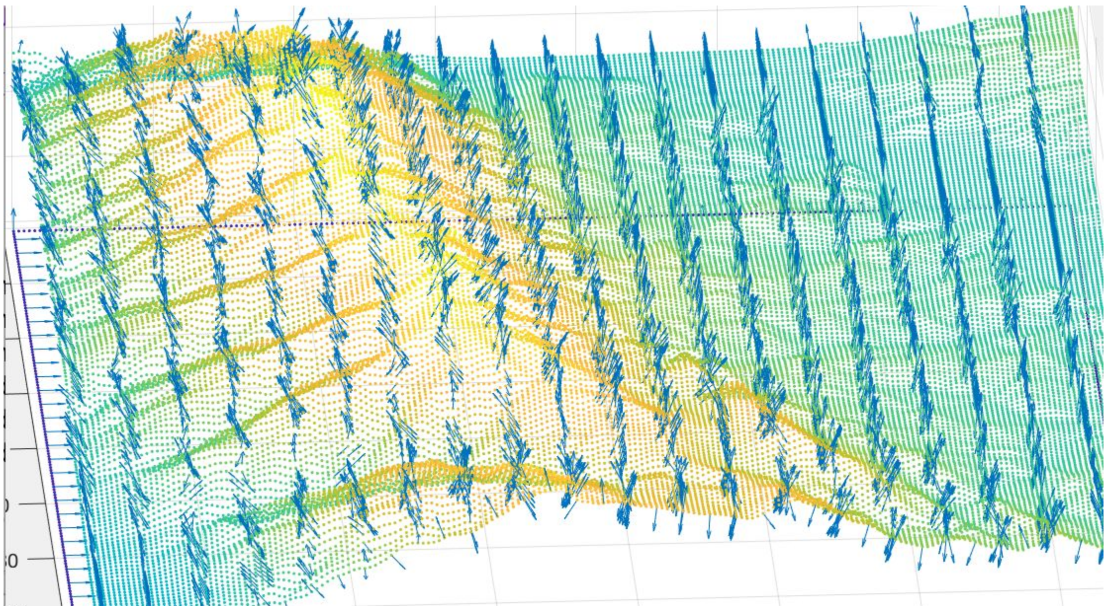


(Figure 5.1)

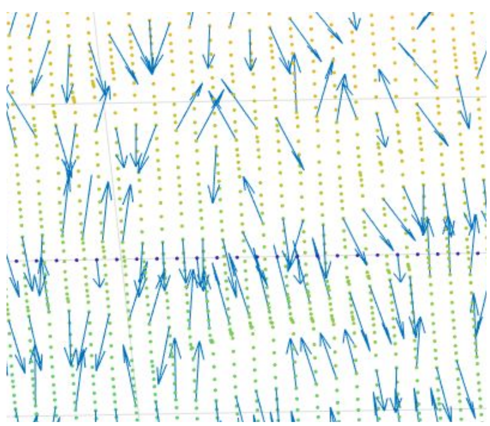
(The figure's scale is moderated to adapt Terrain2STL:
Top Left: Latitude: 41.1413; Longitude: 111.9183: x=0, y=200
Down Right: Latitude: 41.0075555;Longitude:-111.7647778 x=150, y=0)

The point cloud model is based on the three coordinates x, y and z, and represent respectively the latitude, longitude and elevation of a point on the mountain. For each point in the point cloud, it is possible to calculate a normal vector of that point by finding the neighboring points, creating a plane out of those points, and calculating the direction vector v orthogonal to that plane. The resulting vector reflects the direction in which the small local section of the mountain faces.

Of the 40796 points in the point cloud set, we calculated the normal vectors every 10 point, obtaining a total of roughly 4080 vectors. Below is a graph of the direction vectors placed on their respective points:

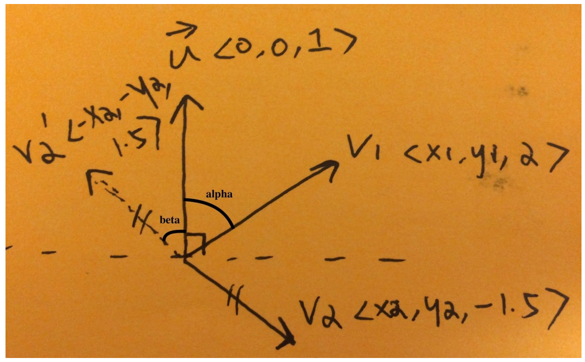


(Figure 5.2)



(Figure 5.3)

Upon closer inspection, we found that some of the vectors have a negative z component value, and point towards the inside of the mountain, instead of outwards to the sky. Those vectors are flipped to become their opposite so that all vectors are pointing outward:



(Figure 5.4)

We theorized that for any vector v, its angle Θ with the upward pointing unit vector u <0,0,1> is an indicator of how steep a local region is on the mountain. For a relatively smooth area, the angle between its normal vector and u would be a small value, as u is the normal vector of a completely horizontal plane; for steeper areas, the angle difference increases.

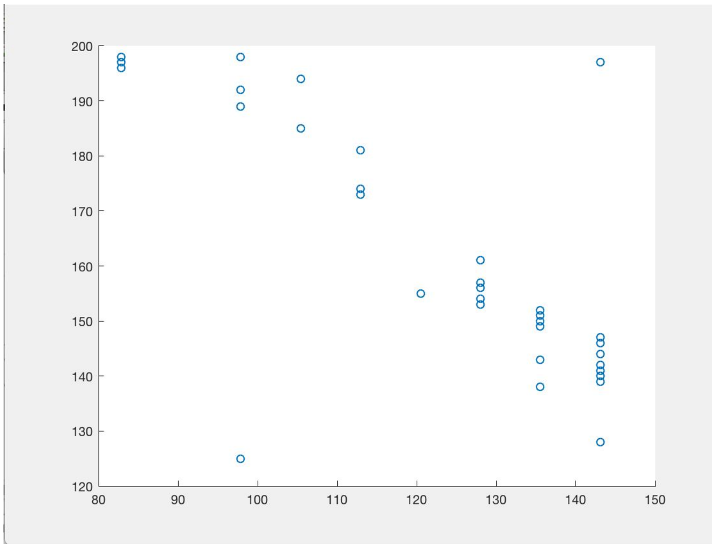
Based on the dot/scalar product of vectors, we were able to find out the set of angles between u and all 4080 v vectors. The dot product of two vectors a = [a1, a2, ..., an] and b = [b1, b2, ..., bn] is defined as:

$$\mathbf{a}\cdot\mathbf{b}=\sum_{i=1}^{n}a_ib_i=a_1b_1+a_2b_2+\cdots+a_nb_n$$

whereas according to the geometric definition, the dot product value is also

$$\mathbf{a}\cdot\mathbf{b}=\|\mathbf{a}\|\ \|\mathbf{b}\|\cos(\theta)$$

Therefore, $\Theta = \cos^{-1} [(v_x*u_x+v_y*u_y+v_z*u_z) / |v| * |u|]$, where Θ is the angle between a vertical vector pointing upwards and the normal vector to a certain point on the mountain. To find the nodes, we try to find the normal of points, finding the top 35 most smooth terrain on the map:



(Figure 5.5 The latitude and longitude of the potential nodes)

Using Cluster Analysis in SPSS, we get the following ten nodes:

Final Cluster Centers

	Cluster									
	1	2	3	4	5	6	7	8	9	10
Angle	.27	.26	.40	.39	.46	.24	.27	.38	.32	.38
Latitude	143.09	112.96	100.41	143.09	97.90	82.84	128.03	105.43	135.56	125.51
Longitude	140.50	176.00	196.33	126.33	190.50	197.00	158.00	185.00	148.44	153.33

(Figure 5.6)

The nodes are connected to form potential ski slopes, and we get the following distance between each node by calculating the linear distance between the two nodes:

Node number	1	2	3	4	5	6	7	8	9	10
1	0	3.4541	5.2118	1.0484	5.0007	4.5791	1.7127	4.3247	0.8223	1.6167
2	3.4541	0	1.7711	4.3057	1.552	4.1993	1.7415	0.8706	2.6343	1.9202
3	5.2118	1.7711	0	6.0768	0.4702	5.2222	3.5034	0.9181	4.3965	3.6903
4	1.0484	4.3057	6.0768	0	5.8195	4.4869	2.5976	5.168	1.7341	2.3882
5	5.0007	1.552	0.4702	5.8195	0	4.7582	3.2887	0.6928	4.1791	3.4339
6	4.5791	4.1993	5.2222	4.4869	4.7582	0	4.0295	4.5399	4.1914	3.6873
7	1.7127	1.7415	3.5034	2.5976	3.2887	4.0295	0	2.6121	0.8934	0.3932
8	4.3247	0.8706	0.9181	5.168	0.6928	4.5399	2.6121	0	3.5048	2.7798
9	0.8223	2.6343	4.3965	1.7341	4.1791	4.1914	0.8934	3.5048	0	0.8177
10	1.6167	1.9202	3.6903	2.3882	3.4339	3.6873	0.3932	2.7798	0.8177	0

(Figure 5.7)

To generate the network of the ski slopes, we chose three peaks using k-means clustering again to choose, and we find the following three peaks:

Final Cluster Centers

	Cluster 1	Cluster 2	Cluster 3
Latitude	41.06	41.06	41.08
Longitude	-111.84	-111.84	-111.85
Elevation	8927.45	9295.05	9540.42

(Figure 5.8)

we used topological structure to connect all the peaks and these nodes, So we constructed slopes using topological structure. The topological structure is often used in subway system, and we use the structure in this problem to construct all the potential routes (13*13 diagram).

C. The Optimization of Skiing Slopes and Nodes for Ski Lifts

1. Basic Description of Linear Programming:

Linear Programming is a well-known mathematical model to achieve the goal, using the technique for the optimization of the objective of a linear objective function. It is heavily used for planning, production, transportations, and etc. With the existing constraints, such as limited expenditure, workforce, and distribution, linear programming can provide a feasible and optimized solution for the problem.

In this part, we apply Linear Programming to our model. Based on the data of all the potential skiing slopes provided, we use Lindo/Lingo to satisfy the requirements with the minimum cost.

2. Metric Design:

In order to choose the best slopes, we quantify the choice of all potential slopes with a 0-1 metric.

3. The establishment of linear programming:

To reduce the expenditure of the skiing fans, we decide to minimize the cost of construction, so we choose the combination of slopes with the shortest overall distance while the distribution of different levels is guaranteed. In this model, we have the following hypothesis:

1. The length of the slopes are calculated as linear distance from the starting point to its destination (from nodes to nodes);
2. The difficult level of each ski slopes are determined as $\frac{rise}{run}$, and if one part of the entire slope is difficult, the entire route is considered difficult (even if other parts are all intermediate and beginner level);

Objective function: minimizing the total distance of the ski slopes:

$$min \sum_{i=1}^{13} \sum_{j=1}^{13} A_{ij} D_{ij}$$

To meet the needs of ski fans and make the Wasatch Peaks Ranch competitive for winter Olympics, we list the following object function:

(1) The total distance of selected slopes should be least 160 miles in total:

$$\sum_{i=1}^{13} \sum_{j=1}^{13} A_{ij} D_{ij} \geq 160;$$

(2) The total distance of slopes for beginners should be approximately 20% of the total distance;

$$(i,j) \in B, \sum_{i=1}^{13} \sum_{j=1}^{13} \frac{A_{ij}}{N} = 0.20$$

(3) The total distance of slopes for intermediates should be approximately 40% of the total distance;

$$(i,j) \in I, \sum_{i=1}^{13} \sum_{j=1}^{13} \frac{A_{ij}}{N} = 0.40$$

(4) The total distance of slopes for professionals should be approximately 40% of the total distance.

$$(i,j) \in H, \sum_{i=1}^{13} \sum_{j=1}^{13} \frac{A_{ij}}{N} = 0.40$$

So our combined model is:

$$\text{Goal: } min \sum_{i=1}^{13} \sum_{j=1}^{13} A_{ij} D_{ij}$$

$$\text{S.t. } \sum_{i=1}^{13} \sum_{j=1}^{13} A_{ij} D_{ij} \geq 160$$

$$(i,j) \in B, \sum_{i=1}^{13} \sum_{j=1}^{13} \frac{A_{ij}}{N} = 0.20$$

$$(i,j) \in I, \sum_{i=1}^{13} \sum_{j=1}^{13} \frac{A_{ij}}{N} = 0.40$$

$$(i,j) \in H, \sum_{i=1}^{13} \sum_{j=1}^{13} \frac{A_{ij}}{N} = 0.40$$

$$A_{ij} \in \{0, 1\}$$

4. The result of the model:

As a result, we find the following routes:

	A	B	C	D	E	F
2	Route Numbe	Route Difficult	Route Start	Route End	Distance(km)	Connected No
3	1	Beginner	Peak3	Node 2	8.1363	2
4	2	Beginner	Peak3	Node 7	6.5458	7
5	3	Beginner	Peak1	Node 1	10.2203	7,1
6	4	Beginner	Peak1	Node 7	6.7554	7
7	5	Intermediate	Peak1	Node 2	8.0395	2
8	6	Intermediate	Peak1	Node 4	15.826	3,4
9	7	Intermediate	Peak3	Node 4	4.0482	4
10	8	Intermediate	Peak2	Node 2	12.4297	4,2
11	9	Intermediate	Peak3	Node 5	9.5394	5
12	10	Intermediate	Peak1	Node 5	9.8357	5
13	11	Intermediate	Peak2	Node 4	6.64776	7,4
14	12	Professional	Peak2	Node 3	9.8654	3
15	13	Professional	Peak3	Node 1	5.9584	9,1
16	14	Professional	Peak2	Node 7	6.5131	7
17	15	Professional	Peak1	Node 3	10.1468	3
18	16	Professional	Peak4	Node 7	6.5025	7
19	17	Professional	Peak4	Node 1	5.9588	9,1
20	18	Professional	Peak4	Node 5	9.4025	5
21	19	Professional	Peak4	Node 4	8.394	2,4
22				Total Distance =	160.76556	

(Figure 5.9)

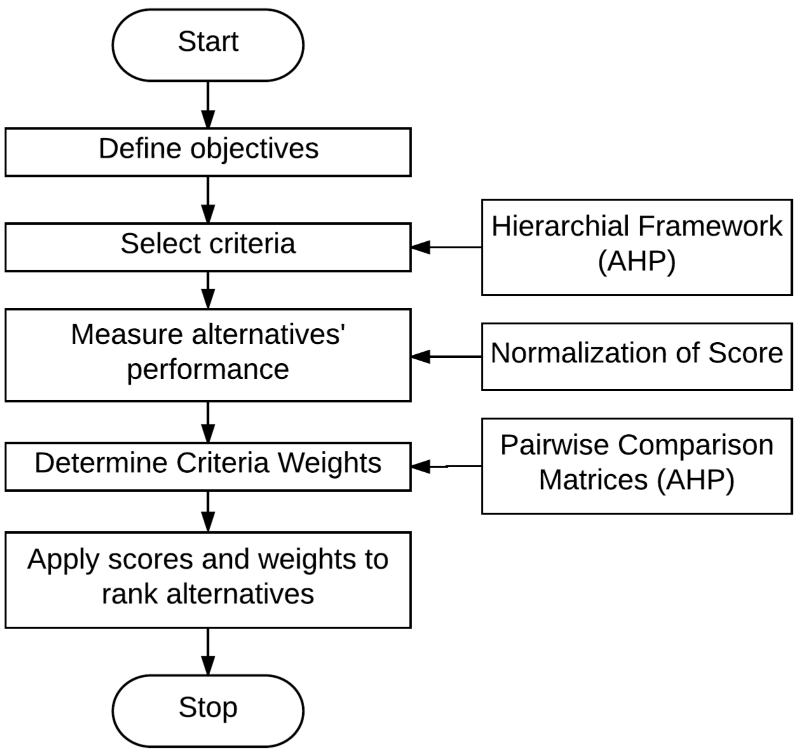
With the minimum total distance and relative 20%-40%-40% ratio for difficulty distribution.

VI. Ranking our ski resorts against other ski resorts

1. **Introduction**

Our objective is to rank our proposed ski area against existing ski resorts in North America. This requires us to develop a comprehensive and consistent model for evaluating ski resorts with some flexibility in the selection of criteria. Through preliminary research, we discovered that the desirability of ski resorts depend on a variety of both independent and interrelated factors. In order to be as transparent and consistent as possible in our evaluation, we decide to utilize the multiple-criteria decision analysis (MCDA), a comprehensive, structured and coherent decision-making tool. The following figure shows the proposed MCDA framework for evaluation. In the rest of the work on evaluation, section 2 sets out the methodology for developing the model, section 3 describes the application and presents the results, and section 4 puts forth the conclusions.

Proposed Evaluation Framework:



B. Methodology

2.1 Objective defining and criteria selecting

In ranking our proposed ski area against existing ski resorts in North America, the objective will be desirability to skiers. In ranking against past Winter Olympics location, the objective will be the satisfaction of the requirements by the sports events.

We will pick criteria for each purpose by consulting research papers, well-recognized ski resorts report websites, and experienced skiers.
For a structured and direct understanding of the relationships between the criteria and the objective, we will construct an analytical hierarchy.

2.2 Alternatives' performance measuring

2.2.1 Alternatives

We will consider the ski resorts given in the SkiSlopeComparison file for ranking of ski resorts in North America.

2.2.2 Data processing

Since the criteria will cover very different aspects of the ski resorts, the data for each criteria will have different indication, units, and dimensions. Therefore, we need to transform the data to:

1) Ensure that a higher value indicates better performance in each criterion by taking the reciprocal of the values for which a higher number indicate poorer performance (to be consistent with all other measures).
2) Eliminate the units and rescale the data into smaller consistent range so that the new index can provide useful and intuitive information on the performance of the ski resorts. We would normalize the data into a range of (0,1) using the following feature scaling formula:

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

where x is an original value, and x' is the normalized value. This formula will work well with our objective because there will be none or few outliers in our data, considering that the different ski resorts are all artificially built to serve the same specific purpose of skiing.

2.3 Criteria Weights

The analytic hierarchy process (AHP) developed by Thomas Saaty is a structured method for organizing and analyzing complex decisions. It has been widely accepted and applied to solve complex MADM problems. Because it enables our varied and incommensurable criteria to be compared to each other in a consistent way, we implement APH in our evaluation to calculate the numerical weights of the ranking criteria. The steps we take are as below:

Step 1: *Hierarchal framework construction*:
Decompose the decision-making problem into a hierarchy. The goal of the problem is defined at the first level of the hierarchy, the ranking criteria and sub-criteria at the second level, and the alternative at the third level.

Step 2: *Criteria Weight determination*:

a) Formulating matrices for all the ranking criteria by making pairwise comparison on a (1-9) scale defined according to the methodology adopted by Caldara:

Table 2. Adopted scale of importance.

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
Reciprocals of above	If factor i has one of the above numbers assigned to it when compared to factor j, then j has the reciprocal value when compared with i

Adapted from Caldara et al (13).

b) Normalizing the resulting matrices: each element in the column is divided by the column sum to yield its normalized score, reducing the sum of each column to 1.

c) Checking the consistency of the original preference ratings:

i. Calculate the consistency measures by multiplying the the pair-wise matrix by the weights, and then dividing it by the criterion weight.
ii. Calculate *λmax* by averaging the consistency measures.
iii. Calculate the approximate consistency index (CI) using the following formula:

$$CI = \frac{\lambda max - n}{n - 1}$$

where n is the matrix order number.
iv. Calculate the consistency ratio (CR) using the following formula:

$$CR = \frac{CI}{RI}$$

Where the random index (RI) is determined based on the matrix order number by the following table:

Table 1 – Random index.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty (1977).

If CR ≤ 0.1, the judgement is considered acceptable. Else we will reexamine and revise the ratings we give in pair-wise comparison.

2.4 Ranking Alternatives

We will calculate the final weighted total score of each alternative by:

1) Adding weight to the raw scores by multiplying each raw score with its corresponding criterion weight
2) Adding up the weighted score for each alternative to get the final weighted total score of each alternative

We will then rank all the alternatives according to their final scores.

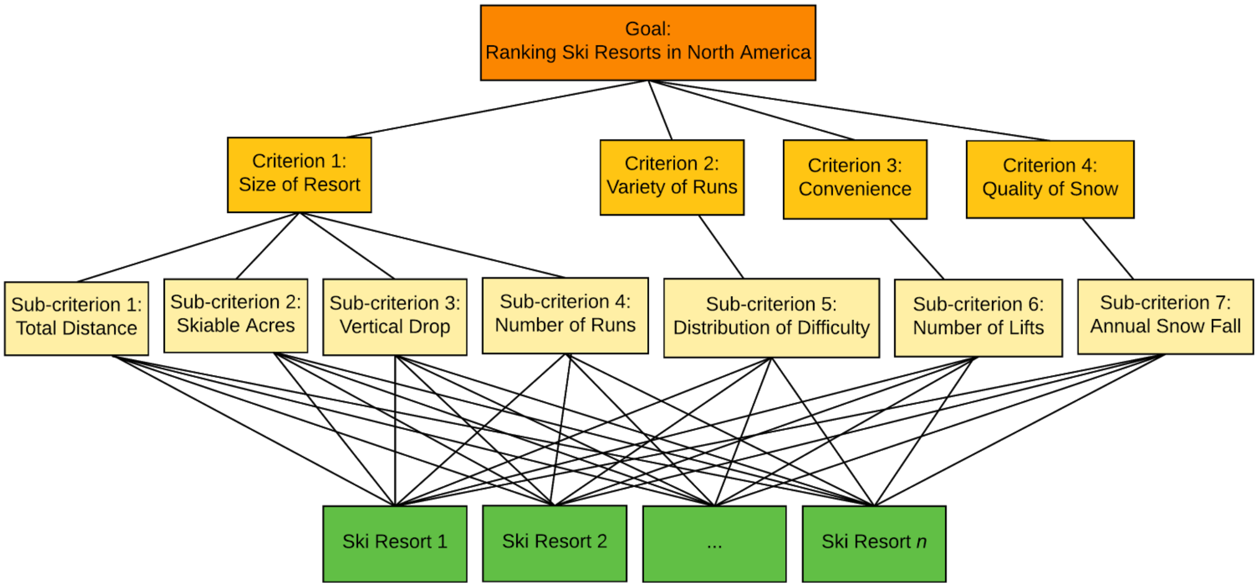
3. Application

3.1 Objective defining and criteria selecting

Criteria	*Description*
Total distance	Longer total distance of the slope indicates bigger size of the resort, resulting in higher desirability.

Skiable Acres	Longer total distance of the slope indicates bigger size of the resort, resulting in higher desirability.
Vertical Drop	Calculated from peak elevation - base elevation. Greater vertical drop indicates bigger size of the resort, resulting in higher desirability.
Number of Runs	More runs indicates bigger the size of the resort, resulting in higher desirability.
Distribution of Difficulty	The ideal distribution of the difficulty of trails is defined to be 20% beginner level, 40% intermediate level and 40% difficulty level. The deviation from the ideal distribution is calculated with a formula similar to that of standard deviation, where we take the square root of the sum of squared difference between the ideal percentage and the real percentage of a specific resort. Smaller deviation from the ideal distribution of difficulty indicates a more ideal variety in trails, resulting in higher desirability.
Number of Lifts	More lifts means skiers can get around more conveniently, resulting in higher desirability.
Annual Snowfall	Greater annual snow fall indicates better quality of the skiing experience, resulting in higher desirability.

Then we constructed the analytical hierarchy structure:



2.2 Alternatives' performance measuring

2.2.1 Alternatives and Data Processing

We gather data from both the given spreadsheet and online websites. Then, we calculate the secondary data we need from the primary data. The data of the final criteria that will enter into evaluation is highlighted, with the same color indicating the same category of criteria.

North American Ski Resorts - Partial List (Original Data)																	
Name	Beaver Creek	Big Sky Resort	Breckenridge	Breckenridge	Jackson Hole	Killington	Lake Louis	Park City Mountain	Silver Star	Squaw Valley	Steamboat Springs	Sugarloaf Mountain	Sun Peaks	Vail	Whistler Blackomb	Winter Park Resort	Wasatch
State	Colorado	Montana	Colorado	British Columbia	Wyoming	Vermont	Alberta	Utah	British Columbia	California	Colorado	Maine	British Columbia	Colorado	British Columbia	Colorado	Utah
Country	USA	USA	USA	Canada	USA	USA	Canada	USA	Canada	USA	USA	USA	Canada	USA	Canada	USA	USA
Slopes Total (km)	150	250	153	142	116	126.4	139	250	115	100	165	119	135	234	200	143	161
Skiable Acres	1832	5800	2908	2500	2500	1509	4200	7300	3269	3600	2956	1153	4270	5289	8171	3000	5500
Peak Elevation (m)	3488	3398	3914	2134	3185	1285	2637	3029	1915	2760	3221	1286	2082	3433	2284	3676	-
Base Elevation (m)	2255	2072	2926	1052	1924	355	1646	2080	1155	1890	2103	426	1198	2457	653	2743	-
Vertical Drop (m)	1233	1326	988	1082	1261	930	991	949	760	870	1118	860	884	976	1631	933	1402
Number of Runs	149	308	155		116	140	139	324	115	170	165	160	122	193	200	134	80
• Green (km)	28.5	55	28	42	16	37.4	35	27	20	25	25	28	13.5	57	40	11	32
• Green %	19.0%	22.0%	18.3%	29.6%	13.8%	29.6%	25.2%	10.8%	17.4%	25.0%	15.2%	23.5%	10.0%	24.4%	20.0%	7.7%	19.9%
■ Blue (km)	64.5	69	60	58	50	43	62	152	50	45	95	40	78	84	110	53	66
■ Blue %	43.0%	27.6%	39.2%	40.8%	43.1%	34.0%	44.6%	60.8%	43.5%	45.0%	57.6%	33.6%	57.8%	35.9%	55.0%	37.1%	41.0%
♦ Black (km)	57	126	65	42	50	46	42	71	45	30	45	51	43.5	93	50	79	63
♦ Black %	38.0%	50.4%	42.5%	29.6%	43.1%	36.4%	30.2%	28.4%	39.1%	30.0%	27.3%	42.9%	32.2%	39.7%	25.0%	55.2%	39.1%
Deviation from Ideal Distribution	0.0374	0.1631	0.0311	0.1418	0.0760	0.1186	0.1199	0.2553	0.0443	0.1225	0.2224	0.0784	0.2183	0.0599	0.2121	0.1981	0.0133
Reciprocal of Deviation from Ideal Distribution	26.73	6.13	32.16	7.05	13.15	8.43	8.34	3.92	22.55	8.16	4.50	12.76	4.58	16.69	4.71	5.05	75.40
Number of Lifts	16	28	23	9	12	20	7	38	12	24	17	13	9	25	26	22	5
Avg Annual Snowfall (in)	195	400	300		459	250	180	360	275	450	349	200	220	346	461	365	400

Then we processed our data to ensure that a higher value indicates better performance.

	North American Ski Resorts - Partial List (Raw Score)																		
#	Evaluation Criteria	Weight	Beaver Creek	Big Sky Resort	Breckenridge (USA)	Jackson Hole	Killington	Lake Louis	Park City Mountain	Silver Star	Squaw Valley	Steamboat Springs	Sugarloaf Mountain	Sun Peaks	Vail	Whistler Blackomb	Winter Park Resort	Wasatch	Max	Min
C1	Size																			
SC1	Slopes Total (km)	0.13	150	250	153	116	126.4	139	250	115	100	165	119	135	234	200	143	161	250	100
SC2	Skiable Acres	0.06	1832	5800	2908	2500	1509	4200	7300	3269	3600	2956	1153	4270	5289	8171	3000	5500	8171	1153
SC3	Vertical Drop (m)	0.01	1233	1326	988	1261	930	991	949	760	870	1118	860	884	976	1631	933	1402	1631	760
SC4	Number of Runs	0.03	149	308	155	116	140	139	324	115	170	165	160	122	193	200	134	80	324	80
C2	Variety																			
SC5	Deviation from Ideal Distribution	0.11	26.73	6.13	32.16	13.15	8.43	8.34	3.92	22.55	8.16	4.50	12.76	4.58	16.69	4.71	5.05	75.40	75.40	3.92
C3	Convenience																			
SC6	Number of Lifts	0.30	16	28	23	12	20	7	38	12	24	17	13	9	25	26	22	5	38	5
C4	Quality																			
SC7	Avg Annual Snowfall (in)	0.36	195	400	300	459	250	180	360	275	450	349	200	220	346	461	365	400	461	180

Then we normalized our data.

	North American Ski Resorts - Partial List (Normalized Data)																		
#	Evaluation Criteria	Weight	Beaver Creek	Big Sky Resort	Breckenridge (USA)	Jackson Hole	Killington	Lake Louis	Park City Mountain	Silver Star	Squaw Valley	Steamboat Springs	Sugarloaf Mountain	Sun Peaks	Vail	Whistler Blackomb	Winter Park Resort	Wasatch	Max	Min
C1	Size																			
SC1	Slopes Total (km)	0.13	0.33	1.00	0.35	0.11	0.18	0.26	1.00	0.10	0.00	0.43	0.13	0.23	0.89	0.67	0.29	0.41	1.00	0.00
SC2	Skiable Acres	0.06	0.10	0.66	0.25	0.19	0.05	0.43	0.88	0.30	0.35	0.26	0.00	0.44	0.59	1.00	0.26	0.62	1.00	0.00
SC3	Vertical Drop (m)	0.01	0.54	0.65	0.26	0.58	0.20	0.27	0.22	0.00	0.13	0.41	0.11	0.14	0.25	1.00	0.20	0.74	1.00	0.00
SC4	Number of Runs	0.03	0.28	0.93	0.31	0.15	0.25	0.24	1.00	0.14	0.37	0.35	0.33	0.17	0.46	0.49	0.22	0.00	1.00	0.00
C2	Variety																			
SC5	Deviation from Ideal Distribution	0.11	0.32	0.03	0.40	0.13	0.06	0.06	0.00	0.26	0.06	0.01	0.12	0.01	0.18	0.01	0.02	1.00	1.00	0.00
C3	Convenience																			
SC6	Number of Lifts	0.30	0.33	0.70	0.55	0.21	0.45	0.06	1.00	0.21	0.58	0.36	0.24	0.12	0.61	0.64	0.52	0.00	1.00	0.00
C4	Quality																			
SC7	Avg Annual Snowfall (in)	0.36	0.05	0.78	0.43	0.99	0.25	0.00	0.64	0.34	0.96	0.60	0.07	0.14	0.59	1.00	0.66	0.78	1.00	0.00

2.3 Criteria Weights

First we formulated our comparison matrices:

Pairwise Comparison Matrix O-C				
O	C1	C2	C3	C4
C1	1.00	2.00	1.00	0.50
C2	0.50	1.00	0.33	0.33
C3	1.00	3.00	1.00	1.00
C4	2.00	3.00	1.00	1.00
Total	4.50	9.00	3.33	2.83

Pairwise Comparison Matrix C1-Sub-C				
C1	Sub-C1	Sub-C2	Sub-C3	Sub-C4
Sub-C1	1.00	3.00	7.00	5.00
Sub-C2	0.33	1.00	5.00	3.00
Sub-C3	0.14	0.20	1.00	0.33
Sub-C4	0.20	0.33	3.00	1.00
Total	1.68	4.53	16.00	9.33

Pairwise Comparison Matrix C2-Sub-C		
C2	Sub-C5	ω
Sub-C5	1	1

Pairwise Comparison Matrix C3-Sub-C		
C3	Sub-C6	ω
Sub-C6	1	1

Pairwise Comparison Matrix C4-Sub-C		
C4	Sub-C7	ω
Sub-C7	1	1

Then we normalized the matrices where it is needed, calculated the weight of each criteria, and checked consistency. All of our weights have passed the consistency check.

Pairwise Comparison Matrix O-C (Normalized)						
O	C1	C2	C3	C4	ω	Consistency Measure
C1	0.22	0.22	0.30	0.18	0.23	4.04
C2	0.11	0.11	0.10	0.12	0.11	4.05
C3	0.22	0.33	0.30	0.35	0.30	4.04
C4	0.44	0.33	0.30	0.35	0.36	4.05
					Consistency Index =	0.02
					Random Index =	0.89
					Consistency Ratio =	0.02
						C.R. < 0.10

Pairwise Comparison Matrix C1-Sub-C (Normalized)						
C1	Sub-C1	Sub-C2	Sub-C3	Sub-C4	ω	Consistency Measure
Sub-C1	0.60	0.66	0.44	0.54	0.56	4.22
Sub-C2	0.20	0.22	0.31	0.32	0.26	4.17
Sub-C3	0.09	0.04	0.06	0.04	0.06	4.04
Sub-C4	0.12	0.07	0.19	0.11	0.12	4.04
					Consistency Index =	0.04
					Random Index =	0.89
					Consistency Ratio =	0.04
						C.R. < 0.10

Weight Sub-C-C				
	C1	C2	C3	C4
Sub-C1	0.56	0.00	0.00	0.00
Sub-C2	0.26	0.00	0.00	0.00
Sub-C3	0.06	0.00	0.00	0.00
Sub-C4	0.12	0.00	0.00	0.00
Sub-C5	0.00	1.00	0.00	0.00
Sub-C6	0.00	0.00	1.00	0.00
Sub-C7	0.00	0.00	0.00	1.00

Weight C-O	
	O
C1	0.23
C2	0.11
C3	0.30
C4	0.36

Final Weight Sub-C-O	
	O
Sub-C1	0.13
Sub-C2	0.06
Sub-C3	0.01
Sub-C4	0.03
Sub-C5	0.11
Sub-C6	0.30
Sub-C7	0.36

2.4 Ranking Alternatives

We calculated the final weighted score of each alternative as such:

	Beaver Creek	Big Sky Resort	Breckenridge (USA)	Jackson Hole	Killington	Lake Louis	Park City Mountain	Silver Star	Squaw Valley	Steamboat Springs	Sugarloaf Mountain	Sun Peaks	Vail	Whistler Blackomb	Winter Park Resort	Wasatch
Final Weighted Total Score	0.22	0.70	0.43	0.47	0.27	0.10	0.74	0.25	0.56	0.41	0.14	0.15	0.58	0.72	0.45	0.49

The ranking therefore is:

Rank	Ski Resort	Final Weighted Total Score
1	**Park City Mountain**	0.74
2	**Whistler Blackomb**	0.72
3	**Big Sky Resort**	0.70
4	**Vail**	0.58
5	**Squaw Valley**	0.56
6	**Wasatch**	0.49
7	**Jackson Hole**	0.47
8	**Winter Park Resort**	0.45
9	**Breckenridge (USA)**	0.43
10	**Steamboat Springs**	0.41
11	**Killington**	0.27
12	**Silver Star**	0.25
13	**Beaver Creek**	0.22
14	**Sun Peaks**	0.15
15	**Sugarloaf Mountain**	0.14
16	**Lake Louis**	0.10

In conclusion, considering the size, variety, convenience, and quality of a ski resort, our design of Wasatch ski resort ranks the 6th against 15 other major ski resorts in North America. This proves our plan to be very cost-effective since we minimized cost in designing the Wasatch resort.

VII. Model Evaluation:

i.Strengths:

- We apply the model of 0-1 Programming in our model. The 0-1 Model can effectively give an optimal selection of ski slopes in the resort. The model simplifies our computer programming process, making the problem more accountable to understand and solve.
- Tractability: Our model is easy to analyze and apply, and the calculation is easy to follow.
- Generalizability: Our model fits multiple situations and circumstances given the amount of variables it contains.
- Precision: Our model can offer an overall accurate design of the most cost-efficient most for the ski resort design.
- We employ multiple-criteria decision analysis, taking most factors into consideration while evaluating the top ski resorts around the world.

ii.Weaknesses:

- Our model contain rounded decimal numbers that may cause inaccuracy in nodes' locations;
- The process of designing optimal ski slopes is over-simplified. Certain assumptions make our model fail to be truly realistic.
- Our model doesn't take into account the other specific factors when evaluating the top ski resorts, including transportation, location, and safety precautions.

VIII.Reference.

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IX. Appendix.

1.1 Exact Location for Peaks and Bowls:

	A	B	C	D	E	F	G	H	I	J	K
1	**Peaks**						**Bowls**				
2	**Elevation**	**Latitude (N)**	**Longitude (W)**	**Convrted Lat**	**Converted Long**		**Elevation**	**Latitude (N)**	**Longitude (W)**	**Converted Lat**	**Converted Long**
3	8960.839906	41°06'43.04"N	111°51'19.98"W	41.11194444	-111.8555278		8423.688062	41°01'01.25"N	111°49'19.09"W	41.017	-111.8219444
4	9180.383851	41°06'29.93"N	111°51'14.25"W	41.10830556	-111.8539444		8159.263251	41°01'22.53"N	111°49'25.15"W	41.02291667	-111.8236389
5	9043.951849	41°06'23.47"N	111°51'17.80"W	41.1065	-111.8549444		8132.330887	41°01'48.66"N	111°49'33.09"W	41.03016667	-111.8258333
6	8999.868766	41°06'06.97"N	111°51'20.16"W	41.10191667	-111.8555833		8247.53675	41°02'31.28"N	111°49'46.04"W	41.042	-111.8294444
7	9523.216412	41°05'50.53"N	111°51'05.80"W	41.09736111	-111.8516111		7935.900204	41°03'23.53"N	111°50'01.93"W	41.05652778	-111.8338611
8	9546.095785	41°05'32.07"N	111°51'17.70"W	41.09222222	-111.8549167		8331.679563	41°03'51.72"N	111°50'10.51"W	41.06436111	-111.83625
9	9587.395442	41°05'15.68"N	111°51'03.37"W	41.08766667	-111.8509167		8130.873092	41°04'20.59"N	111°50'19.29"W	41.07236111	-111.8386667
10	9660.743362	41°04'55.09"N	111°51'04.26"W	41.08194444	-111.8511667		8337.362561	41°05'06.65"N	111°50'33.31"W	41.08516667	-111.8425833
11	9313.01357	41°04'32.17"N	111°50'53.92"W	41.07558333	-111.8483056		8482.047125	41°05'30.03"N	111°50'40.42"W	41.09166667	-111.8445556
12	9349.059557	41°04'07.49"N	111°51'04.94"W	41.06872222	-111.8513611		5784.060846	41°07'08.95"N	111°49'29.52"W	41.11913889	-111.8248611
13	9334.976615	41°04'02.20"N	111°51'06.63"W	41.06727778	-111.8518333		6200.582147	41°04'11.19"N	111°48'18.12"W	41.06975	-111.8050278
14	9456.360486	41°03'46.27"N	111°50'56.60"W	41.06283333	-111.8490556		5977.47902	41°05'16.73"N	111°48'23.85"W	41.08797222	-111.8066111
15	9293.289282	41°03'28.92"N	111°50'40.30"W	41.05802778	-111.8445278		5836.34683	41°06'11.66"N	111°48'28.66"W	41.10322222	-111.8079444
16	9242.578837	41°03'06.26"N	111°50'38.06"W	41.05172222	-111.8438889						
17	9290.630007	41°02'59.05"N	111°50'37.37"W	41.04972222	-111.8436944						
18	9302.509435	41°02'42.41"N	111°50'21.85"W	41.04511111	-111.8393889						
19	9221.27981	41°02'25.82"N	111°50'20.47"W	41.0405	-111.839						
20	9360.17164	41°02'15.48"N	111°50'04.36"W	41.03761111	-111.8345278						
21	9367.06573	41°02'12.83"N	111°50'02.50"W	41.03688889	-111.8340278						
22	9468.713297	41°01'56.27"N	111°50'19.08"W	41.03227778	-111.8386111						
23	9285.656683	41°01'33.06"N	111°50'14.88"W	41.02583333	-111.8374444						
24	9025.812713	41°01'05.67"N	111°49'31.87"W	41.01822222	-111.8255						
25	8832.67889	41°00'54.23"N	111°49'23.57"W	41.01505556	-111.8231944						