Optimising Snowmaking Operations

BLUE MOUNTAIN

MGSC 662: Decision Analytics

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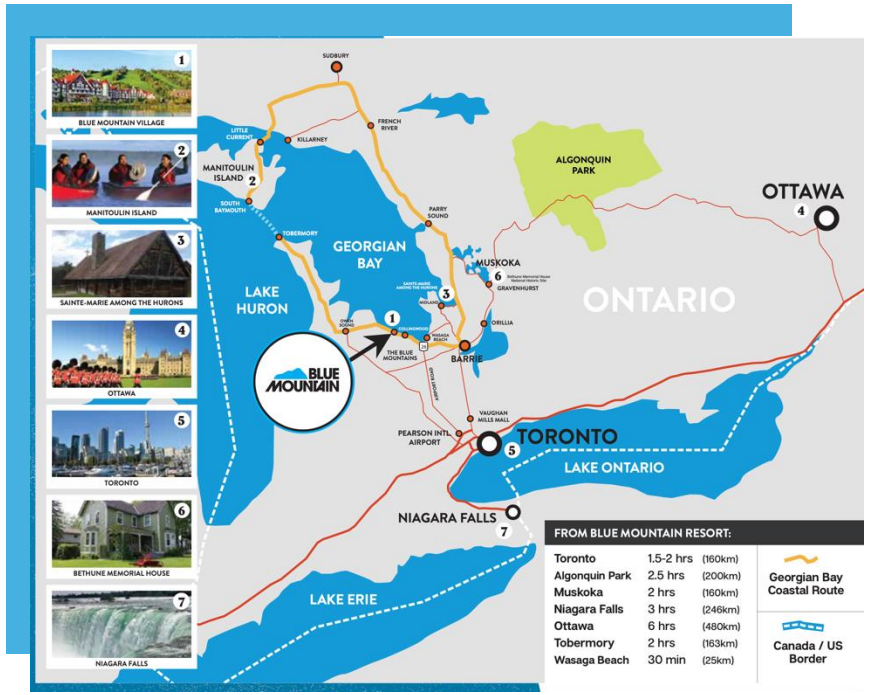
Blue Mountain: Ontario's Largest Ski Resort



Just a 2-hour drive from Toronto – attracts a mix of lakefront homeowners, cottagers, and city tourists

Accessible and family-friendly: modest terrain that is perfect for new to intermediate skiers

One of the few outdoor activities to embrace Canada's cold winters

Beyond the Resort: An Economic Pillar for the Region

Ontario's Only Four-Season Mountain Village Resort

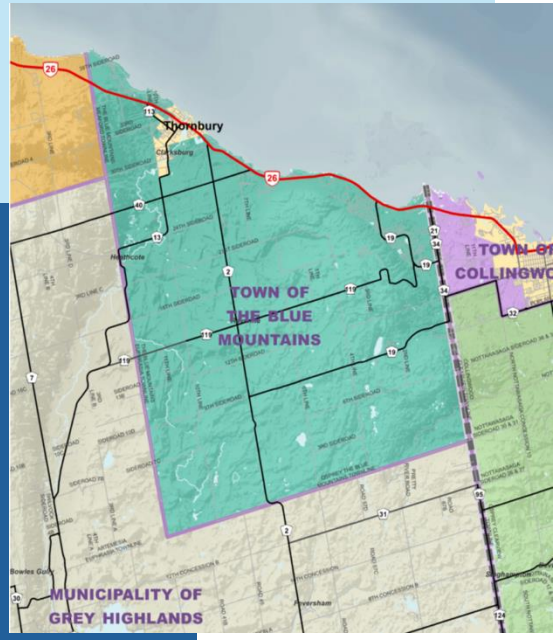
Winter is the core

Skiing contributes the majority to the resort's revenue

Stability during slower months for other industries

Beyond the Resort: An Economic Pillar for the Region

Critical for the Community



Helping Local Businesses:
Breweries, Orchards, Farmer's Markets

Real Estate and Housing:
Market prices due to popularity of the resort

Job Creation and Stability:
Employees of the resort, jobs for industries

Long-Term Community Growth:
Municipal development

The Problem

The success of Blue Mountain Resort heavily depends on the availability of snow

Natural Snowfall + Manmade Snow = Sufficient Skiing Conditions

Decreased Ski Numbers → Lower Economic Activity in Surrounding Townships

Decreased Ski Numbers → Less Resort Revenue

Pressures of Warmer Climate → More Reliance on Manmade Snow

Pressures of Warmer Climate → Greater Resource Utilization and Cost

Pressures of Warmer Climate → Hurting Sustainability and Reputation

Optimising Manmade Snow Coverage

What are we Optimising?

The placement of snow guns across the resort to ensure adequate coverage

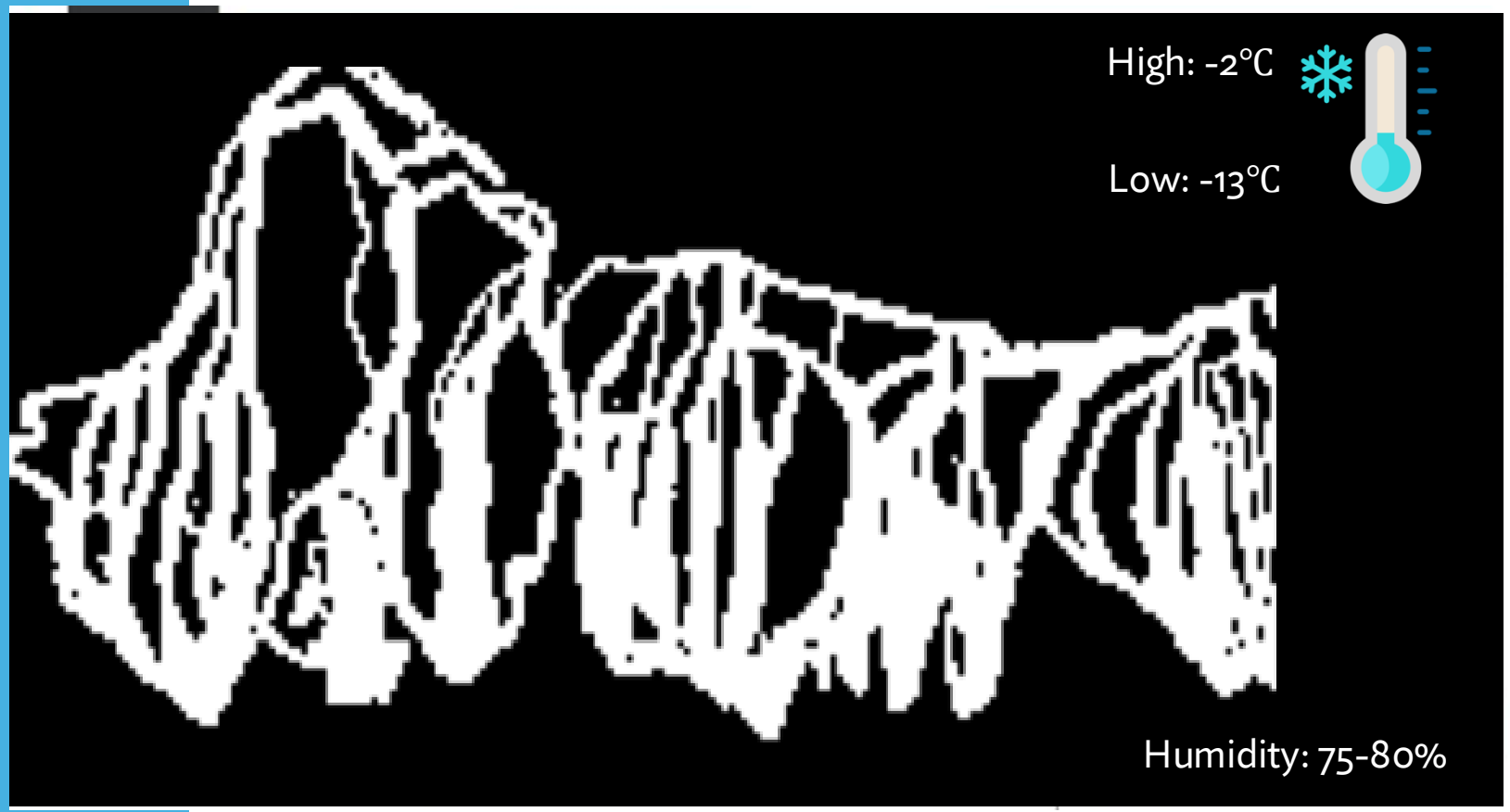
Why Optimise?

Reduce the cost of producing snow
Lower environmental impact
Meet visitor expectations

BLUE MOUNTAIN

Mapping out the Mountain

Elevation:
220m



Source:
1. https://www.bluemountain.ca/-/media/blue-mountain/mountain-report/maps/fy25/winter/maps/bmr-winter-25-mountain-web.pdf?rev=da3491df1096415e85db4d6755901829
2. https://www.theweathernetwork.com/ca/historical/ontario/blue-mountain-ski-area

Mapping out the Mountain

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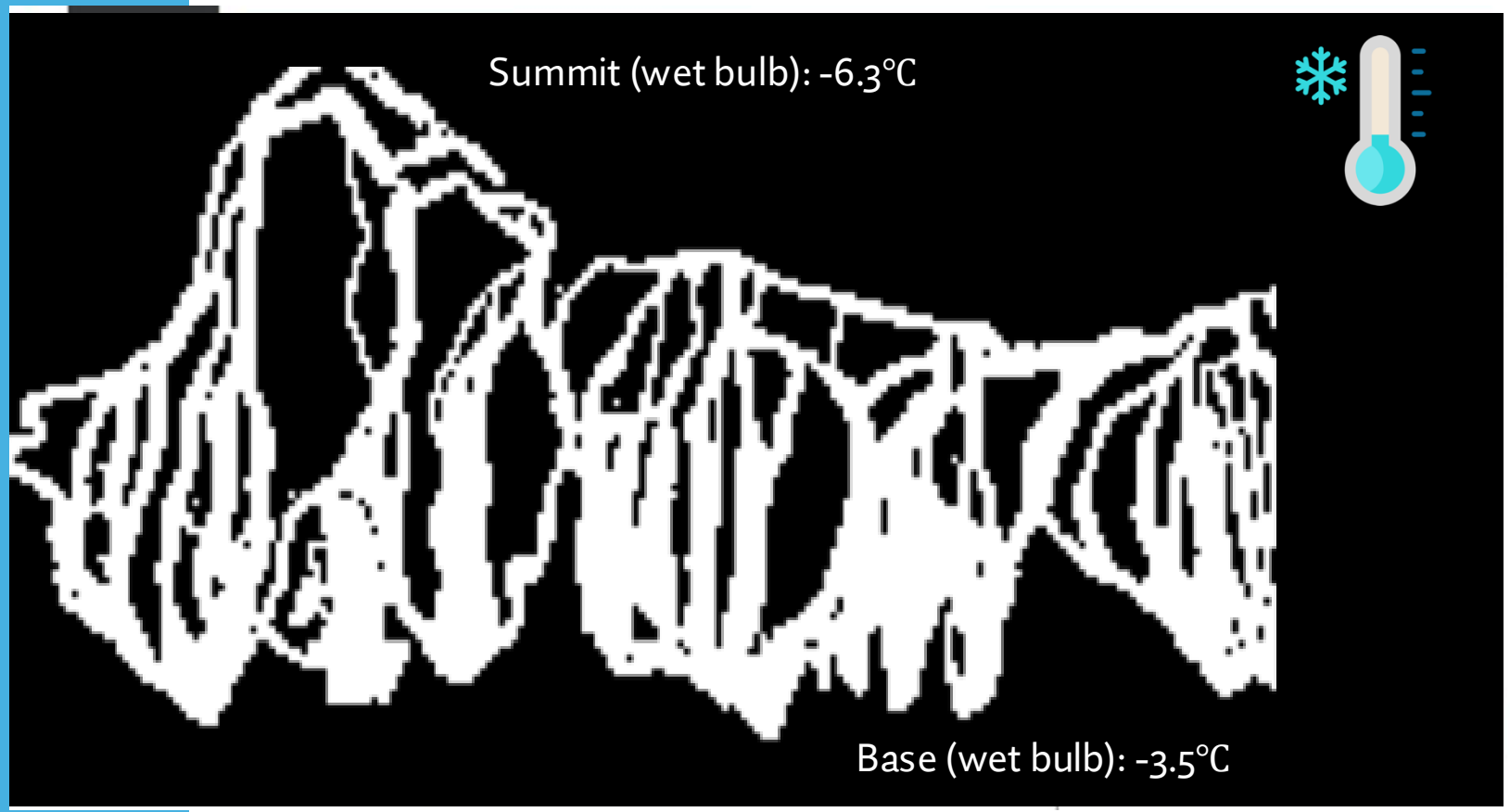


Source: https://www.technoalpin.com/en/wet-bulb-calculator

Snow lances

Fan guns

Snow Factory

Demac Lenko

Snowmaking industry's innovative leader

Fan gun Ventus

Throwing range: 70m

Mini operating temperature (wet-bulb): -2.5°C

Mini distance between snow guns: 30m

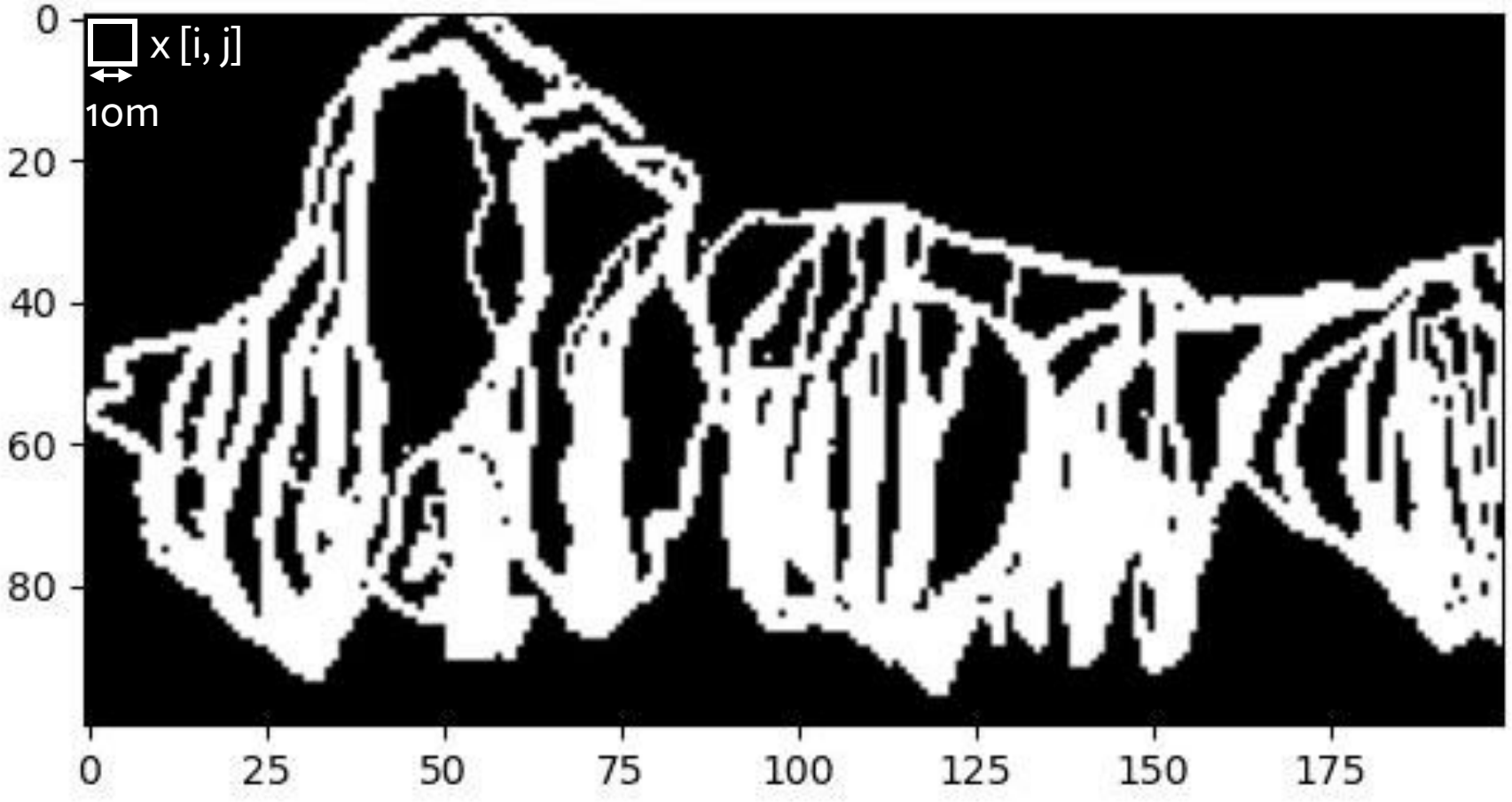
Demac Lenko

Snowmaking industry's innovative leader

Source: https://www.demaclenko.com/media/download/ventus4.oblizzard-productcatalog_low_en.pdf?ts=1667211673

Simplifying **the problem**

Decision Variables



Objective Function:

Minimise the number of snow guns placed on the mountain

$$\text{Minimise} \quad \sum_{i=0}^{height-1} \sum_{j=0}^{width-1} x_{i,j}$$

Where:

- $x_{i,j} \begin{cases} 1 \; if \; snow \; gun \; is \; placed \; at \; position \; (i,j) \\ 0 \; otherwise \end{cases}$

Constraint 1

Every section of the slope will need to be covered in snow i.e. ≥ 1 snow gun is placed within its surrounding coverage area

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Every section of the slope will need to be covered in snow i.e. ≥ 1 snow gun is placed within its surrounding coverage area

$$\sum_{ni=i-\left\lfloor\frac{coverage\ size}{2}\right\rfloor}^{i+\left\lfloor\frac{coverage\ size}{2}\right\rfloor} \sum_{nj=j-\left\lfloor\frac{coverage\ size}{2}\right\rfloor}^{j+\left\lfloor\frac{coverage\ size}{2}\right\rfloor} x_{ni,nj} \geq 1\,,$$

$\forall\ (i, j)$ such that slope exists in matrix

Where:

- $x_{ni,nj}$: Binary variable indicating whether a snow gun is placed at position (ni, nj)
- $coverage\ size$: Range of snow gun

Constraint 2

A snow gun can only be placed at each spot on the slope if the temperature is less than or equal to minimum operating temperature

$$x_{i,j} \cdot (T_{i,j} - T_{min}) \leq 0 \quad \forall \text{ i, j}$$

Where:

- $x_{i,j}$ Binary variable indicating whether snow gun is placed at position (i, j)
- $T_{i,j}$: Temperature at cell (i, j)
- T_{min}: Minimum operating temperature for Fan gun Ventus

Constraint 3

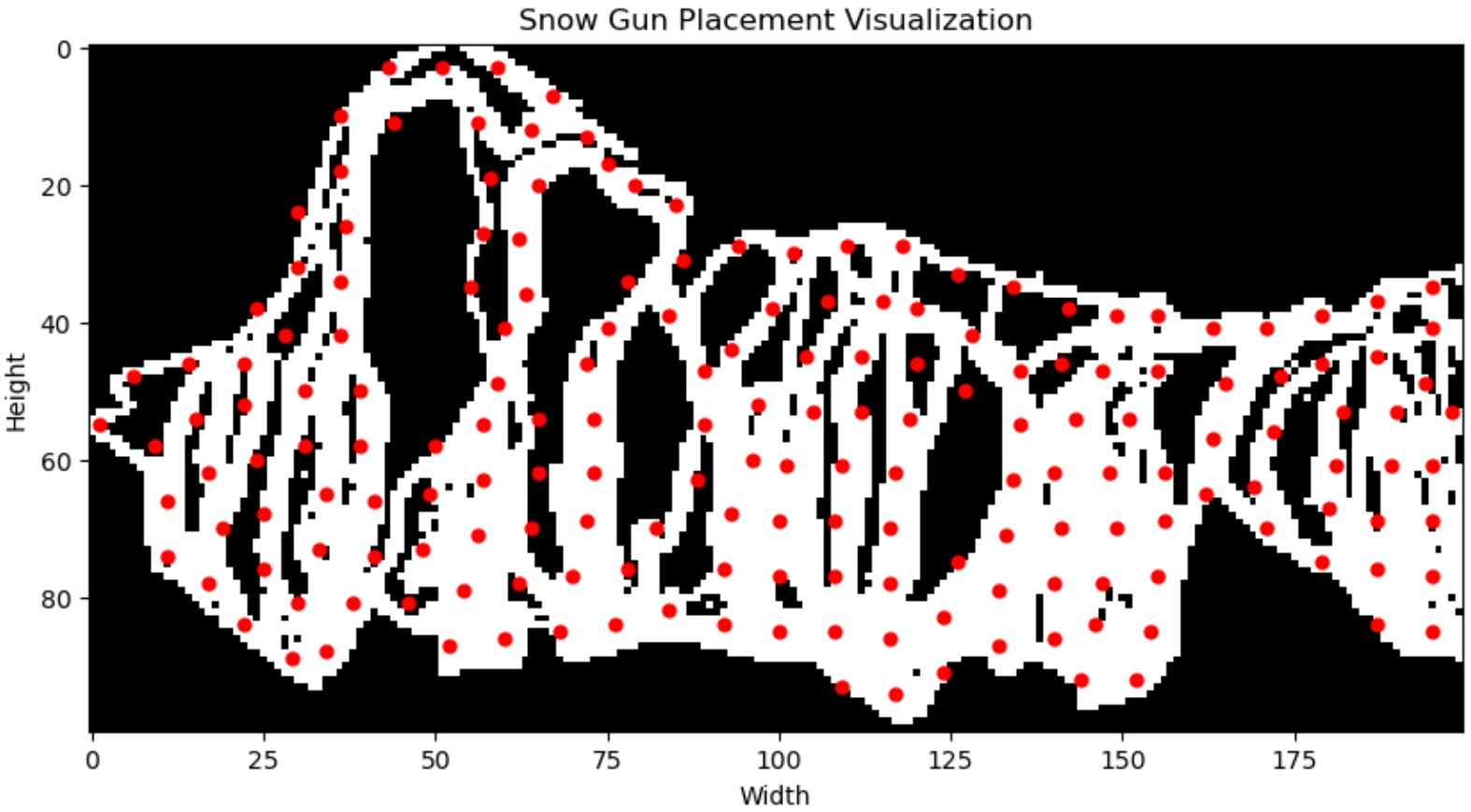
No 2 snow guns can be placed within a given distance d of each other

$$x_{i,j} + x_{k,l} \leq 1$$

$$\forall\ (\mathrm{i}, \mathrm{j}), (\mathrm{k}, \mathrm{l}) \text{ such that } |i - \mathrm{k}| + |\mathrm{j} - 1| \leq d$$

Where:

- $x_{i,j} = 1$ if snowgun is placed at cell (i, j)
- $x_{k,l} = 1$ if snowgun is placed at cell (k, l)
- $|i - \mathrm{k}| + |\mathrm{j} - 1|$: Manhattan distance between the 2 points

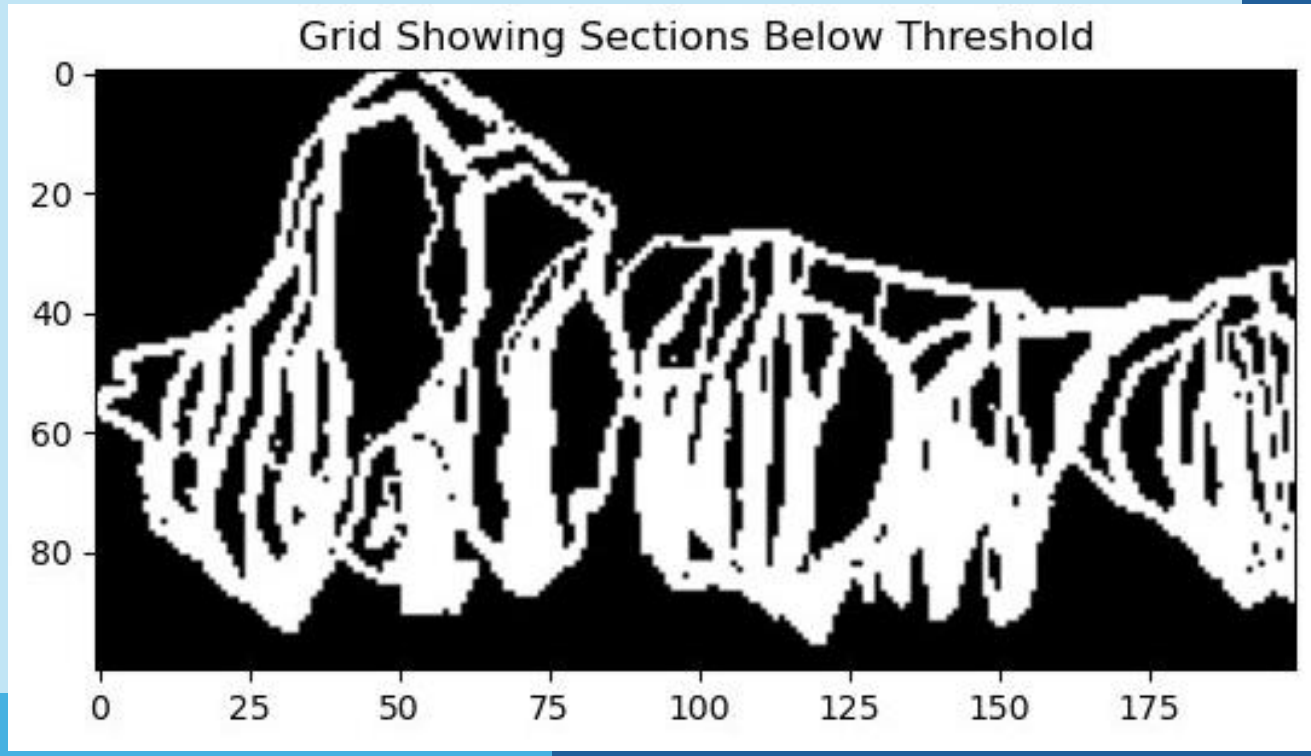


Total number of snow guns: 186

The Solution

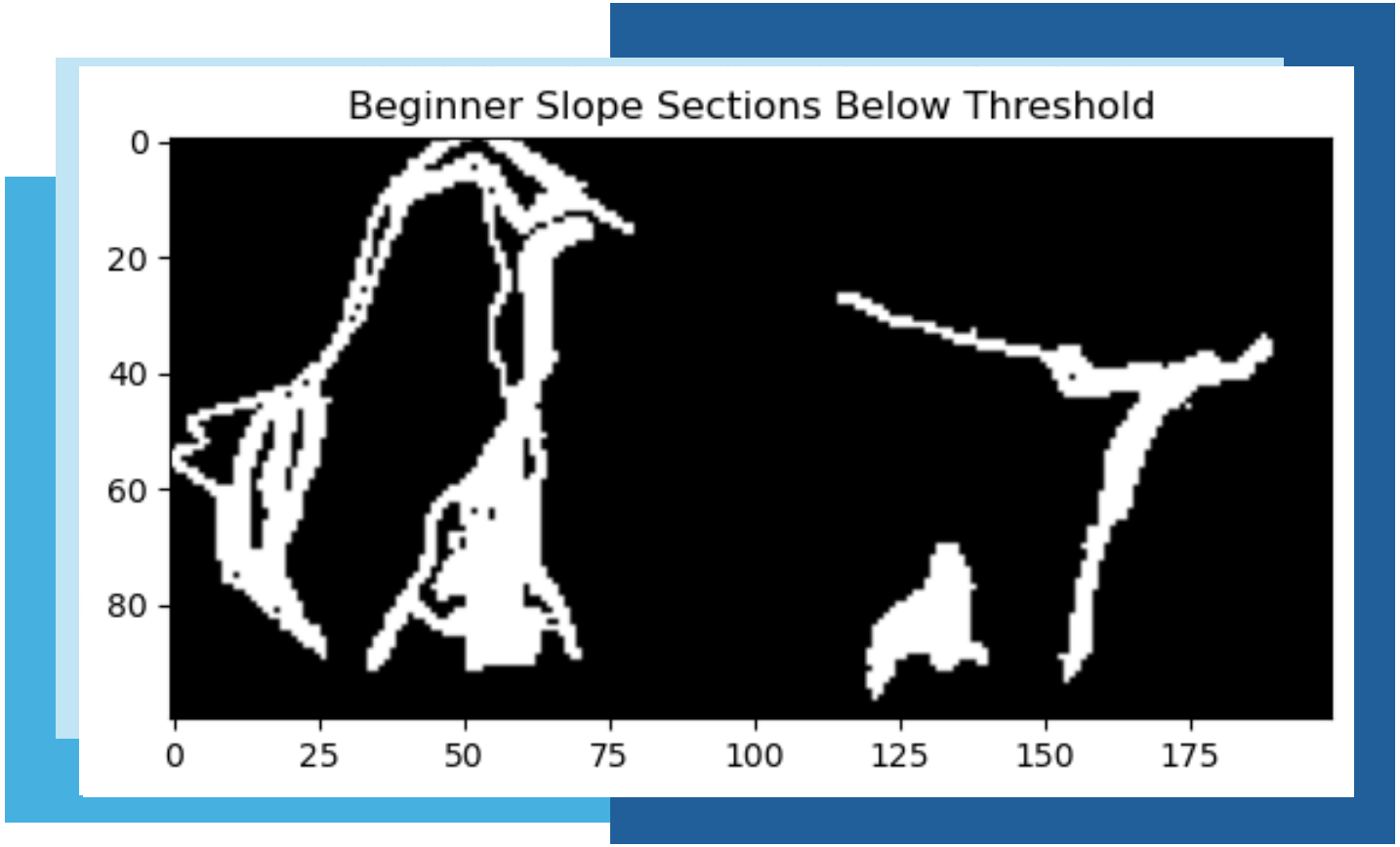
More *realistic* considerations

3 Levels of Terrain



3 Levels of Terrain

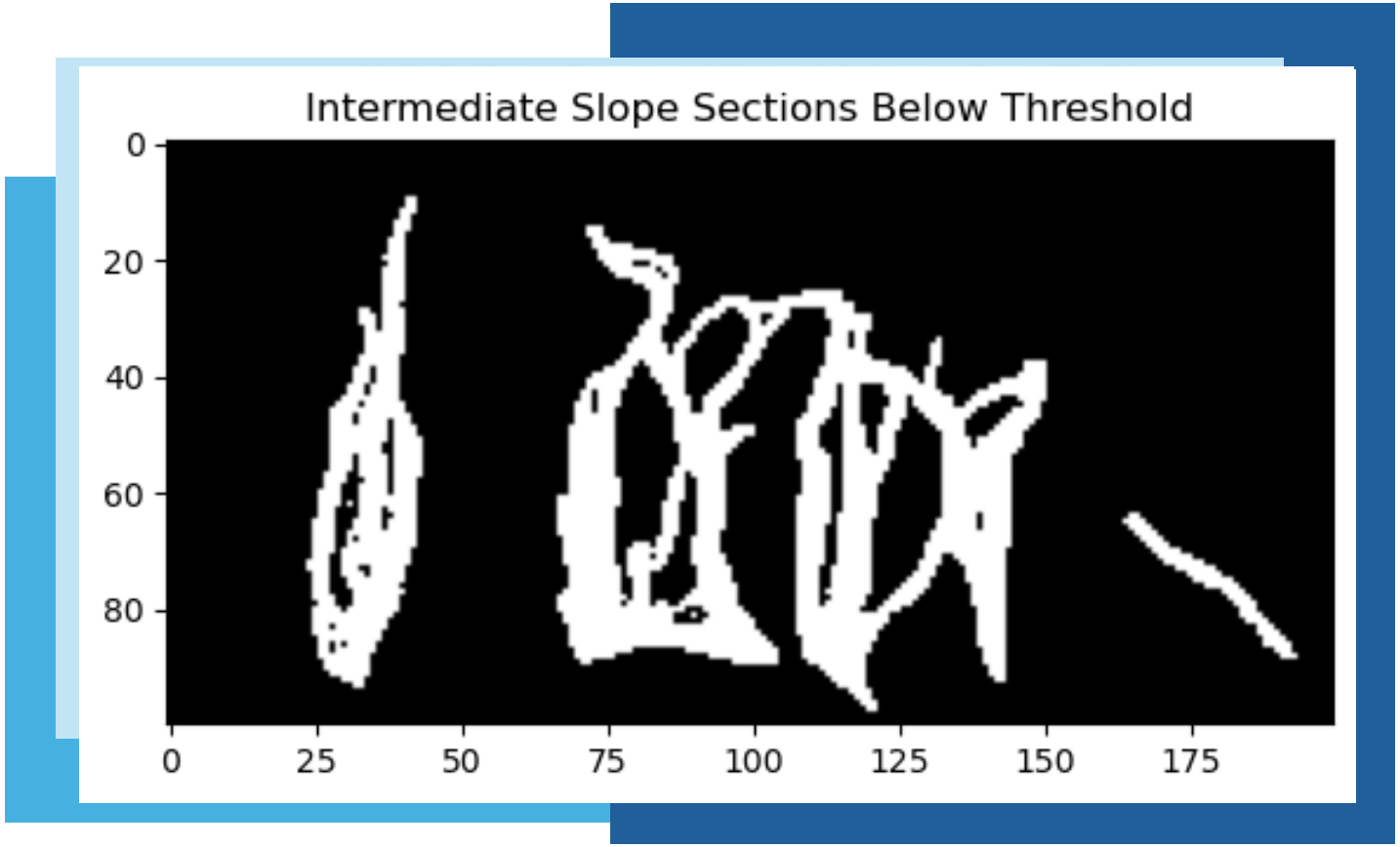
Beginner



Snow requirement: 400m³/h

3 Levels of Terrain

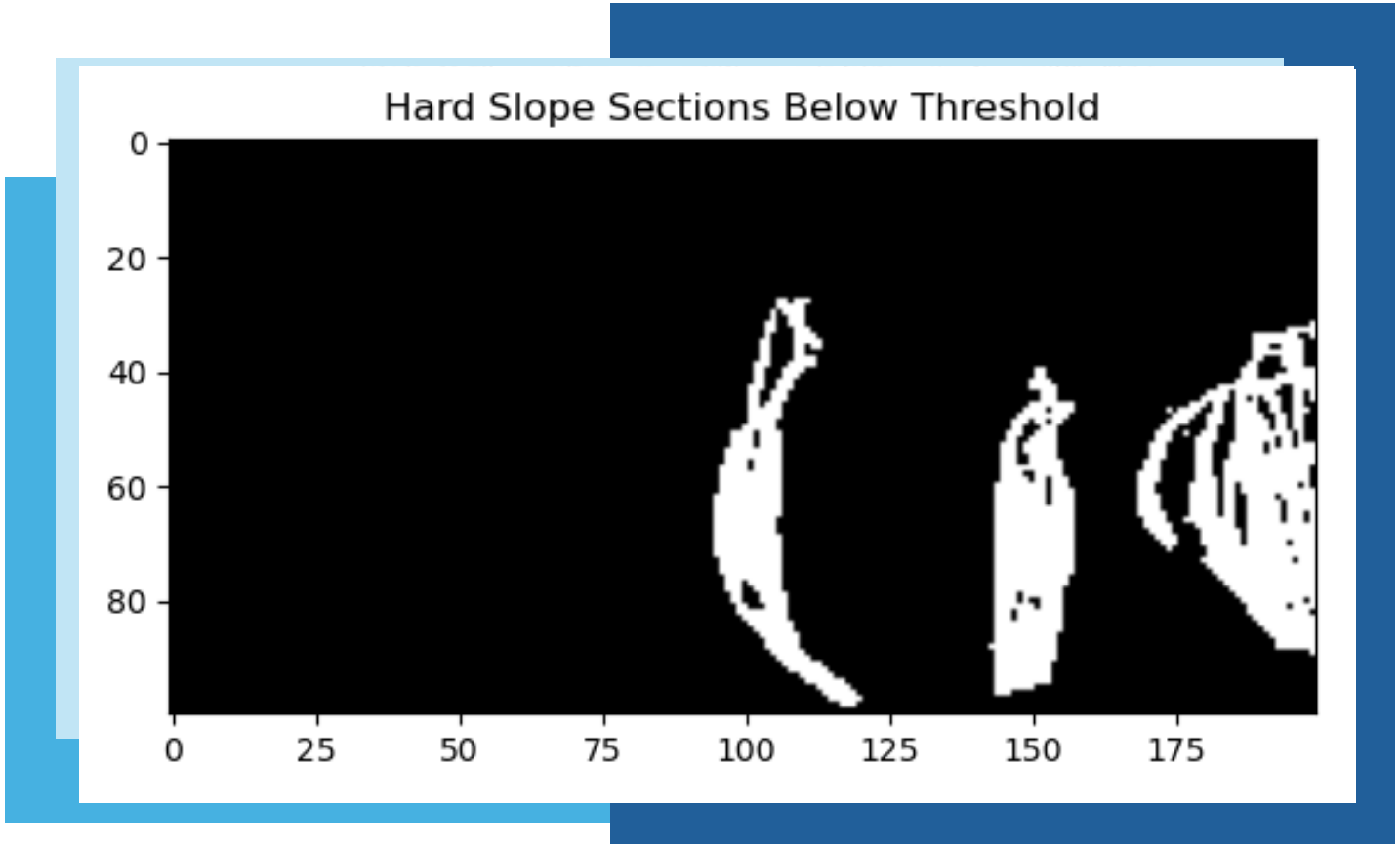
Beginner
Intermediate



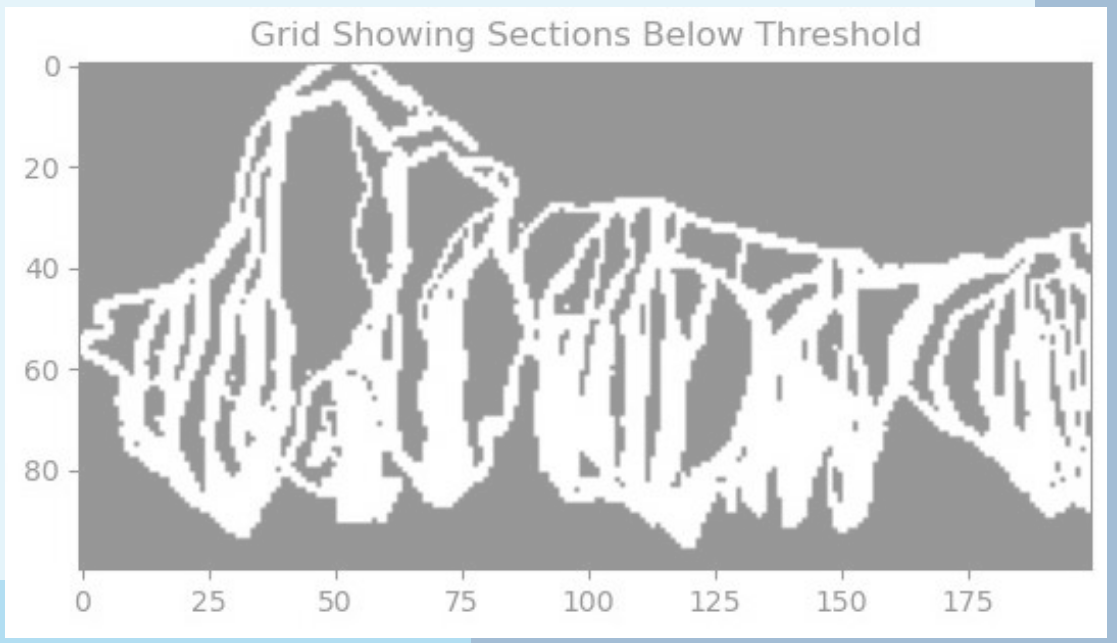
Snow requirement: 200m³/h

3 Levels of Terrain

Beginner
Intermediate
Difficult



Snow requirement: 100m³/h



3 Levels of Terrain:

Beginner

Intermediate

Difficult

5 Different Types of Snow guns:

Lances x 2

Snow guns x 3

Varying Electricity and Water Consumption

Snow gun Specifications

Lance EOS

Lance DUO

Fan gun Ventus

Fan gun Evo

Fan gun Titus

Range (m) = 30, 30, 70, 60, 80

Power consumption (kW/h) = 2, 4.8, 20, 14.2, 23

Water consumption (l/h) = 24840, 28800, 32400, 28800, 43200

Min operating temperature (°C) = -4, -4, -2.5, -2.5, -2.5

Min distance (m) = 20, 20, 30, 30, 30

Snow production (m^3/h) = 69, 80, 90, 80, 120

Snow gun technical specifications from Demac Lenko

ESG Pillars

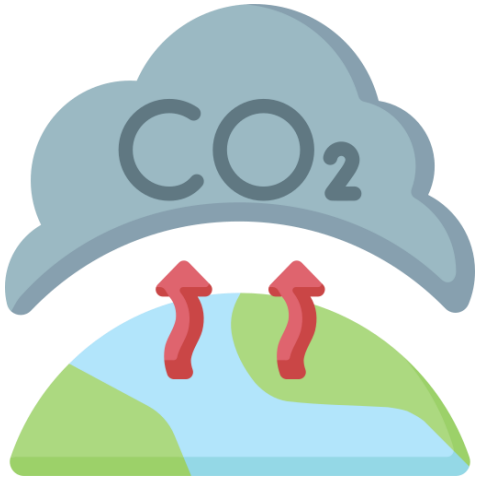
Adapted from Techtarget

ESG Pillars

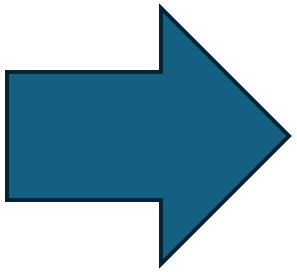
Adapted from Techtarget

Environmental impact of Snow making

Journal Current Issues in Tourism



478 GWh of electricity annually



1700 homes

Sustainability of Snowmaking as Climate Change (mal)Adaptation: An Assessment of Water, Energy, and Emissions in Canada's Ski Industry, *Current Issues in Tourism* (2023). DOI: 10.1080/13683500.2023.2214358

Environmental impact of Snow making

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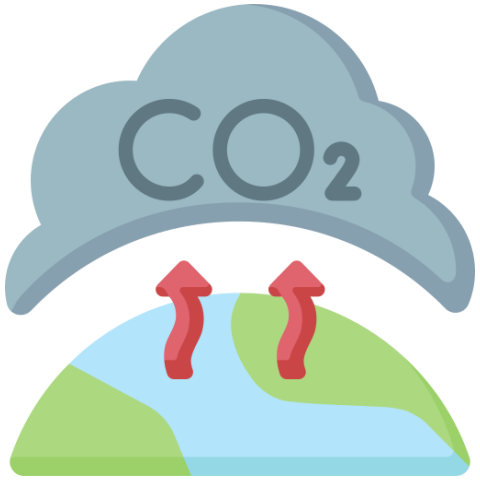
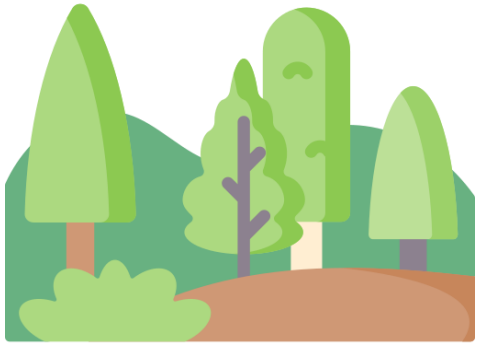


130,095 tons of emissions

155,000 acres of forest to offset CO_2



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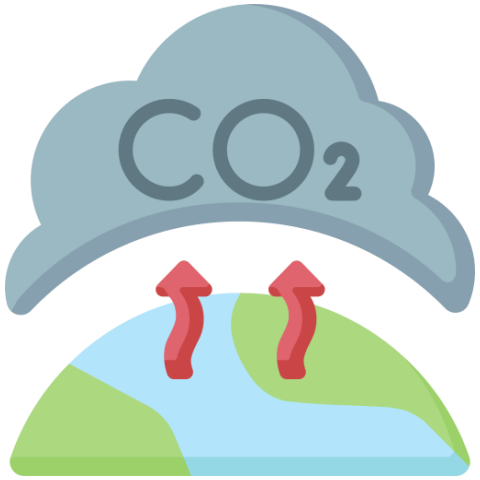

130,095 tons of emissions

55 – 97%
by 2050

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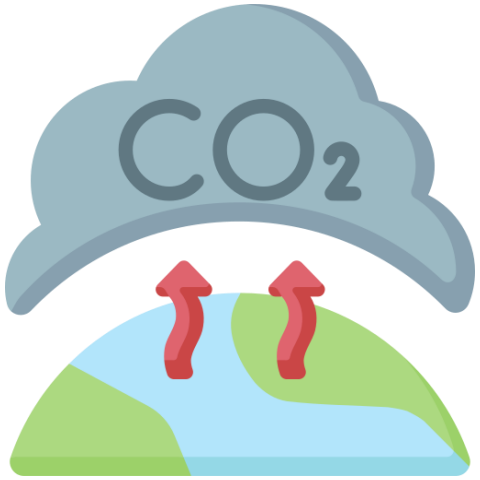
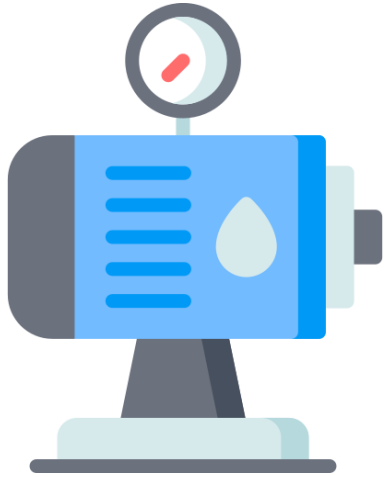


130,095 tons of emissions

43.4 million m^3 water



Spandre, P., Morin, S., Lafaysse, M., Lejeune, Y., François, H., and George-Marcelpoil, E. (2016). Integration of snow management processes into a detailed snowpack model. *Cold Regions Sci. Technol.* 125, 48–64. doi: 10.1016/j.coldregions.2016.01.002

Environmental impact of Snow making

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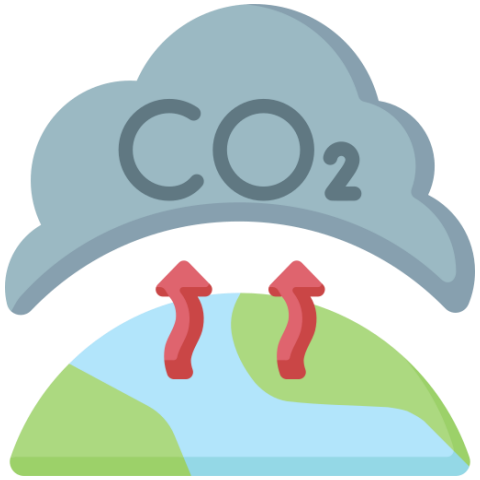

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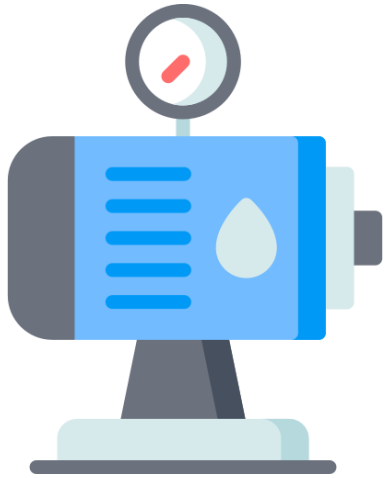

7-35% water lost to evaporation

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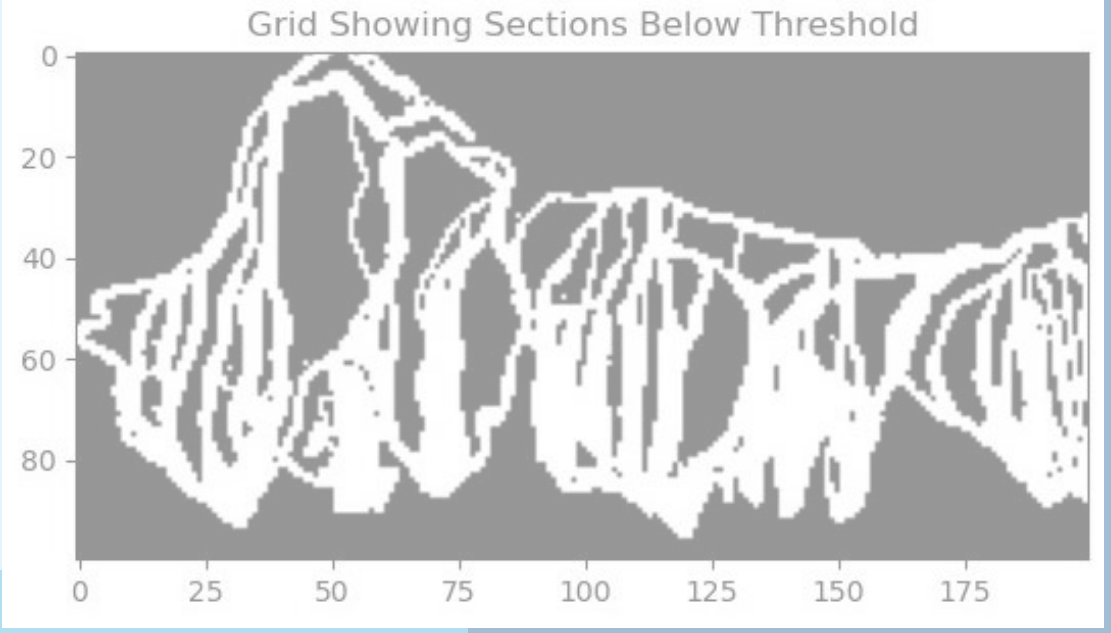
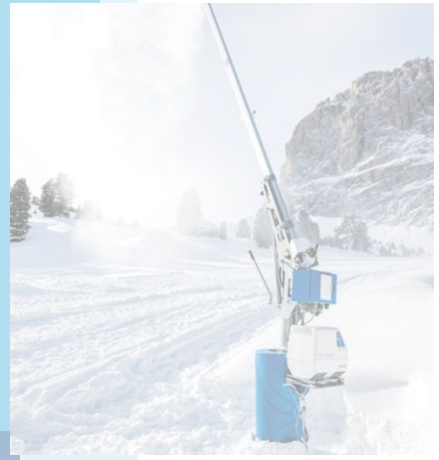


5 Different Types of Snow guns:

Lances x 2

Snow guns x 3



3 Levels of Terrain:

Beginner

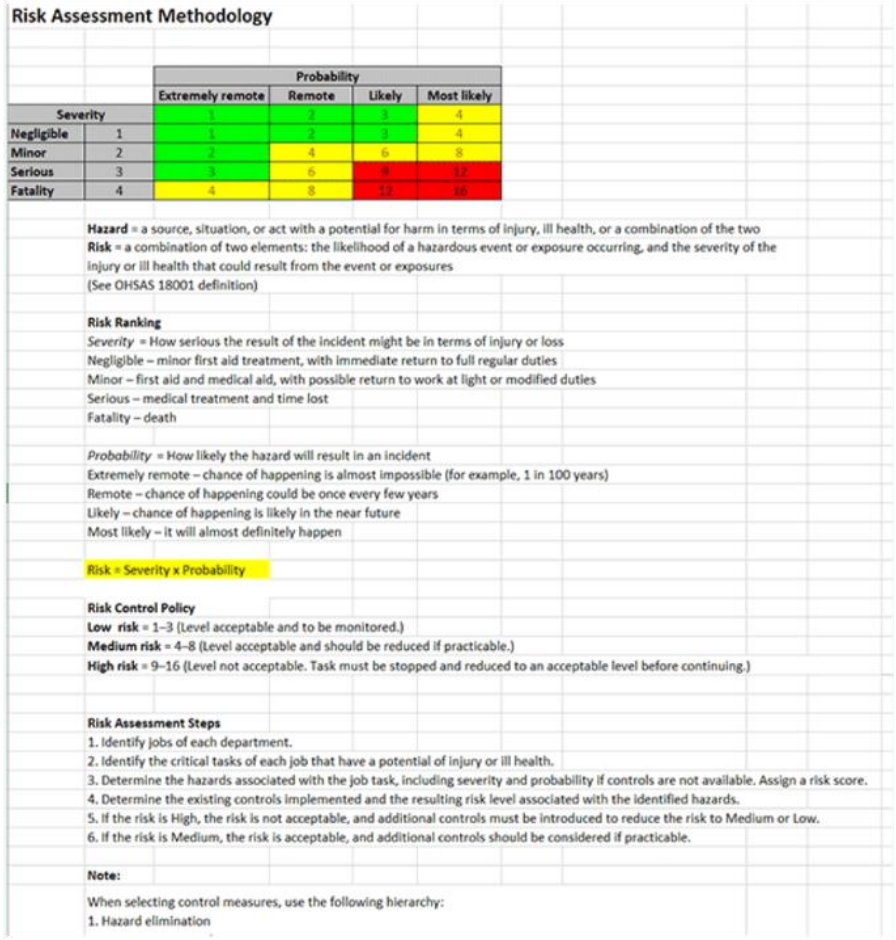
Intermediate

Difficult

Varying Electricity and Water Consumption

Safety

Hazard & Risk Assessment for Ski Areas



Risk Assessment Methodology

		Probability			
		Extremely remote	Remote	Likely	Most likely
Severity		1	2	3	4
Negligible	1	1	2	3	4
Minor	2	2	4	6	8
Serious	3	3	6	9	12
Fatality	4	4	8	12	16

Hazard = a source, situation, or act with a potential for harm in terms of injury, ill health, or a combination of the two
Risk = a combination of two elements: the likelihood of a hazardous event or exposure occurring, and the severity of the injury or ill health that could result from the event or exposures
(See OHSAS 18001 definition)

Risk Ranking
Severity = How serious the result of the incident might be in terms of injury or loss
Negligible – minor first aid treatment, with immediate return to full regular duties
Minor – first aid and medical aid, with possible return to work at light or modified duties
Serious – medical treatment and time lost
Fatality – death

Probability = How likely the hazard will result in an incident
Extremely remote – chance of happening is almost impossible (for example, 1 in 100 years)
Remote – chance of happening could be once every few years
Likely – chance of happening is likely in the near future
Most likely – it will almost definitely happen

Risk = Severity x Probability

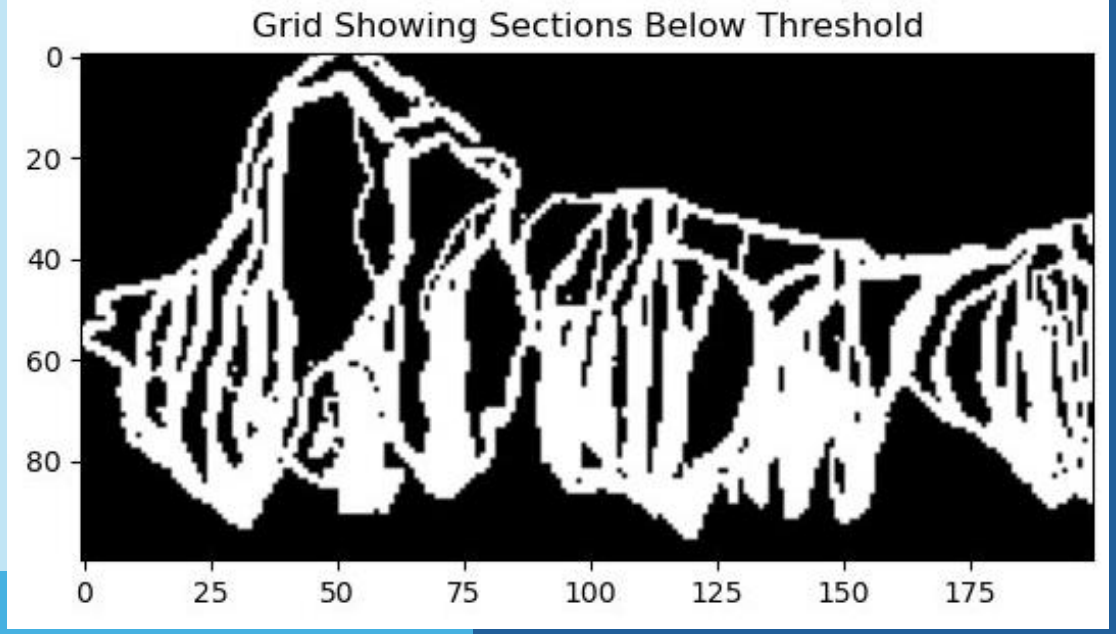
Risk Control Policy
Low risk = 1–3 (Level acceptable and to be monitored.)
Medium risk = 4–8 (Level acceptable and should be reduced if practicable.)
High risk = 9–16 (Level not acceptable. Task must be stopped and reduced to an acceptable level before continuing.)

Risk Assessment Steps
1. Identify jobs of each department.
2. Identify the critical tasks of each job that have a potential of injury or ill health.
3. Determine the hazards associated with the job task, including severity and probability if controls are not available. Assign a risk score.
4. Determine the existing controls implemented and the resulting risk level associated with the identified hazards.
5. If the risk is High, the risk is not acceptable, and additional controls must be introduced to reduce the risk to Medium or Low.
6. If the risk is Medium, the risk is acceptable, and additional controls should be considered if practicable.

Note:
When selecting control measures, use the following hierarchy:
1. Hazard elimination

Assessment conducted in medium sized ski area provided by go2HR, BC's tourism & hospitality, human resources and health & safety association

https://www.go2hr.ca/explore-all-resources/health-safety/hazard-identification-risk-assessment-tool-for-ski-areas



5 Different Types of Snow guns:

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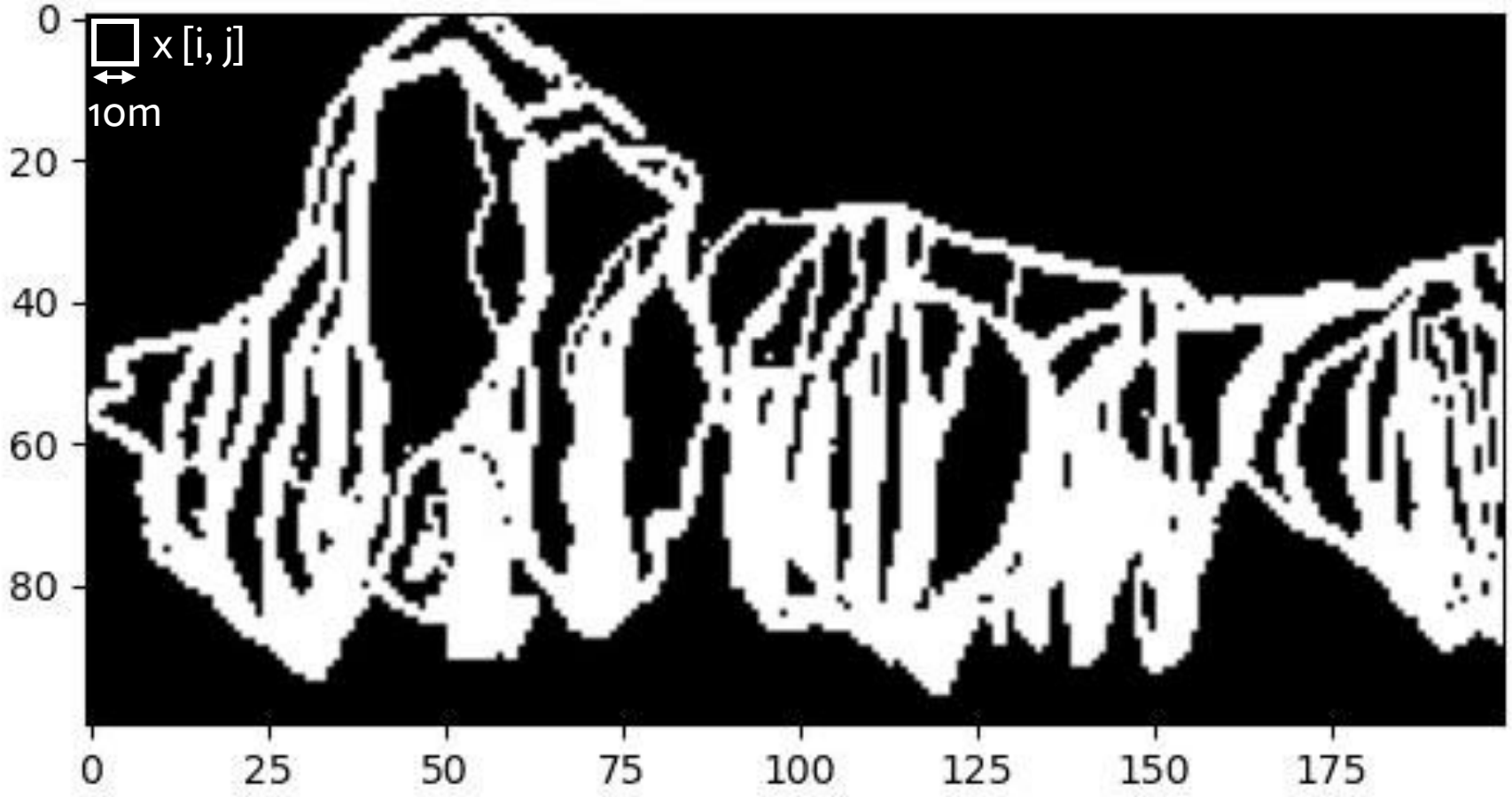
Decision Variables



For each snow gun, k

Objective Function 1: Cost

Minimise total cost of snow gun placement

Minimise

$$\sum_{i=0}^{height-1} \sum_{j=0}^{width-1} \sum_{k=0}^{4} x_{i,j,k} \cdot cost\_per\_snowgun[k]$$

Where:

- $x_{i,j,k}$: $\begin{cases} 1 \; when \; snow \; gun \; of \; type \; k \; is \; placed \; at \; position \; (i,j) \\ 0 \; otherwise \end{cases}$
- Cost per snow gun comprises of
  - Electrical cost = Power consumption · 0.125 (cents/kWh)[1]
  - Water cost = Water consumption[2] · 3.16/ 1000

[1] Electrical costs based on Hydro One electrical usage fees when electrical consumption > 750kW
[2] Water costs based on fees given by City of Toronto for total water consumption > 5000m^3

Objective Function 2: Safety

Maximise safety score of the ski resort

Maximise

$$\sum_{i=0}^{height-1} \sum_{j=0}^{width-1} \sum_{j=0}^{len(snowguns)-1} x[i,j,k] \cdot (3 \cdot black\_cells[i,j]$$
$$+ 2 \cdot (black\_cells[(\max(0, i-1), j]$$
$$+ black\_cells[\min(height-1, i+1), j]$$
$$+ black\_cells[i, \min(width-1, j+1)])$$
$$+ 1 \cdot (black\_cells[\max(0, i-2), j]$$
$$+ (black\_cells[min(height-1, i+2), j]$$
$$+ (black\_cells[i, \max(0, j-2)]$$
$$+ (black\_cells[i, \min(width-1, j+2)]))$$

Where:

- $x_{i,j,k}$: Binary variable indicating whether a snow gun of type k is placed at position (i, j)
- $black\ cells_{i,j}$: Matrix containing positions of all non-ski-slop areas which are shaded black on the map

Constraint 1

Every section of the slope will need to be covered in snow i.e. ≥ 1 snow gun is placed within its surrounding coverage area

$$\sum_{k=0}^{4} \sum_{ni=i-\left\lfloor \frac{coverage\ size[k]}{2} \right\rfloor}^{i+\left\lfloor \frac{coverage\ size[k]}{2} \right\rfloor} \sum_{nj=j-\left\lfloor \frac{coverage\ size[k]}{2} \right\rfloor}^{j+\left\lfloor \frac{coverage\ size[k]}{2} \right\rfloor} x_{ni,nj,k} \geq 1\,,$$

$\forall\ (i, j)$ such that ski slope exists in matrix

Where:

- $x_{i,j,k}$: Binary variable indicating whether a snow gun of type k is placed at position (i, j)
- $coverage\ size_k$: Range of snow gun k

Constraint 2

Every section of the slope can only hold at most 1 snow gun

$$\sum_{k=0}^{4} x_{i,j,k} \leq 1$$

$\forall\, i \in [0, height - 1], \forall\, j \in [0, width - 1]$ for each grid cell (i, j)

Where:

- $x_{ni,nj,k}$: Binary variable indicating whether a snow gun of type k is placed at position (ni, nj)
- Sum covers the region of cells within defined coverage area around each required cell (i, j)

Constraint 3

Total snow production for each section of slope must meet or exceed the minimum snow production required for the slope type

$$cell\ snow\ production_{i,j} = \sum_{k=0}^{4} \sum_{n_i=\max(0,i-\left\lfloor\frac{coverage\ size_k}{2}\right\rfloor)}^{\min(height,i+\left\lfloor\frac{coverage\ size_k}{2}\right\rfloor)} \sum_{n_j=\max(0,j-\left\lfloor\frac{coverage\ size_k}{2}\right\rfloor)}^{\min(width,j+\left\lfloor\frac{coverage\ size_k}{2}\right\rfloor)} x_{ni,nj,k} \cdot snow\ production_k$$

$$cell\ snow\ production_{i,j} \geq required\ snow_{i,j}$$

Where:

- $x_{ni,nj,k}$: Binary variable indicating whether snow gun k is placed at position (ni, nj)
- $coverage\ size_k$: Range of snow gun k
- $cell\ snow\ production_{i,j}$: Snow production received by each position (i, j)
- $snow\ production_k$: Snow production by snow gun k
- $required\ snow_{i,j}$: Minimum snow requirement for each cell belonging to beginner/ intermediate/ hard slope

Constraint 4

A snow gun can only be placed at each spot on the slope if the temperature is less than or equal to minimum operating temperature

$$\text{For all } i, j, k:$$

$$\begin{cases} \text{If beginner\_mask}[i,j] = 1: & x[i,j,k] \cdot (\text{temperature\_matrix}[i,j] - \text{min\_temp}[k]) \leq 0, \\ \text{If intermediate\_mask}[i,j] = 1: & x[i,j,k] \cdot (\text{temperature\_matrix}[i,j] - \text{min\_temp}[k]) \leq 0, \\ \text{If hard\_mask}[i,j] = 1: & x[i,j,k] \cdot (\text{temperature\_matrix}[i,j] - \text{min\_temp}[k]) \leq 0. \end{cases}$$

Where:

- $x_{i,j,k}$: Binary variable indicating whether snow gun k is placed at position (i, j)
- $temperature\ matrix_{i,j}$: Temperature at cell (i, j)
- min_temp_k: Minimum operating temperature for snow gun k
- $beginner\_mask_{i,j}$= 1 if the cell (i, j) belongs to beginner slope

Constraint 5

No 2 snow guns can be placed within a given distance of each other

$$x_{i,j,k} + x_{ni,nj,nk} \leq 1. \quad \forall\, k, nk\ \forall (i,j),(ni,nj),$$

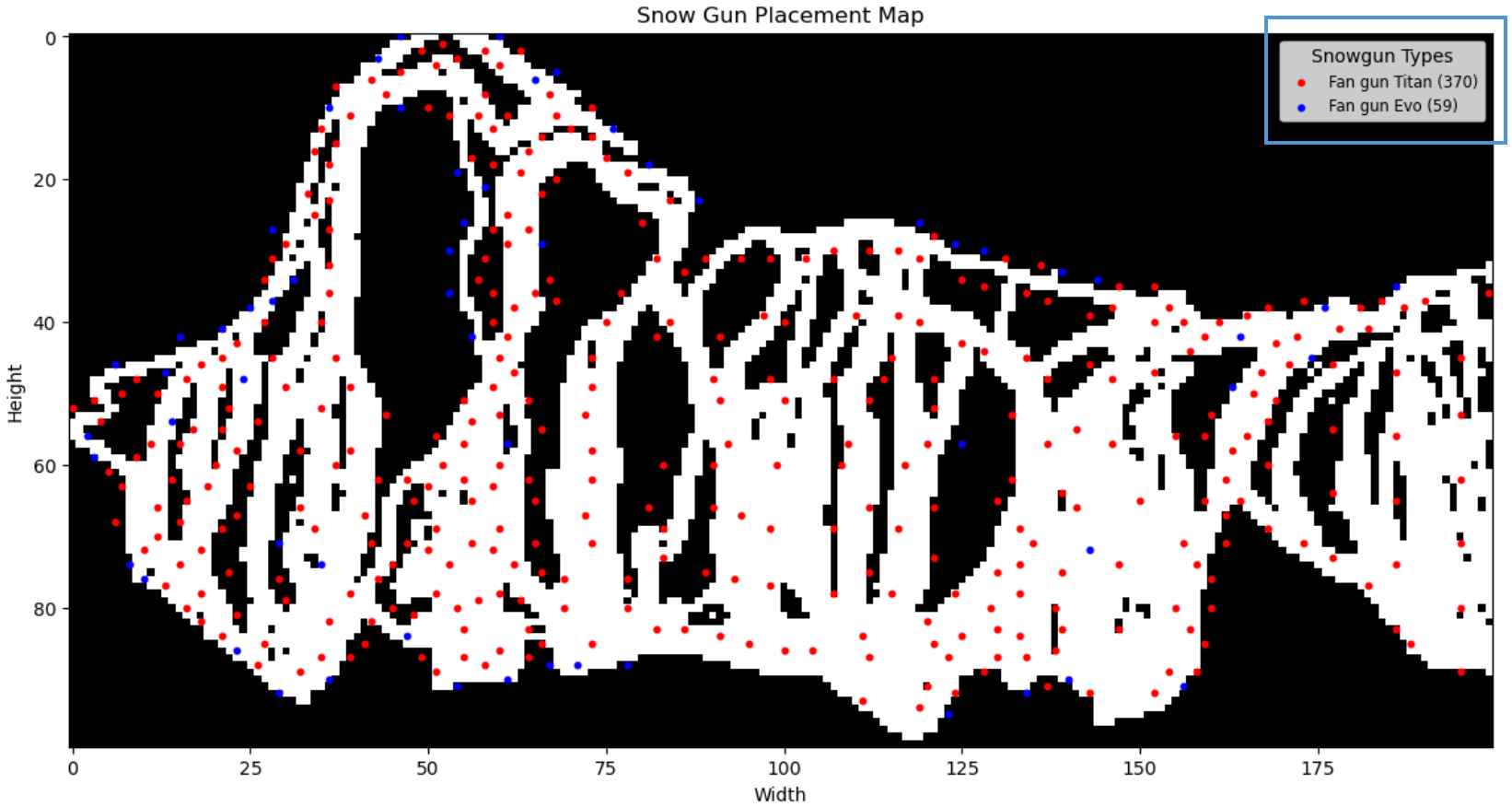
Subject to $|i - ni| + |\mathrm{j} - nj| \leq \max(\min\_distance[k], \min\_distance[nk])$

and *(i, j) ≠ (ni, nj)*

Where:

- $x_{i,j,k}$: Binary variable indicating whether a snow gun of type k is placed at position (i, j)
- $|i - ni| + |\mathrm{j} - nj|$: Manhattan distance between locations (i, j) and (ni, nj)
- $min\_distance_k$: refers to the respective minimum distance requirements for snow gun k

Note: Distance between snow guns applies across all slopes



Total cost: $57047.39
Security score: 3869

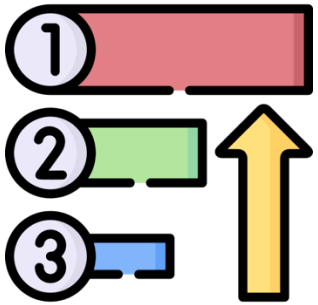
The Solution

Business Value & Future Extensions

Implications/ Benefits

Operational Efficiency

Optimised utilisation of snow guns

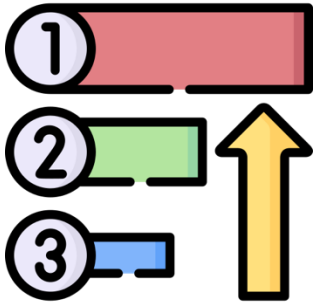


Slope-specific adjustments to fulfill demand

Implications/ Benefits

Operational Efficiency

Optimised utilisation of snow guns



Slope-specific adjustments to fulfill demand

Enhanced Safety

Reduced operational interferences

Reduced obstruction for skiers/ snowboarders

Implications/ Benefits

Financial savings

Cost-effective operations

Strategic Planning

Informed decisions

Flexible & scalable

Implications/ Benefits

Environmental Sustainability

Water conservation

Reduced carbon footprint

Implications/ Benefits

Environmental Sustainability

Water conservation

Reduced carbon footprint

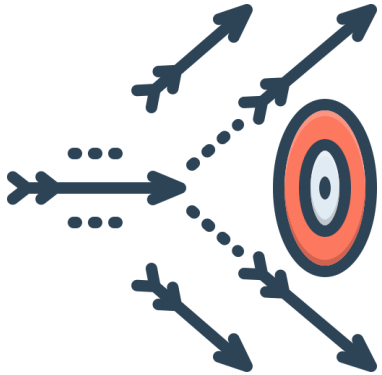
Improved Customer Experience

Better ski conditions

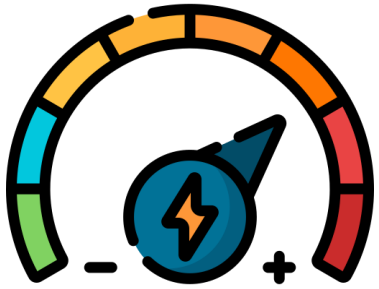
Slope availability

Competitive advantage

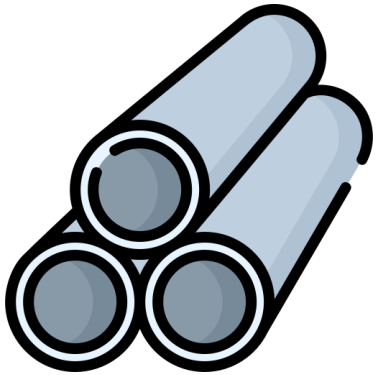
Limitations & Future Considerations



Noise in image processing



Computationally heavy



Infrastructure constraints not considered

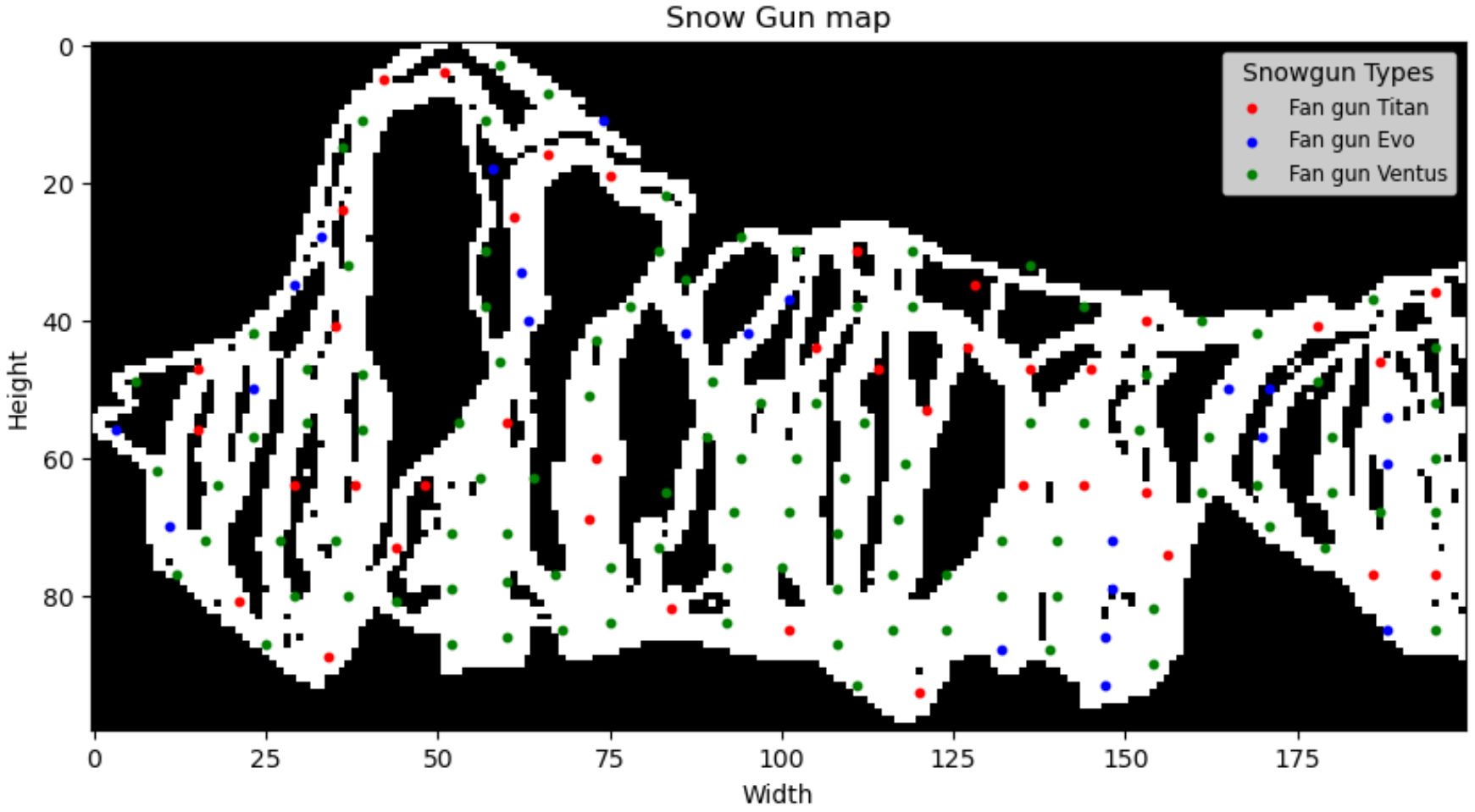
Feasibility of access to slopes not accounted

Weather conditions not fully assessed

The End

Appendix

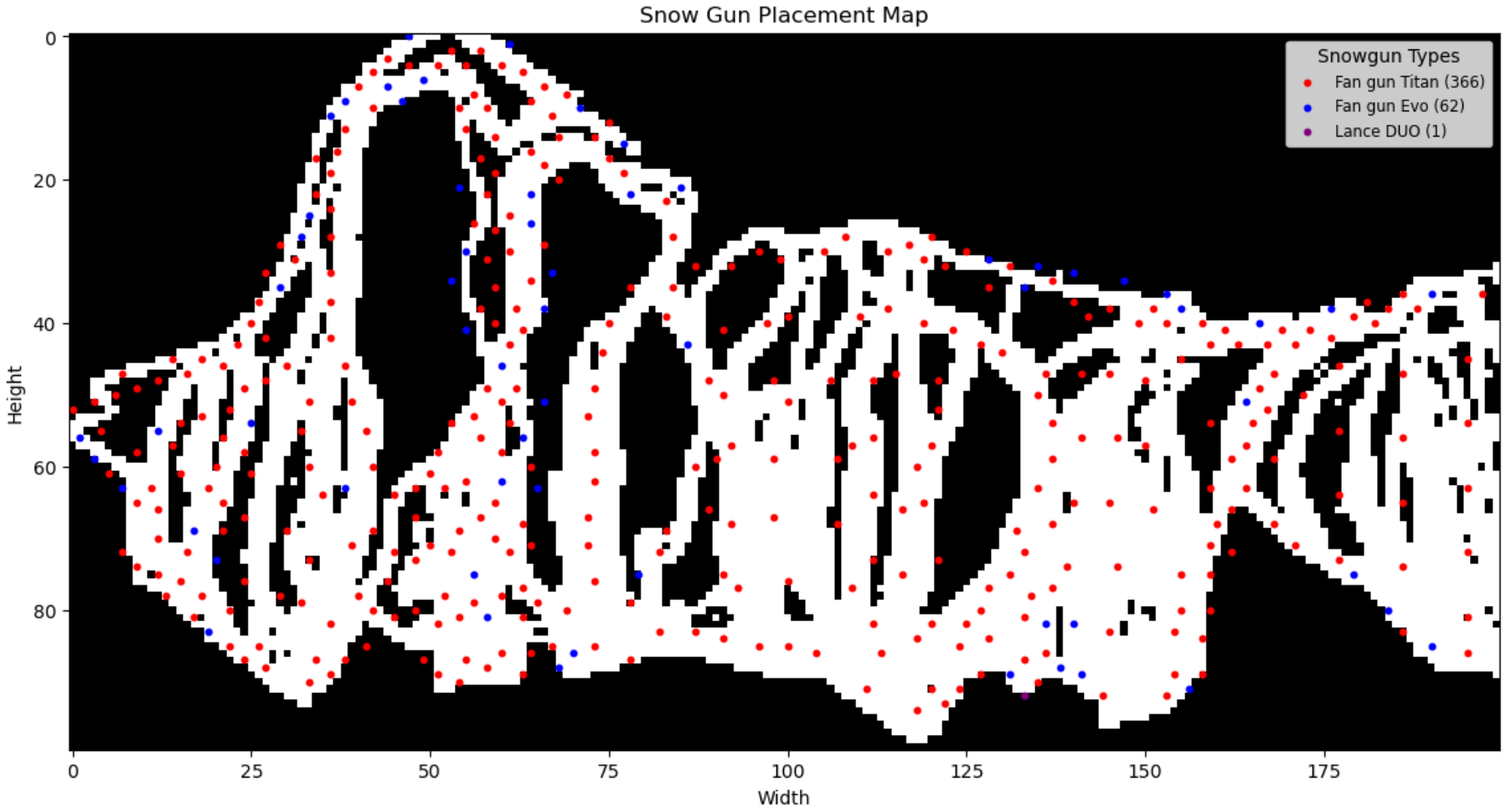
Iteration 2



Fan gun Titan: 39
Fan gun Evo: 23
Fan gun Ventus: 105
Lance EOS: 0
Lance DUO: 0

Total cost: $18592.92

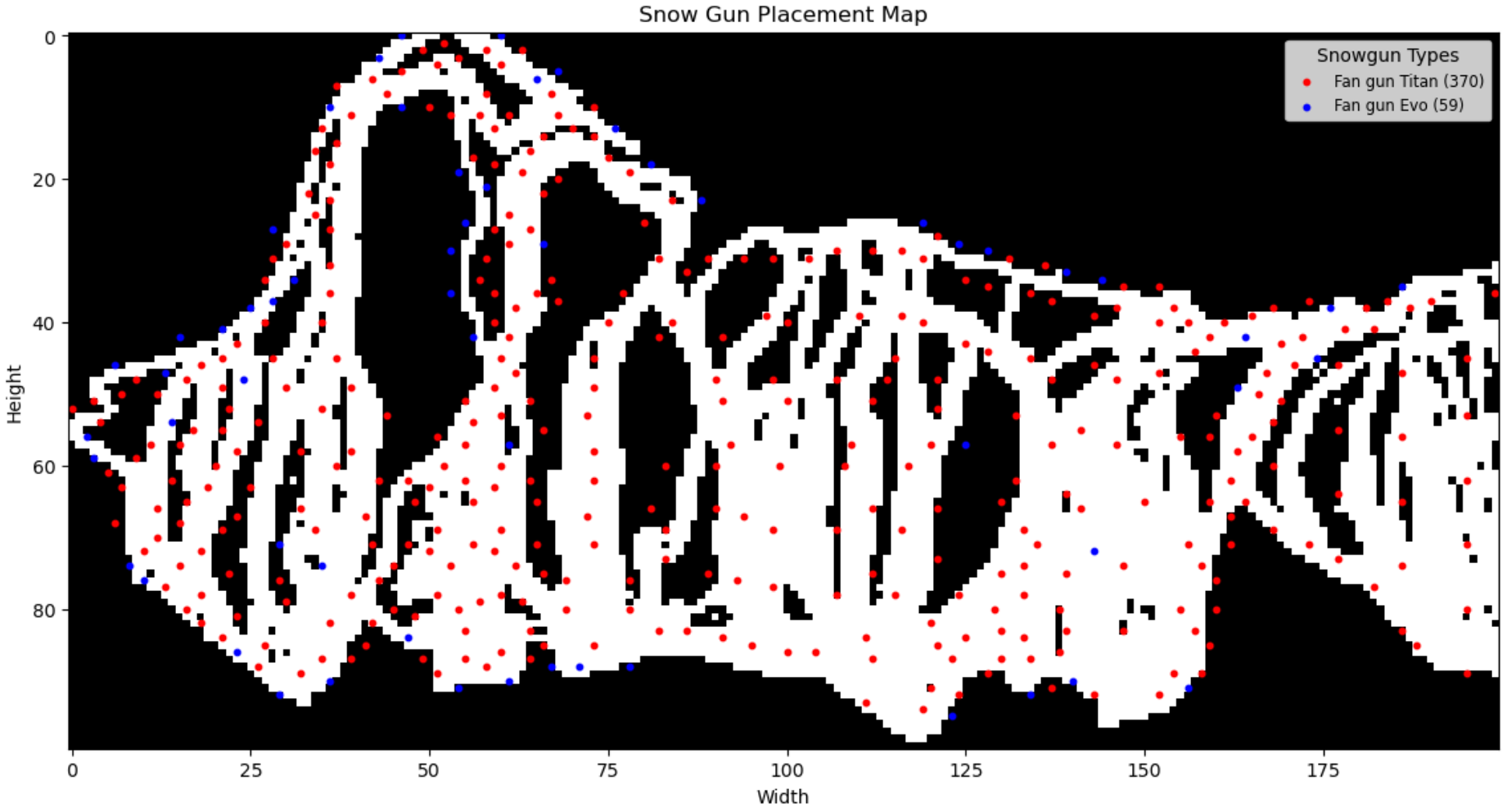
Iteration 3



Fan gun Titan: 366
Fan gun Evo: 62
Fan gun Ventus: 0
Lance EOS: 0
Lance DUO: 1

Total cost: $56860

Iteration 4



Fan gun Titan: 370
Fan gun Evo: 59
Fan gun Ventus: 0
Lance EOS: 0
Lance DUO: 0

Total cost: $57047.39
Security score: 3869