Programming Competition Case

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1. Background

In 2019 alone it was reported that there were 4,000 forest fires that burned 1.8 million hectares of land across Canada [1]. These numbers are not the worst Canada has experienced but there is an increasing trend in the frequency of forest fires across the country. It is only appropriate that each province does what they can to help predict and prevent the spread of future forest fires.

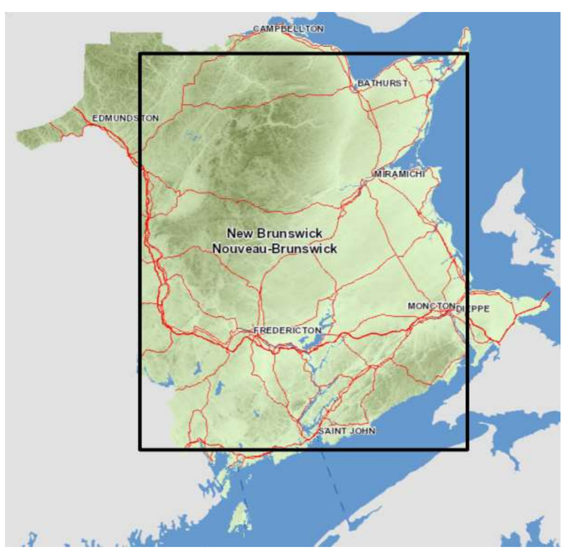
In the province of New Brunswick, according to the New Brunswick Forest Fire Watch [2], the 10-year average of forest fires between 2011-2020 was 198 fires with an average of 332.4 hectares of forest burnt. These numbers pale in comparison to the nationwide statistics, however, the province believes that investing in a program to predict the likelihood of fires occurring could bring down the national rates and mitigate future catastrophes. The province of New Brunswick is also extremely focused on protecting and preserving its many key locations such as national landmarks and historical sites that could potentially be damaged.

Figure 1: Fundy National Park [3].

Figure 2: Kouchibouguac National Park [4].

With the increasing danger that climate change presents to our environment, the province of New Brunswick has determined that action must be taken to help predict and combat forest fires. The province has been divided into approximately 73,000 fire zones, each covering 1 km^2 of land. The province intends to use each of these fire zones as a means of predicting, tracking, and analyzing forest fires that occur within them. With the data that each of these fire zones will provide, the province can then allocate firefighting resources as required. This will allow for predicted forest fires to be combated in the most efficient way possible.

Figure 3: Region of focus for the fire zones



The province is undecided as to what information is useful for this type of project and has thus prepared many data files. Having many concerns as to the execution of the project, the Government of New Brunswick has decided to contract a group of engineers to work on the design. The province hopes that with the help of a team of engineers, a program can be developed that can use the data effectively.

2. Competition Challenge

The province of New Brunswick has contracted you, a group of engineers, to develop a software implementation that will generate a forest fire prediction plan.

Several large data sets pertaining to forest fires in New Brunswick have been collected and will be supplied, as can be seen in Table 1. The province of New Brunswick wants the likelihood of a forest fire occurring to be represented by a probability percentage. This means that it is up to your group of engineers to develop a metric, an example is seen in Equation 1. The metric will be your group's method of mathematically quantifying the probability of a fire occurring in any given fire zone. The provided data sets are in a .csv format, where each cell represents a 1km x 1km fire zone and the data within that cell represents the given data for that fire zone, see Appendix A for detailed information.

Table 1: Data sets and the variables used to describe them in the metric, see Appendix A.

Data Set	Variable	Unit
Temperature predictions	$\boldsymbol{A_{temp}}$	°C
Average rainfall in an area	$\boldsymbol{A_{rain}}$	mm/km^2
Location of water in the map	$\boldsymbol{M_{water}}$	---

Number of fireworks purchased in past year	$U_{firework}$	# Of fireworks
Density of foliage/forests	$A_{foliage}$	% Of area covered by foliage
Density of population	A_{pop}	People/km^2
Annual camping traffic	U_{camp}	# Of Campers Per Year
Frequency of Arson related crimes	U_{arson}	# Of Reports per Year
Key locations	---	---
Fire station locations	---	---

The metric example can be seen:

$$M(i,j) = 0.5 \times A_{foliage}(i,j) + 0.35 \times \frac{A_{temp}(i,j)}{\max(A_{temp})} + 0.15 \times \frac{U_{firework}(i,j)}{\max(U_{firework})} \quad \text{(Eq. 1)}$$

Where M, is the matrix containing the values of the metric (%), i and j represent row and column indices respectively. The remaining variables are seen in Table 1.

The developed software implementation should be able to read in these large data sets from the files and implement the designed forest fire probability metric. This metric, once explained and defended to the New Brunswick Forest Fire Watch, will then be used to help the province understand which areas are the most at-risk of forest fires.

If your team of engineers can successfully meet the province's requirements for the forest fire probability code, then the province will choose to extend the code to predict where the forest fires are most likely to occur. Once predictions have been made, the province also wants to be able to help the regions prepare as much as possible. Therefore, the designed software should then be able to take the probability data previously calculated and, using the input data set of key locations (cities, towns, monuments, parks, etc.) based on fire zones, determine which key locations are the most at-risk when a forest fire occurs. This will allow the province to equip these key locations with the required resources to help combat a possible forest fire.

The province's final goal for your team is to be able identify local firefighting resources that should be used, that way it makes managing and dispatching these resources quicker and easier. As part of the data sets provided by the government, there is a .csv file that describes several locations of fire stations scattered across the province in a select few fire zones. There are three different types of fire stations within the province:

- Type A (represented by an "A" in cell):
    - Uses water planes
    - Can respond to fires within 200 km radius
    - Requires water access within 50 kilometers
- Type B (represented by a "B" in a cell):
    - Has well-kept fire trucks equipped with hoses and ladders.
    - Can respond to fires within 120 km radius
    - Can only function in cities or towns (fire hydrant access)
- Type C (represented by a "C" in a cell):
    - Has a large fleet of ATV's
    - Travels back to fire station to refill water
    - Can respond to fires within 80 km radius

The program should allocate each fire station to AT MOST a single key location. It is not viable to spread firefighting resources from a single station across multiple key locations. It is important to note that some key locations may require more access to firefighting resources based on its risk. All key locations should have at least one firefighting resource allocated to them. The criteria for which decides what makes a particular fire station suitable for a key location must be described.

This software will prove to be an extremely valuable and important tool that the Government of New Brunswick can use to help combat the danger presented by forest fires. The government requires the code to be well documented as described in the design deliverables.

3. Specific Solution Objectives

This problem is divided into 3 stages:

1. **Stage 1**: Determine and implement a forest fire probability metric
    a. This metric must be mathematical in nature.
    b. May only use the provided input data sets as variables in the metric (you do not have to use each data set).
    c. Must justify, in detail, the design choices made for the forest fire probability metric. A portion of your presentation time must be dedicated to explaining your justification for the metric to the judges.
    d. Implement your metric within your program such that your program can read in the required data sets and calculate the probability of a forest fire for each fire zone in the province.
    e. Must provide an output that visualizes your forest fire probability metric for each fire zone within the province. This can be in the form of a heatmap, surface graph, or M by N table where each cell represents a fire zone and the data within each cell is the result of calculating the metric for that cell.
2. **Stage 2**: Employ the forest fire probability metric to determine at-risk key locations across the province

a. Your program must be able to read the key locations input data set and use the output from Stage 1 to determine which key locations are the most at-risk for forest fires.
b. The specific “at-risk” criteria for a key location must be determined, properly implemented, and explained. Your explanation must include an example of why a particular key location would be more at risk of a forest fire than another key location (e.g., key location X is more at risk than key location Y because it is in a dry part of the province and has a high probability of forest fire based on our metric).
c. Key locations are represented as large, singular entities within the provided key location data set. Thus, an individual key location is not just the singular fire zone for which it resides, but all the surrounding fire zones that share the same key location value within the key location data set. Your program must consider the fact that a key location encompasses multiple fire zones, and this will impact your definition of at-risk or not.
d. Must provide an output that visualizes the key locations across the province and how at-risk they are of a forest fire based on your definition of at-risk and your metric developed in Stage 1. The visual output can mimic what was done in Stage 1. Your output must include a ranking assigned to each key location that ranks them in order of risk. It is important that your ranking system demonstrates the relationship from one key location to another (e.g., key location A is ranked 1 and key location B is ranked 5, thus key location A is more at risk of a forest fire than B). You must explain this ranking system in your presentation.

3. **Stage 3**: Allocate firefighting resources to at-risk key locations

a. Your program must be able to read the fire station locations data set and use your output from Stage 2 to determine which firefighting resources should be allocated to each key location, Appendix A, Table 2.
b. Your program must consider the three different types of fire stations and the various requirements of each of them as this will have an impact of which fire stations are responsible for which key locations.
c. Must provide an output that visualizes the path between key locations and their assigned fire station(s). If a particular fire station has not been assigned to a key location, then no action is required. The visual aspect of this output can be similar to what was done in the previous two stages, yet all that is necessary is that there is a clear path between a fire station and its key location such that it is obvious which fire stations are responsible for different key locations.

4. Further Expectations/ Deliverables

You will have **8 hours** to complete this competition. At the 8-hour mark, your team must provide all the outputs from the programs, your finalized code, and your group's presentation. Anything not in the folder before the deadline will not be considered as part of your submission.

Code Deliverable:

- All your code needs to be in the provided GitHub repositories Main branch before the 8-hour deadline in order for it to be considered.
- Basic instructions must be provided on how to compile and run your code.
    - You must specify the <u>language</u> and <u>version</u> your code uses.
    - You can assume that anyone who runs the code has the appropriate language installed.
    - A list of required packages is advised (i.e., Pandas, NumPy).

Presentation Deliverable:

- Only presentations submitted in the provided GitHub repositories Main branch before the 8-hour deadline will be used in the presentation period. No work may be done on the presentation deliverable after the deadline has passed.
- You must discuss your group's chosen metric.
- You should discuss choices made in the code, for example what language was chosen, and what packages where used.
- Discuss your criteria behind identifying what is considered an "at-risk" location.
- The presentation should review any and all results that could be collected from your team's program.
- You need to show some measure of CPU usage and memory (RAM) usage. This can be done by taking the time from start to completion of the program, identifying the peak CPU load, and the peak RAM load that the program causes.

5. Judging Metrics

The judges will be using the matrix shown below in Figure 4 to determine how well your team meets expectations. The judging metrics, and all competition rules can be found in the CEC 2022 Rule Book.

Programming Judging Matrix		
Strategy/Algorithm	Simplicity	/10
	Ingenuity	/10
	Ability to Achieve Desired Outcome	/15
		/35
Code	Structure	/10
	Consistency	/5
	Readability	/10
	Efficiency	/10
		/35
Resource Management	Memory Usage Efficiency	/5
	Program's CPU Usage	/5
		/10
Presentation	Design Process and Justification	/7
	Design Critique	/4
	Voice, Articulation and Timing	/4
	Visual Aids	/2
	Response to Questions	/3
		/20
Deduction Total		
Total		**/100**

Figure 4: Programming Judges Rubric.

Please be aware that there are certain actions that can cause your team to incur penalties, therefore you should be familiar with the penalty matrix in Figure 5.

Figure 5: Programming Penalty Rubric.

Programming Point Penalties	
Plagiarism	Elimination
Documents Received After Deadline	-50
Absent Team Member	-25
Entering presentation room before allotted time (after first offense)	-10
Total	

6. Definitions

Forest Fire Probability Metric: A mathematical formula that considers the numerical values of several variables to calculate a result between 0 and 1. This result represents the probability of a forest fire occurring provided the values of the used variables.

7. References

[1] https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/how-does-disturbance-shape-canad/indicator-forest-fires/16392

[2]https://www2.gnb.ca/content/gnb/en/news/public_alerts/forest_fire_watch.html

[3] https://www.pc.gc.ca/en/pn-np/nb/fundy

[4] https://www.pc.gc.ca/en/pn-np/nb/kouchibouguac

8. Appendix A

Table 1: Data sets with more information.

Filename	Type	Description	Variable	Units
average_predic_temp.csv	Double	Temperature predictions	A_{temp}	°C
average_rainfall.csv	Double	Average rainfall in an area	A_{rain}	mm/km^2
map_water.csv	Integer	Location of water in the map	M_{water}	---
unit_firework_sales.csv	Integer	Number of fireworks purchased in past year	$\boldsymbol{U_{firework}}$	# Of fireworks
average_foliage_density.csv	Double	Density of foliage/forests	$A_{foliage}$	% Of area covered by foliage
average_pop_density.csv	Double	Density of population	A_{pop}	$People/km^2$
unit_camping_traffic.csv	Integer	Annual camping traffic	U_{camp}	# Of Campers Per Year
unit_arson_report.csv	Integer	Frequency of Arson related crimes	U_{arson}	# Of Reports per Year
Key_Site_Locations.csv	Integer	Key locations	---	---
Fire_Station_Locations.csv	Character	Fire station locations	---	---

Table 2: Key Locations, names, corresponding ID Value and the type of location.

Key Location	ID Value	Type
Saint John	2	City
Moncton	3	City
Fredericton	4	City
Miramichi	5	City
Bathurst	6	City
Mactaquac	7	Park

Mount Carelton	8	Park
Parlee Beach	9	Park
Kouchibouguac	10	Park
Fundy	11	Park
Gagetown	12	Military Base

Table 3: Fire Station Information.

Fire Station Type	Radius (km)	Information	Conditions
Type A	200	Water Plane	Requires water access within 50km
Type B	120	Fire Truck	Function only in cities or towns (Fire hydrant access)
Type C	80	ATV	---