Optimal Locations of Disaster Support Centres in Vancouver

Rabe Arshad, Mikhail Narva, and Lingjun(Stella) Wang

Abstract

The geographical location of Vancouver and heavy rainfall in the region makes it more prone to natural disasters like floods and earthquakes. In order for aid and relief to be distributed efficiently, it is important to have relief centres which are near the affected communities and large enough to support a large number of people. The goal of this study is to determine the optimal locations of disaster support centres in Vancouver in order to maximize the assistance to the affected community. The population and disaster risk levels of each district was used in determining where to place each disaster support centre. Two models were produced which produced the optimal locations for 20 and 23 facility centres given a maximum limit of 25 facilities depending on which model was used.

Index Terms

Linear Programming, Facility Locations, Risk Management, Disaster Support.

I. Introduction

Due to the geographical location of the city of Vancouver, which is in the lower mainland of the Greater Vancouver region, earthquake risk and flooding are two major concerns of the provincial and federal governments in Canada. In 2016, the Fraser Basin Council had a review on future flood scenarios [1] and it revealed that Richmond and municipalities upstream are extremely vulnerable to flooding as sea levels continue to rise and the potential for more extreme storms increases. In addition, the city of Vancouver is very close to the Cascadia subduction zone which is a convergent plate boundary that stretches from northern Vancouver Island to Northern California. During the last 140 years, at least ten moderate to large earthquakes have occurred within 250 km of Vancouver and Victoria [2]. In the province of British Columbia, Emergency Management BC (EMBC) has developed a comprehensive provincial earthquake plan where the BC Earthquake Immediate Response Plan (IRP) (2015) is the first component [3]. Although, the Cascadia Subduction Zone scenario was not considered in the IRP due to low population and infrastructure impact, not acknowledging this event would be catastrophic. Therefore, in this study, we determine the optimal locations of disaster support centres in Vancouver in order to maximize the assistance to the affected community. We consider various factors that determine the existing and potential locations of support centres. These factors may include, but not limited to the following: the risk of natural disaster, population density, and area density in the city of Vancouver.

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II. Related work

Facility location planning has always been a focal point of interest in the literature. For instance, Grmez et. al [4] addresses the disaster response and relief facility location problem for Istanbul. She proposes a two-stage distribution system that utilizes existing public facilities as well as new facilities to be established. She also developed a mathematical model that aims to minimize the average distance to the population who need relief services while opening the least number of facilities possible. In [5], the authors discussed classical models such as the single facility location problem, multiple facility location problem, covering problem, contemporary models such as hierarchical facility location problem, etc. It is worth mentioning that chapter 7 in [5] provided us with useful insight on how to construct an effective model for location allocation. In particular, the authors consider three types of facilities: origins, supportive centres, and supported centres. They also constructed several objective functions and constraints for the covering problem.

In [6], the authors study the locations of emergency facilities in the town of Rio Rancho and obtained the optimal location for an emergency facility as a result of their study. The authors begin with a model for a single emergency facility location where the response time for different possible locations was minimized. At the end they concluded that the current facility locations in place are not optimal. Thus it motivated us to study whether the locations of disaster support centres in Vancouver are optimal because the aforementioned scenario could potentially happen in the city as well. Currently, Vancouver has 25 community centres in place to be used as disaster support hubs and we want to analyse if these locations are satisfactory. In contrast to the study by Csoke et al (2015) [6], our study incorporates other related factors such as population density and risk probability in our models.

III. Mathematical Models and Applications

A. Mathematical Models

In this section, the mathematical models used to determine the optimal locations for disaster support centres in Vancouver are presented. The first model deals with maximizing the population and rank weighted sum scores and the second model deals with three different targets in terms of optimizing facility numbers and use.

We begin with dividing the map of the city of Vancouver into $m \times n$ grid cells as shown in Figure 1.

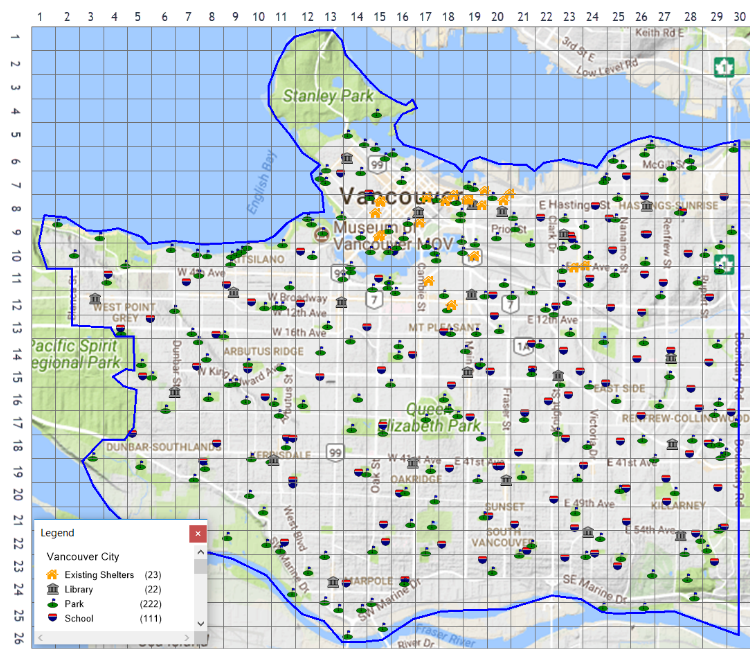

Fig. 1: City of Vancouver with potential facility locations divided into 26×30 grid cells with 500 m^2 area for each grid

We now define the decision variables and parameters that will be utilized in both models.

Let $S \subset \{(i,j)|i = 1,2,3,....m, \quad j = 1,2,3,....n\}$ be the locations of disaster relief centers, $d^{(t)}, t \in \{+,-\}$ be the positive or negative deviation from the right hand side (R.H.S.) of the constraint, and x_{ij} be the disaster relief candidate at location (i,j), such that

$$x_{ij} = \begin{cases} 1 & \text{if we use the facility} \\ 0 & \text{otherwise} \end{cases}$$

Let y_{ij} represent an auxiliary binary variable such that

$$y_{ij} = \begin{cases} 1 \text{ if facility } x_{ij} \text{ is to be used.} \\ 0 \text{ otherwise.} \end{cases} \tag{1}$$

Let w_{ij} be the weight factor of a grid cell at (i,j) based on population density and associated risks factors. Then our objective function can be written where w_{ij} is the weighted sum of population and risk scores in the 5×5 grid cell area around the facility location at (i, j) which can be defined as

$$w_{ij} = \sum_{i-2}^{i+2} \sum_{j-2}^{j+2} (w_p P_{ij} + w_r R_{ij}) \tag{2}$$

where $P_{ij} \in [0, 10]$ is the population score at grid cell (i, j) and $R_{ij} \in [0, 10]$ is the risk score (risk of having floods/ earthquake) at grid cell (i, j). w_p and w_r are the customizable weight factors for the population density and risk such that $w_p + w_r = 1$.
Now, we divide Vancouver into districts $D_1, D_2, ...D_{23} \subset \{1, 2, ..., m\} \times \{1, 2, ..., n\}$, where D_k, $k \in \{1, 2, ...23\}$, can be considered as a partition of $\{1, 2, ..., m\} \times \{1, 2, ..., n\}$. We assume that at least one facility location must exist in each district, which leads to the following constraint.

$$\sum_{(i,j) \in D_k \cap S} x_{ij} \geq 1 \tag{3}$$

Given a possible limit to the allocated budget for facility set-up, there exists a constraint of having maximum facility locations $\mathcal{D}$ in total, which can be modeled as

$$\sum_{(i,j) \in S} x_{ij} \leq \mathcal{D} \tag{4}$$

Let ρ_{ij} be the population at grid cell (i,j). Then μ_{ij} is the weighted sum of population in 5×5 grid cells around the facility location at grid cell (i, j) and is given by

$$\mu_{ij} = \sum_{i-2}^{i+2} \sum_{j-2}^{j+2} \rho_{ij} \tag{5}$$

Let $Cap_{x_{ij}}$ be the capacity of the facility at (i, j), then we have

$$\mu_{ij} x_{ij} \leq Cap_{x_{ij}}, \quad \forall (i, j) \in S \tag{6}$$

*1) **Model I: Maximizing Weighted Scores**:* This model deals with deciding which facilities to choose as disaster support centres in order to maximize the weighted scores. More specifically, given a maximum number of facilities that we can use, $\mathcal{D}$, and each facility having an associated weight w_{ij}, which of these facilities to use so that the sum of the weight scores are maximized. In all formulations, we assume that the prospective facilities do not have a maximum capacity and therefore, can handle any amount of population demand. In light of the aforementioned objective, the objective function along with the constraints are as follows

$$\text{Maximize } Z_I = \sum_{(i,j) \in S} w_{ij} x_{ij} \tag{7}$$

such that

$$w_{ij} = \sum_{i-2}^{i+2} \sum_{j-2}^{j+2} (w_p P_{ij} + w_r R_{ij}) \tag{8}$$

$$w_p + w_r = 1 \tag{9}$$

$$\sum_{(i,j) \in D_k \cap S} x_{ij} \geq 1 \tag{10}$$

$$\sum_{(i,j) \in S} x_{ij} \leq 25 \tag{11}$$

$$\mu_{ij} = \sum_{i-2}^{i+2} \sum_{j-2}^{j+2} \rho_{ij} \tag{12}$$

$$\mu_{ij} x_{ij} \leq Cap_{x_{ij}} \tag{13}$$

$$x_{ij}, y_{ij} \in \{0, 1\} \tag{14}$$

*2) **Model II: Multiple Objective Model**:* This model deals with solving the disaster support facility location problem taking into account three objectives. The main objectives are:

1) Minimize the number of facilities over the demand, $\mathcal{D}$.
2) Minimize underachievement of the optimal solution of the previous model, Z_I^*.
3) Among the chosen facilities, minimize the difference between the population score of the facility, μ_{ij} and its capacity, $Cap_{x_{ij}}$.

As these objectives are conflicting, they are taken into account together into one model. Furthermore, the maximum capacity, $Cap_{x_{ij}}$ of each possible facility is taken into account.
The model is as follows:

Minimize $d_1^+ + d_2^+ + \sum_{z=3}^{254} (d_z^+ + d_z^-)$
subject to:

$$\sum_{(i,j) \in S} x_{ij} - d_1^+ \leq \mathcal{D} \qquad \text{(Facility Demand Target)} \tag{15}$$

$$\sum_{(i,j) \in S} w_{ij} x_{ij} + d_2^- \geq Z_I^* \qquad \text{(Score Target)} \tag{16}$$

$$\mu_{ij} x_{ij} + d_z^- - d_z^+ = Cap_{x_{ij}} y_{ij} \qquad \forall (i,j), z \ \text{(Capacity Utilization Goal)} \tag{17}$$

$$x_{ij} = y_{ij} \tag{18}$$

$$\sum_{(i,j) \in D_k \cap S} x_{ij} \geq 1 \qquad \forall k \ \text{(District Requirement)} \tag{19}$$

$$x_{ij}, y_{ij} \in \{0, 1\} \qquad \text{(Binary)} \tag{20}$$

In this model we have multiple targets to achieve. These targets were reformulated into constraints with decision variables, d^+ and d^-, representing over or underachievement from targets, respectively. Subsequently, the objective function is to minimize the amount of deviation of the goals from the target values. Constraint (15) minimizes the underachievement of the number of facilities used from the facility demand target, D. Similarly, constraint (16) minimizes the underachievement of the total score value of the chosen facilities compared to the score target of Z_I^*. The auxiliary variable y_{ij} is used so that constraint (17) only holds if x_{ij} (and therefore $y_{ij}) = 1$. Moreover, constraint (17) minimizes the difference between the population value, μ_{ij} and capacity $Cap_{x_{ij}}$ of a chosen facility x_{ij}.

IV. Data Collection

We harvest online information regarding the current population of the city of Vancouver and disaster support centres via [7], [8]. Using the collected data, we generated synthetic data sets and a population map for each district of Vancouver, as well as a map depicting potential accommodations for affected people. We assume that facility locations can be located anywhere within the Vancouver region regardless of space or building availability. Regardless of if a school or park can be used for a disaster support centre, it will still be considered in the model. Furthermore, the models assume that following a disaster, people are able to travel to the nearest facility available. This means that it is not considered if a facility can not be reached by alternative routes given if a road can not be used. Also, facility locations are assumed to remain undamaged and viable for use following a disaster. With this, we also assume that if a centre does become unusable, that a separate location within the area is available for use. It is highly crucial to obtain the actual data of potential locations where the affected people can be settled. We consider existing shelters for refugees, libraries, parks, and schools as the potential locations. This data is available on [8]. In order to analyze the data and to perform the proposed study, it is a requirement to map this data to a grid with m x n sub-blocks. Figure 1 depicts the Vancouver map with the potential locations for accommodating displaced or affected people. The locations are plotted on the map with the help of Google Earth [9] and Mapinfo [10]. It is worth mentioning that, for the sake of simplified analysis, the whole map is divided into a grid with 500 x 500 m sub-blocks.

In order to further simplify the mathematical analysis, we divide the city of Vancouver S in sub areas $v \in S$ while each sub area is comprised of a x_v x y_v grid. Then we gather the population values, potential locations, and associated risk factors for each sub area as shown in Table I. We used the elevation of an area as a proxy to understanding its risk to natural disasters. A lower elevation area for example, was determined to be at a higher risk of flooding. We assumed in this model that people were at home so district population values were used as a measure of district population at any time of the day. Furthermore, within each district, we assume that people are randomly distributed among the area. It is worth noting that the ranks and risk factors are calculated as

$$PopulationRank/RiskFactor = \frac{k_{max} - k_{min}}{\tau}; \quad k \in \{P, R\}$$

where τ is the total number of available ranks. Based on the data given in Table I, we represent the data in graphical form depicting population factor, locations density factor, and risk factors (c.f., Fig. 2-4).

TABLE I: Vancouver city data along with rank and risk factors

Sr. No.	Area	Population	Population_Rank	Locations Density	Density_Rank	Altitude (m)	Risk Factor
1	West Point Grey	12795	2	10	2	50	5
2	Dunbar Southlands	21745	4	12	2	90	2
3	Kitsilano	41,375	8	25	7	25	8
4	Arbutus Ridge	15,910	3	17	5	75	3
5	Kerrisdale	14,735	2	15	4	20	9
6	Stanley Park	0	0	4	0	30	8
7	West End	44,540	8	12	2	33	7
8	Downtown	54,690	10	36	9	25	8
9	Fairview	31,440	6	10	2	20	9
10	Shaughnessy	8,810	1	9	1	89	2
11	South Cambie	7,680	1	7	1	85	2
12	Oakridge	12,440	2	11	2	78	3
13	Marpole	23,835	4	16	4	25	8
14	Downtown Eastside	27,305	5	13	3	9	9
15	Strathcona	12,165	2	17	5	5	10
16	Mount Pleasant	26,400	5	20	5	51	5
17	Riley Park	21,795	4	12	2	80	2
18	Kensignton Cedar Cottage	47470	9	18	5	62	4
19	Sunset	36285	7	15	4	81	2
20	Hastings Sunrise	33990	6	38	10	50	5
21	Renfrew Collignwood	50505	10	30	8	97	1
22	Victoria Fraserview	30710	6	16	4	87	2
23	Killarney	28450	5	16	4	103	0

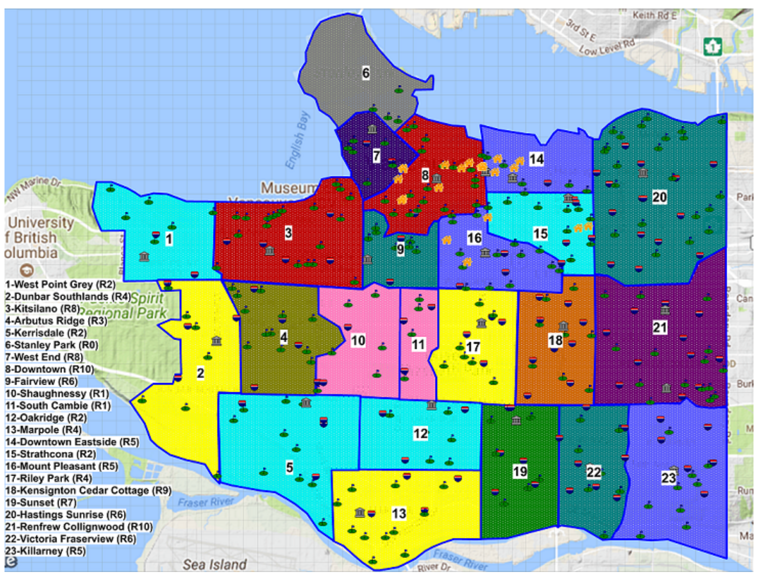

Fig. 2: Vancouver map depicting population density

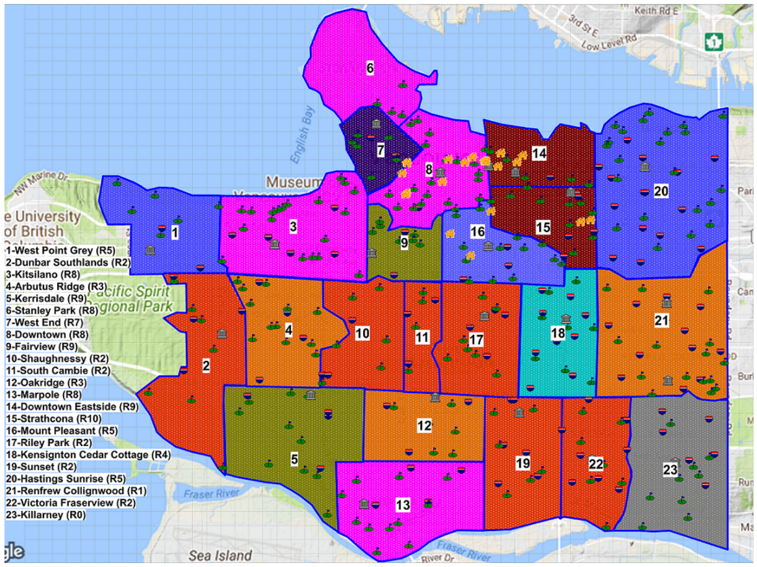

Fig. 3: Vancouver map depicting flood risk factors

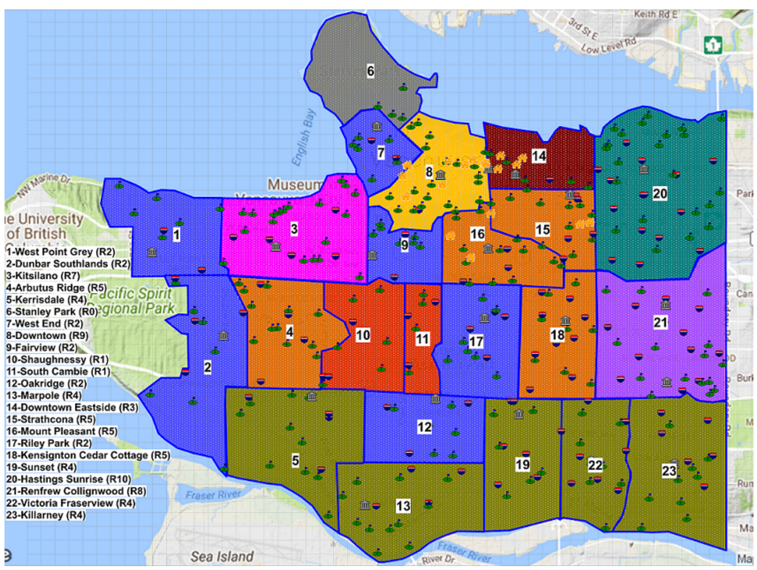

Fig. 4: Vancouver map depicting potential locations density

TABLE II: Converted score ranges for parameter ranks.

Rank	0	1	2	3	4	5	6	7	8	9	10
Converted Range	0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100

V. Data mapping and generation

The following procedure was utilized in order to generate the data required for running the model:

1) Risk and population rank scores of the districts are converted to a number range according to Table II.
2) Given the range, a random number is assigned within the range to each cell in the grid. This is done for both risk and population rank scores.
3) A weighted sum is obtained for each square in the grid by taking risk rank weight w_r to be $\frac{2}{3}$ and population rank weight w_p to be $\frac{1}{3}$. The weighted sum would then be $= \frac{2}{3}(ConvertedRiskRank) + \frac{1}{3}(ConvertedPopulationRank)$.
4) Sum the weighted sum of all squares in a 5 by 5 grid around and including each facility location. The sum would be the coefficient for that prospective facility.
5) To each cell within a district, a random number between (0,1) is assigned such that the sum of all of the grids = 1, which is then multiplied by the total population of the district. This gives a randomized distribution of the population across the district.
6) Models are then simulated based on the generated data.

The following procedure was utilized in order to generate simulated facility capacity data for use when applicable in the model:

1) The list of all population values are obtained for each possible facility location.
2) The interquartile range (IQR) of the data set is then determined.
3) A capacity $Cap_{x_{ij}}$ is assigned to each facility by obtaining a random number in the IQR.

This procedure randomly chooses facilities which can not accommodate the demand in its local area while keeping many facilities viable for use.

VI. Data Collection and Optimization Software

All data collection and simulation was performed with Microsoft Excel 2016. IBM ILOG CPLEX 12.7.1 was used together with the data obtained from Excel to solve all models. CPLEX code can be seen in the Appendix.

VII. Model Application

A. Model I: Maximizing Weighted Scores

A facility demand $\mathcal{D} = 25$ was chosen as it is the current number of disaster support hubs that are available for use in Vancouver. In this original model, it has been determined that each facility x_{ij} is uncapacitated and thus could be used regardless of its population value, μ_{ij}. Furthermore, in the calculation of the score value, w_{ij}, for each facility, x_{ij}, a weight of $\frac{2}{3}$ was used for the risk score and $\frac{1}{3}$ for population score. Then the weights for each facility are calculated as follows:

$$w_{ij} = \sum_{i-2}^{i+2} \sum_{j-2}^{j+2} \left\{ \frac{2}{3}(\text{risk score of } x_{ij}) + \frac{1}{3}(\text{population score of } x_{ij}) \right\}, \forall (i,j)$$

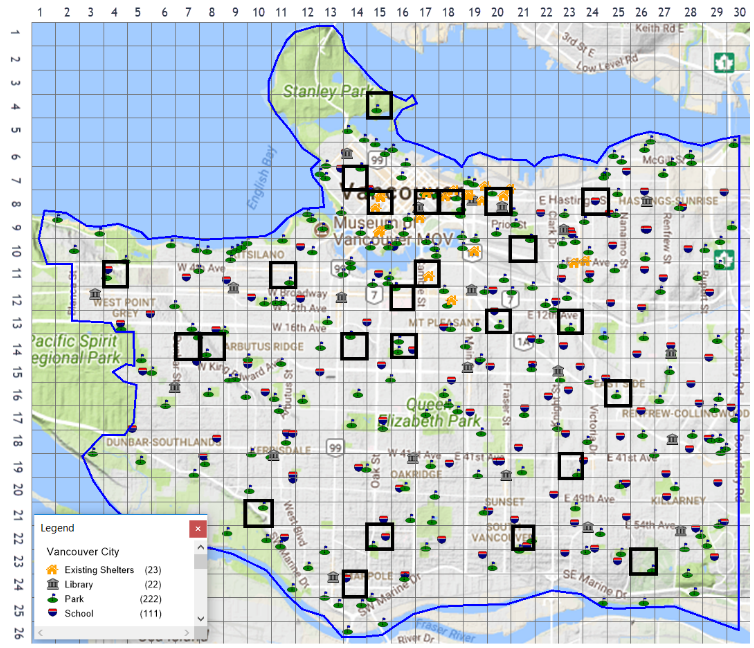

Fig. 5: Optimal facility locations for the original model with risk and population weight scores of (risk score weight, population score weight) = $(\frac{1}{3}, \frac{2}{3})$

25 facilities were chosen as optimal facility locations in Vancouver given the original model. Many facilities are concentrated within the downtown region of Vancouver. Conversely, it is expected that those residing near and to the west of Queen Elizabeth park go to the support centres around the area. The optimal locations found with this model are shown in Figure 5.

B. Model II: Multiple Objective Model

In this model, same values for $\mathcal{D}$ was used, the target was to reduce the positive deviation above the goal of 25 facilities for Vancouver. As for the score target, the optimal solution of Model I, $Z_I^* = 33,336$ was used. Finally, the capacity values for each facility x_{ij} was obtained from a random sampling from the Interquartile Range (IQR) of the population sum values as described in the Data Collection section.

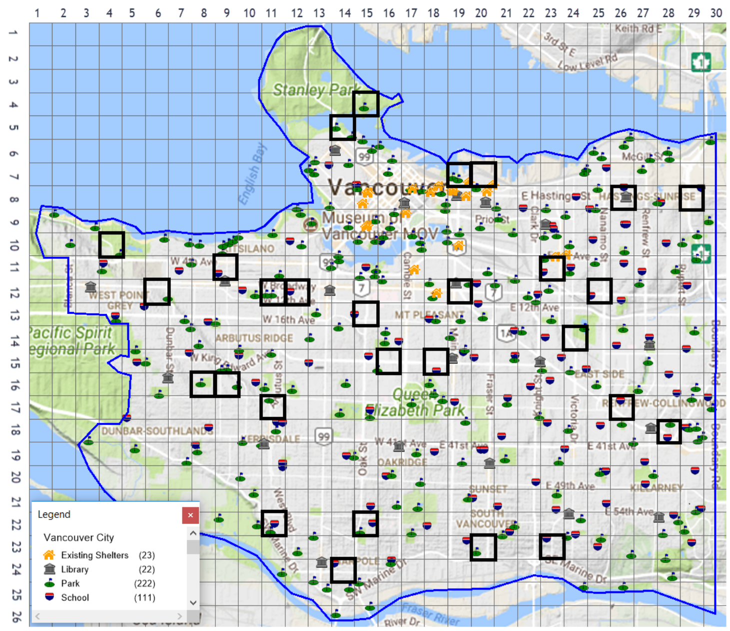

Fig. 6: Optimal facility locations for the second model with risk and population weight scores of (risk score weight, population score weight) = $(\frac{1}{3}, \frac{2}{3})$

Similar to the optimal solution of Model I, 25 facilities were also chosen for this model. It can be seen from the optimal solution that there is less concentration of facilities in the downtown region as compared to the Model I solution. Furthermore, more facility demand is satisfied in the West Broadway region as well as the area surround Queen Elizabeth park.

VIII. Variations on the Model

In this section, we present variations on the two original models. First, we present cases for Model 1 where we only consider risk score or population score in the calculation of the coefficients, w_{ij}. Then we show three different variants where we consider different weights for the population and risk scores when we calculate the coefficients. We then consider how the first model changes when we take into account the capacities of each facility location. As for the second model, we show three different variants where we place priority on the fulfilment of one goal over the others.

A. Model I Variants

1) Risk or Population Scores Exclusively: The results obtained in the previous section for Model I was obtained using risk and population score weights of $\frac{1}{3}$ and $\frac{2}{3}$, respectively. In this section we discuss the changes in the optimal solution if only risk score or population score is considered in the calculation of the coefficients, w_{ij} for each facility location, x_{ij}. Specifically, the weights of each score are as follows: (risk score weight, population score weight) = $(0, 1)$ and $(1, 0)$. The results are then compared to the original model and to each other.

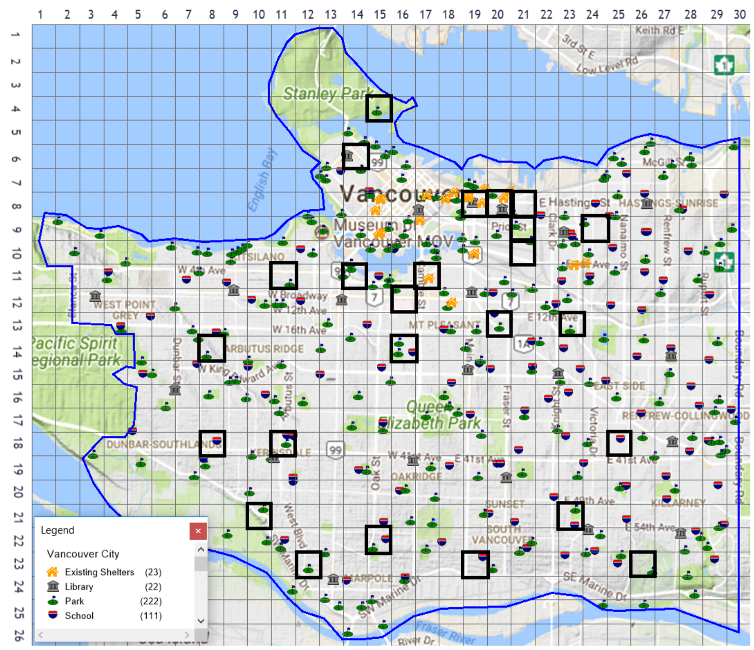

Fig. 7: Optimal facility locations for the first model with risk and population weight scores of (risk score weight, population score weight) = $(0, 1)$.

As compared to the original optimal solution for Model I, it can be seen that with the (0, 1) variant, there is no longer a concentration of facilities in the downtown region. Rather, this concentration can now be seen in the Strathcona region. More coverage are in the Kerrisdale and Dunbar-Southlands areas which is coupled with a removal of the facility in West Point Grey. As expected, there is more coverage in the higher population districts in this model variant.

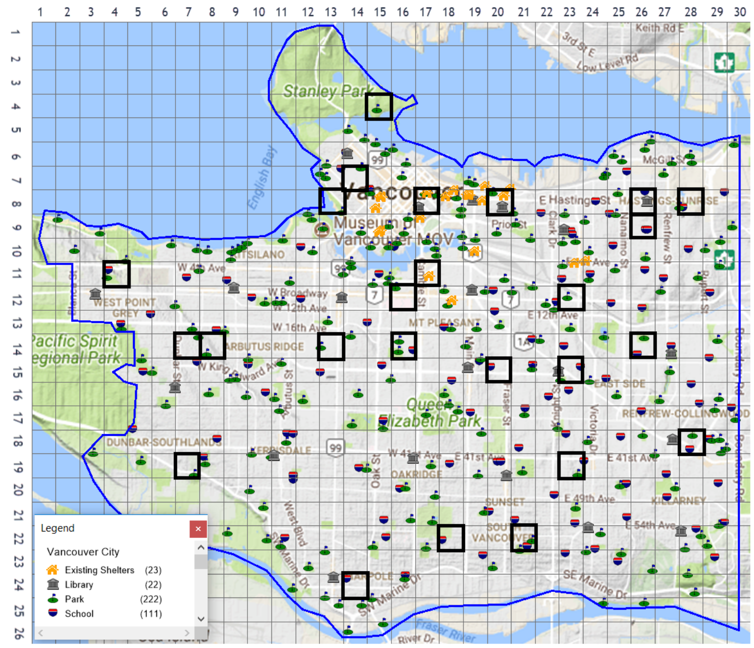

Fig. 8: Optimal facility locations for the first model with risk and population weight scores of (risk score weight, population score weight) = $(1, 0)$.

As compared to the original optimal solution for Model I, it can be seen that there is one less facility serving the Downtown area. In contrast, more facilities have been chosen in the Hastings area. The single facility located in Kitsilano is non-existent in the (1,0) variant. Lastly, less facilities are chosen to cover the Marpole area with one more facility in the Dunbar-Southlands neighbourhood. As expected, the model added more facilities to regions with higher risk scores.

Upon comparing both variants to each other, it can be seen that in the (0, 1) variant, we see more coverage in the south-west region of Vancouver, namely in the Kerrisdale, Marpole, and Dunbar-Southlands areas. The (1,0) model solution has more facilities in the east side of Vancouver and less in the west given the lesser amount of coverage in the Kitsilano and West Point Grey locations. Furthermore, the (1, 0) variant does not have a concentration of facilities in the Strathcona region and has more spread out coverage in the northern part of the city.

2) Varying Weights of Mixed-Score Variants: In the previous section, the effect of considering only risk or population exclusively in the determination of each facility score, w_{ij} was observed. The effects of different weights, when both factors are considered, are now observed. Two variants, namely, (risk score weight, population score weight) = $(\frac{2}{3}, \frac{1}{3})$ and $(\frac{1}{2}, \frac{1}{2})$, are considered.

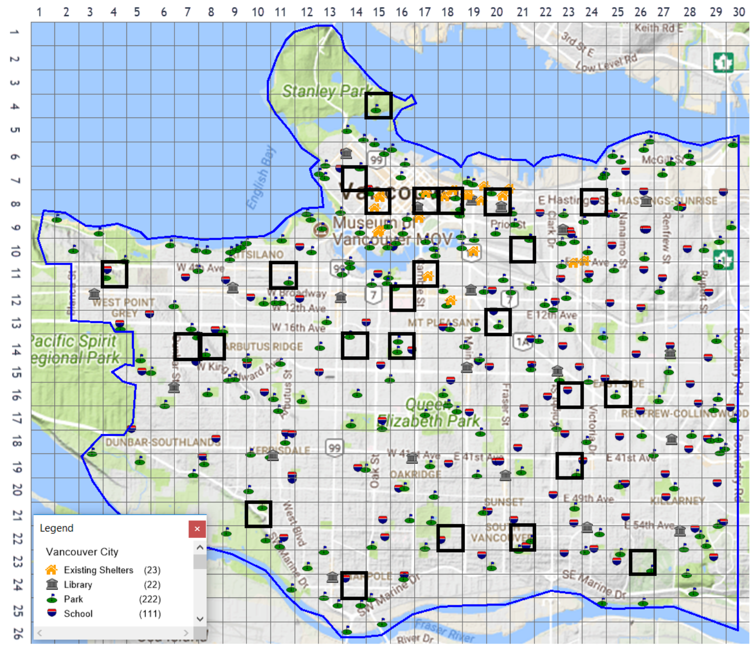

Fig. 9: Optimal facility locations for the first model with risk and population weight scores of (risk score weight, population score weight) = $(\frac{1}{2}, \frac{1}{2})$.

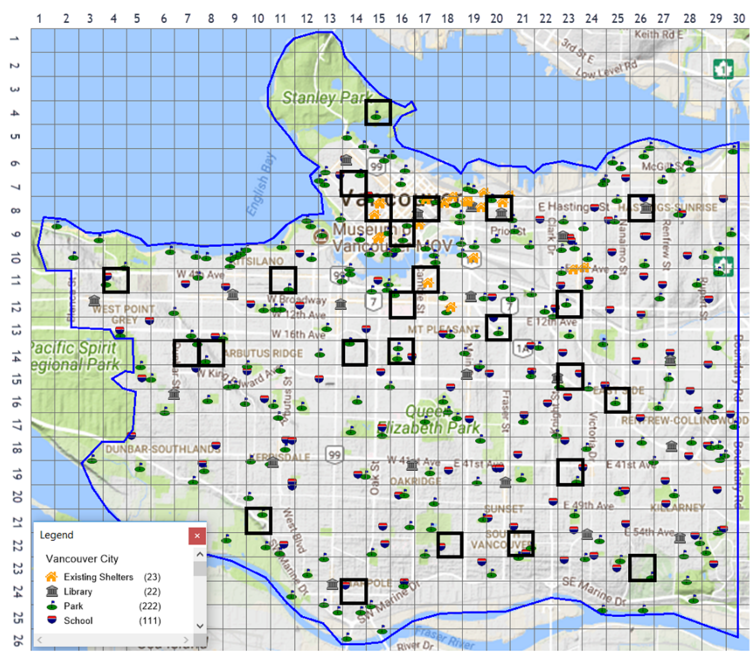

Fig. 10: Optimal facility locations for the first model with risk and population weight scores of (risk score weight, population score weight) = $(\frac{2}{3}, \frac{1}{3})$

It can be seen from both variants that the optimal solutions do not vary much from the optimal solution of the original model. Twenty of the facilities chosen are ubiquitous in both variants and the original optimal solution. These facilities are in Figure 11.

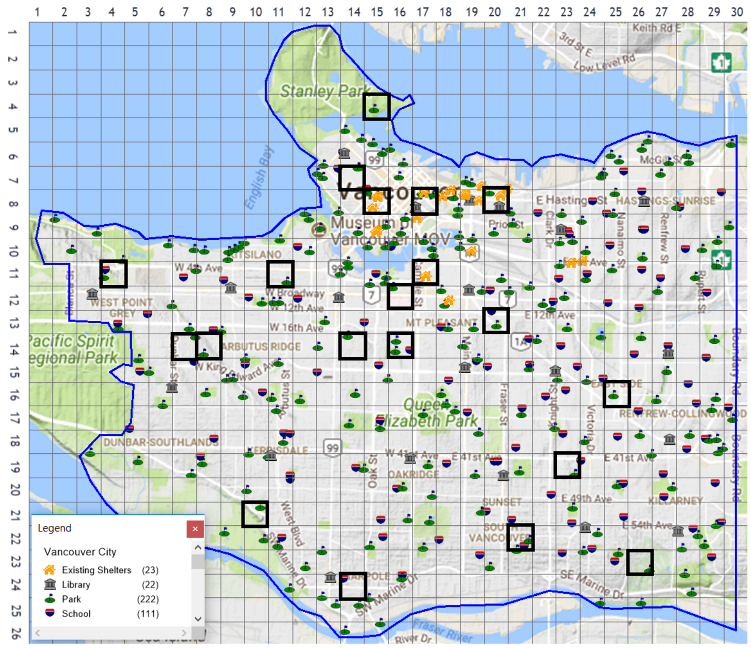

Fig. 11: Similar optimal facility locations of the two different variants and the original model formulation

If both factors, population and risk, are considered in the decision making process using this model, it can be inferred that these facilities must be chosen.

3) Facilities with Capacities: The model including facility capacities is now considered. As described in section IV ,each possible facility location is given a capacity, $Cap_{x_{ij}}$ of how many people a location can accommodate.

Due to the values of $Cap_{x_{ij}}$ however, the model is infeasible as there exists numerous districts which do not have facilities which can accommodate the population in its area. No feasible solution exists that can satisfy the constraint that every district must have at least 1 facility in its region.

Therefore, this model can not be used if facility capacity is considered given the capacity data that is used. If such is the case, Model II should be used as this allows for large deviations from the capacity target.

B. Model II - Varying Priorities

In the original Model II formulation, the priority for each of the three goals can be modified by changing the coefficients of the decision variables, d. For example, if the facility demand target has a higher priority than the other two goals, the objective function would change as follows:

$$\text{Minimize } 1000d_1^+ + d_2^+ + \sum_{z=3}^{254}(d_z^+ + d_z^-)$$

where the coefficient of 1000 was chosen in order to ensure the priority of the facility demand target compared to the other goals.

In this section, we consider three different variants where each target individually is given priority over the other goals. As with the original formulation, we use a demand value of 25, $\mathcal{D} = 25$, a score target of $Z_I^* = 33,336$, and facility capacity values as described in Section IV.

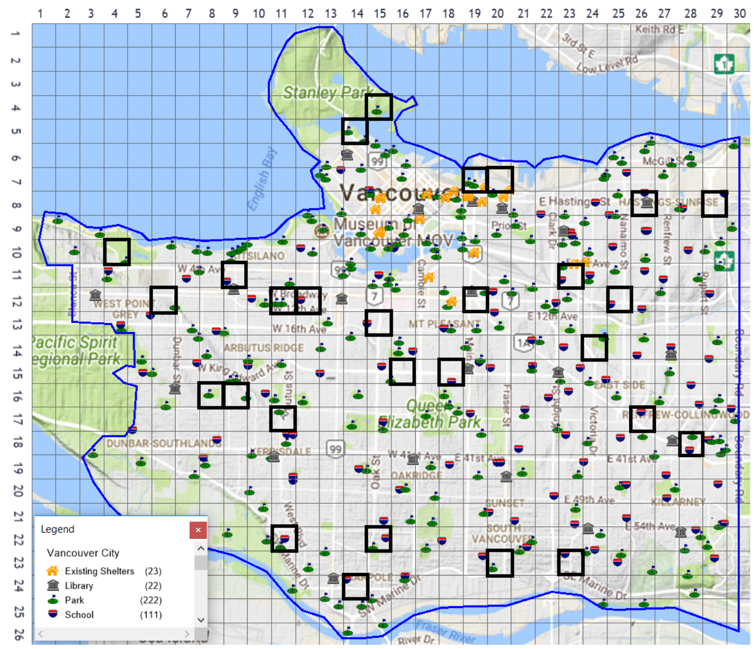

Fig. 12: Optimal facility locations for the second model with risk and population weight scores of (risk score weight, population score weight) = $(\frac{1}{3}, \frac{2}{3})$

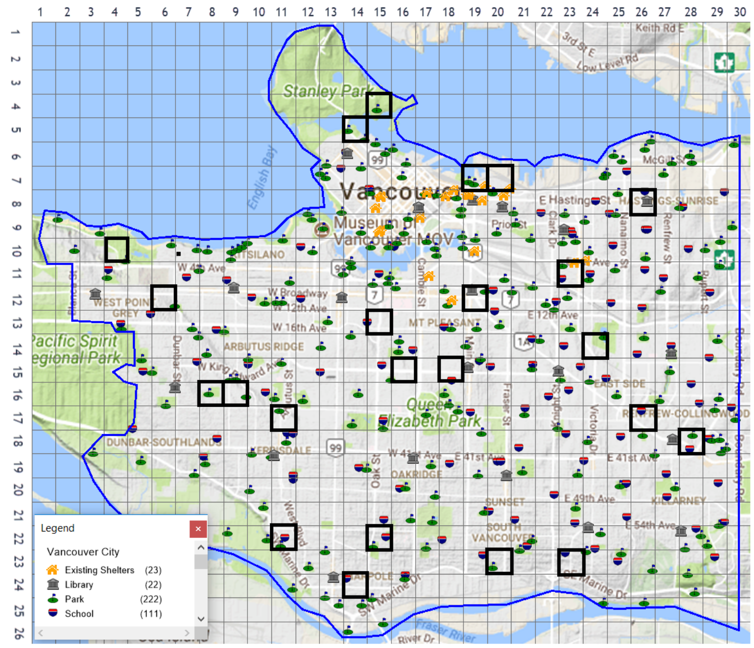

Fig. 13: Optimal facility locations for the second model where the main priority is the maximization of the capacity of each chosen facility

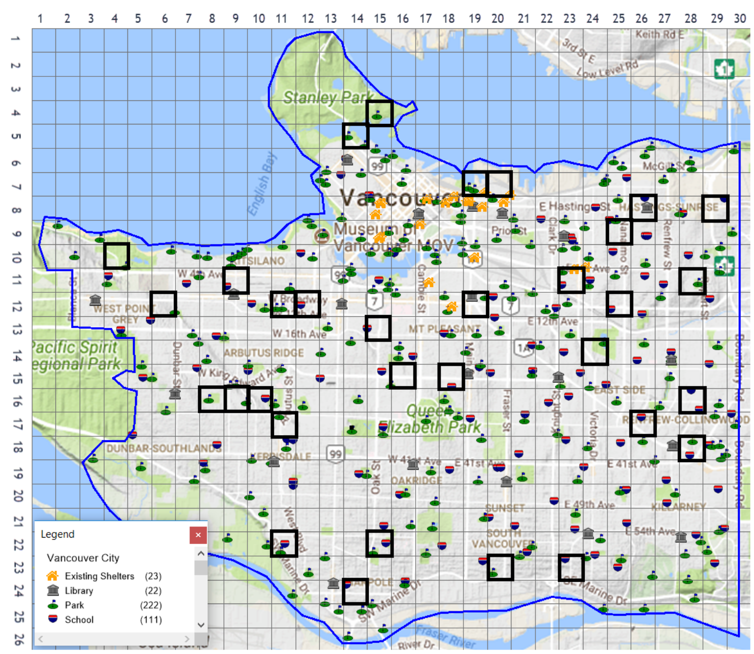

Fig. 14: Optimal facility locations for the second model where the main priority is the minimization of the negative deviation of the total score from the goal of 33,336

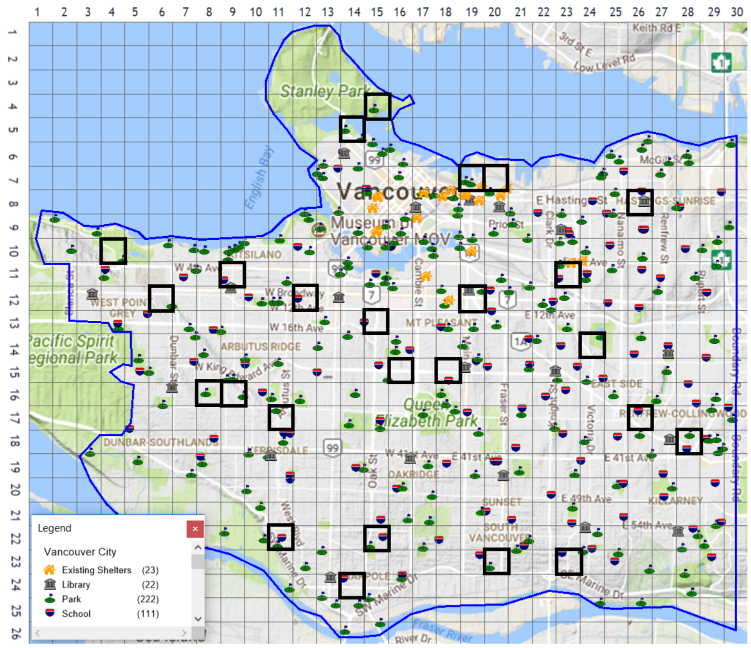

Fig. 15: Optimal facility locations for the second model where the main priority is the minimization of the number of facilities over 25

Figure 15 shows that the optimal solution for this variant has 25 facilities as expected because the main priority was given to minimizing the amount of facilities over 25. This differs from the optimal solution of the original model by having 3 less facilities. Figure 14 depicts that the optimal solution for this variant has 32 facilities. This is as expected because the main priority is the maximization of the score. Figure 13 depicts that, for this variant, the optimal solution contains 23 facilities. This is due to how emphasis was placed on the target that when a facility is used, the population for the area must be as similar to the capacity of the facility as possible.

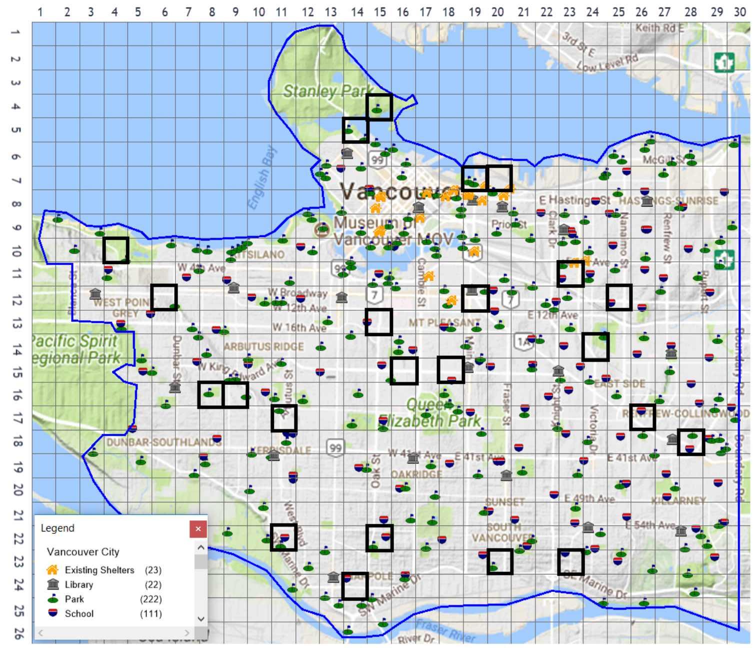

Fig. 16: Similar facility locations among the three variants and the original model formulation

We can see that regardless of the priority placed among the three goals, 23 facilities remained part of the optimal solution for every model.

IX. Conclusion

In this study, we consider two different models where the goal is to determine the optimal location of disaster support centres in Vancouver. With the first model, the goal was to maximize the total sum of weights given the population and risk levels of each district. In the second model, we aim to find an optimal location for the facilities given three separate goals. The goals are minimizing the amount of facilities chosen above 25, minimizing the underachievement of the objective function value from the score target, and ensuring that if a facility is chosen, it is used to the fullest extent possible.

As expected, if we only consider the population and risk scores, the optimal locations given the first model would be to place them in locations with higher risk and population scores. When we consider both risk and population scores in the calculation of the scores for each facility, there are facilities that do not change as part of the optimal solution. Therefore, it is suggested that if the only goal is to maximize the total weight of the facilities, that these 20 locations are chosen.

For the variants of the second model, we can see that despite which goal is given the top priority, that there remains 23 facilities that are always part of the optimal solution. Therefore, we suggest that these 23 facilities are chosen as disaster support centres during times of disaster if maximum capacity utilization and facility amount is important in the decision making process.

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