A GIS-based multi-criteria evaluation for insurance agency site selection in Wellington

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1. Background Research

The present study aims to select the optimal location of insurance agencies in Wellington, New Zealand using QGIS-based multi-criteria evaluation. Insurance agencies specialize in selling and servicing property and casualty insurance policies such as auto insurance, homeowners' insurance, liability insurance, or commercial property insurance. The location of insurance agencies plays an important role in both the customer's perspective and the company's standpoint. As for the former, it is one of the most important factors for an insurance company's selection together with recommendations from relatives or friends, service quality, and cost (Çiğdem, n.d.). Regarding the latter, an appropriate location can not only attract new customers but also save operating costs due to store changes, thus maximizing the input-output ratio.

On the other hand, the scientific and systematic analysis used in decision-making processes also has vital importance to corporate success today in the rapid development and competitive conditions (Erdin & Akbaş, 2019; Wrigley, 2014). It mainly covers four aspects that are spatial analysis methods for site selection, the general procedure for location selection, the criteria of location selection, and the most used tool.

The most frequently used spatial analysis method for site selection is multi-criteria evaluation (MCE) and it has been proven an efficient tool combined with GIS for selecting the optimal site for establishing specific buildings in many fields like energy resources, medical and public services (Shorabeh et al., 2022). The research is always conducted in a way of firstly combining different criteria map layers by overlaying operations, then assigning weights to standards based on the pairwise comparison method, next selecting the suitable locations, and finally combining criteria sets to obtain the final ideal locations. On the other hand, multicriteria decision-making (MCDM) is commonly used when the decisions are controversial, within which analytic hierarchy process (AHP) and analytic network process (ANP) are specific methods that help decision-makers in systematically evaluating criteria, determining the relative importance, and making informed decisions. AHP focuses on capturing each stakeholder's view of the appropriate weights to give each impact factor (O'Sullivan & Unwin, 2003). The combination of GIS and AHP has been used in various location selection problems such as healthcare centers selection, landfill location-allocation, and Dam site selection (Rahimi et al., 2017; Sahraeian et al., n.d.). It usually has four main steps as follows: firstly, identify the criteria. Secondly, structuring the criteria in a hierarchical framework. Thirdly, calculating the weights of the criteria. Finally, ranking the spatial raster according to the obtained index (Sahraeian et al., n.d.). However, AHP has a significant limitation in assuming independency among various criteria of decision-making, which can be solved by ANP. It enables a more comprehensive and systematic analysis by considering the interdependencies among decision attributes (Jharkharia & Shankar, 2007). It also facilitates the inclusion of all relevant criteria, whether they are tangible or intangible, objective or subjective, as they all play a role in making the best decision.

The general procedure for making location decisions is proposed by Stevenson (Yang et al., 2008). Step 1: decide the criteria used to evaluate location alternatives. Step 2: identify important factors. Step 3: develop location alternatives. Step 4: Evaluate the alternative and make a decision.

Determining the criteria for location selection is a complex issue due to the fact that many factors such as the demographical aspect (i.e., population density), economy (i.e., land price, rent price), environmental impact (pollution), and social aspect (target market) should be considered (Sopha et al., 2016). It is possible to say that there are four broad theories about location selection namely central place theory, spatial interaction theory, land value theory, and the principle of minimum differentiation (Erdin & Akbaş, 2019). The central place theory emphasizes the closest distance to customers since the longer the distance is the lower demand for a good or service customers will have (VANDELL & CARTER, 1994). Besides, the traveling time, location accessibility, and store visibility are factors influencing customers' store choice (Jaravaza & Chitando, 2013). However, spatial interaction theory disagrees with the nearest choice assumption and believes that customers tend to prioritize the attractiveness of alternative shopping areas and better parking space over the distance (Carter & Haloupek, 2002; Jaravaza & Chitando, 2013). The land value theory propounds that companies intend to pay higher rents in order to gain more high-value customers and neglect the effect of operating costs such as renting fees, maintenance, or taxes (Nwogugu, 2006; Prendergast et al., 1998). Finally, the principle of minimum differentiation theory proposes that closeness to rivals holds greater significance compared to closeness to customers (Litz & Rajaguru, 2008; Vlachopoulou et al., 2001). Overall, the site selection decision is affected by qualitative and quantitative criteria depending on the trade-off of customers, cost, and revenue (Sopha et al., 2016; Vlachopoulou et al., 2001).

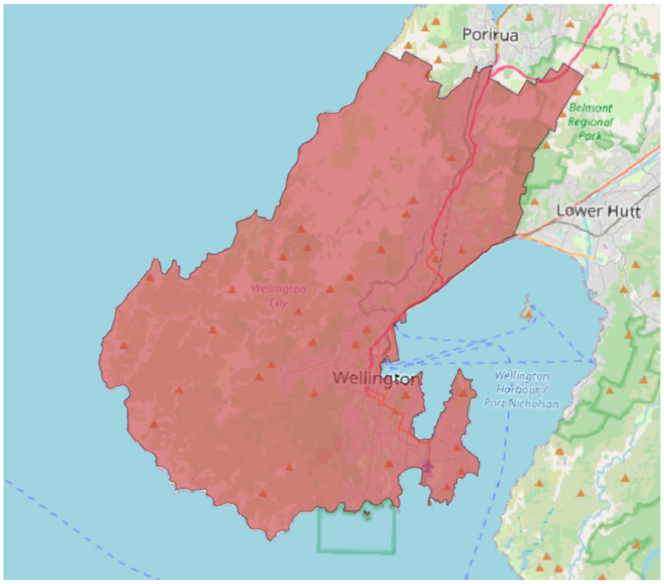
Geographic Information System (GIS) is a set of procedures that provide data input, storage, retrieval, mapping, and spatial analysis and has been increasingly used for location selection (Church, 2002; Erskine et al., 2019). The main reason why it becomes an essential tool for spatial planning and management is that it can not only incorporate multiple criteria in decision-making and visualization but also provide an assessment of choice alternatives (Latinopoulos & Kechagia, 2015).

2. Scope the Project

2.1. Define Wellington

Wellington, the capital city of New Zealand, is located at the southwestern tip of the North Island, between Cook Strait and the Remutaka Range. DMS latitude longitude coordinates for Wellington are 41°17'11.9"S, 174°46'32.05"E. With a latitude of 41° 17' South, Wellington is the southernmost capital city in the world. Wellington is the second-largest city in New Zealand with an area of 289.91 km2 and an estimated population of 213,100 as of June 2022 (“Wellington,” 2023). Also, it is important to note that in terms of geography, Wellington is more densely populated due to the restricted amount of land that is available between its harbor and the surrounding hills, so it has very few open areas to expand. Considering this limitation, insurance companies should select optimum locations for establishing new insurance agencies in the existing space.

Figure 1: Wellington City scope



2.2. Decide the criteria

The criteria for selecting an insurance agency are as follows:

1. Population density: Population density was calculated by dividing the population in every mesh block unit by the area of that unit.
2. Location accessibility: To determine the accessibility, bus station, bus stop, and taxi stop needs to be categorized in the transport layer and a certain buffer area needs to be built.
3. Proximity to a parking place. To determine the proximity, the parking place needs to be categorized in the traffic layer and a certain buffer area needs to be built.
4. Proximity to complimentary outlets: close to the mall, cloth shops, and supermarket.
5. Store visibility: on the side of primary and secondary roads, motorways, and busways.
6. Age distribution: focus on the customer groups between 20 and 65 years old.
7. Cost and sustainability: consider the relative rental fees of different districts.
8. Proximity to competing stores: close to AA insurance stores.

3. Identify Data Needs

3.1. Data description

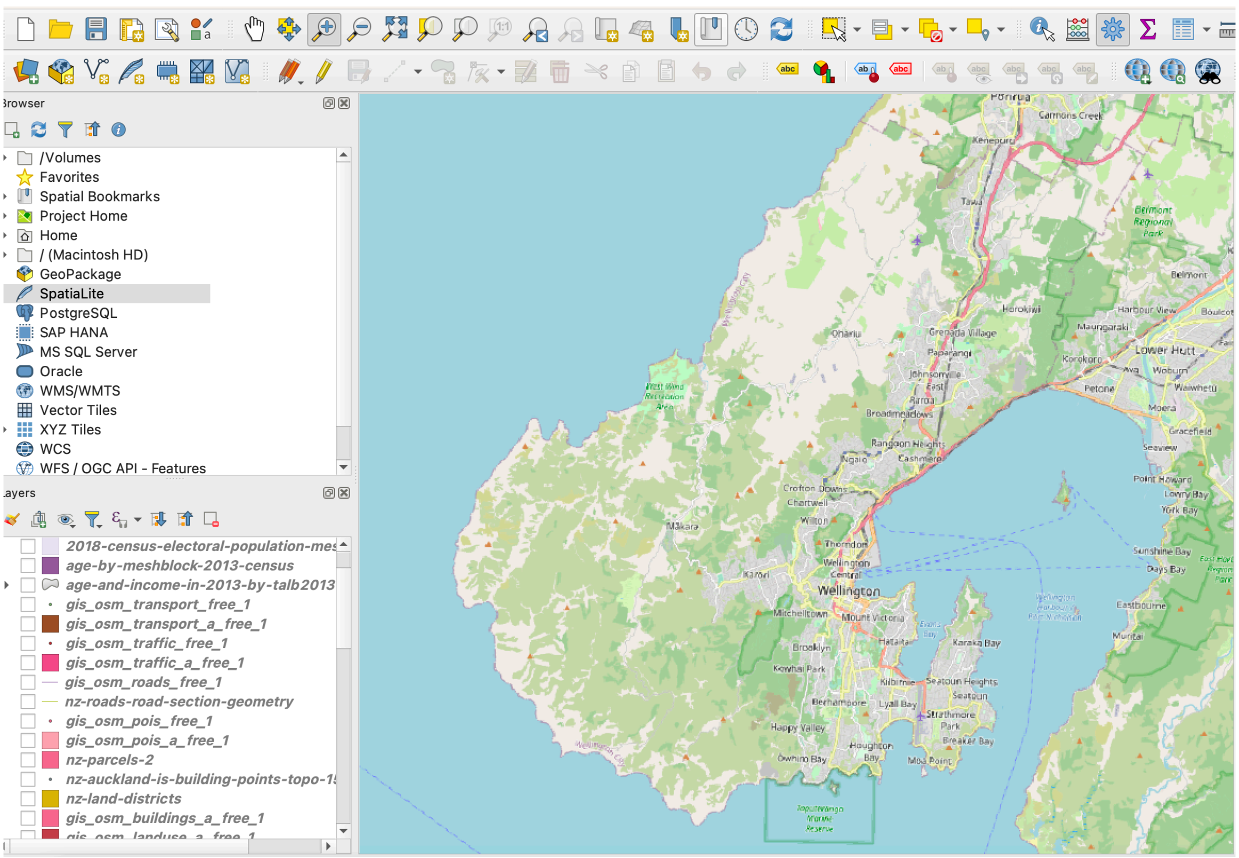
According to the criteria mentioned above, I list the corresponding data categories and search the datasets in Open Street Map (OSM), Koordinates, New Zealand Geographic Board (NZGB), and Land Information New Zealand (LINZ). As a result, a total of 11 datasets were downloaded, including 8 geographic shape files, 1 geospatial dataset, and 1 map sourced from the OpenStreetMap web service. The details of metadata are shown in Table 1.

Table 1: datasets metadata detail

NO.	dataset/information name	description	data source	dataset formats	key attribute information
1	statsnz2018-census-electoral-population-meshblock-2020-SHP	the electoral population at meshblock levels	Koordinates	shape file	General_Electoral_Population, AREA_SQ_KM
2	gis_osm_transport_a_free_1	transport data in NZ	OSM	shape file	fclass (i.e. bus_station, bus_stop)
3	gis_osm_pois_a_free_1	places data in NZ	OSM	shape file	fclass (i.e. bank, mall)
4	nzgb_gazetteer	place name	NZGB	geospatial database	feat_type (i.e. building)
5	gis_osm_traffic_free_1	traffic data in NZ	OSM	shape file	fclass (i.e. parking)
6	lds-nz-roads-road-section-geometry-SHP	road data in NZ	LINZ	shape file	road_type (i.e. bus_way, motor_way)
7	Age and income in 2013 by TALB2013	age and income in different cities	Koordinates	shape file	median_age, median_personal_income
8	Age by meshblock (2013 Census)	age group at	Koordinates	shape file	Age_UR_30_34_2013

		meshblock levels			
9	nz-parcels	base map of NZ	LINZ	shape file	land_district (i.e. wellington)
10	new zealand opens street map	base map of NZ	OSM	Web services	-
11	business district rental fee	rental fee	Google	text sources	-

Fig 2: the screen dumps of QGIS when importing shape files



3.2. Indicators

I create a new attribute named “population density” based on population and area in the dataset “statsnz2018-census-electoral-population-meshblock-2020-SHP” to analyze the population density categories. The formula is population density = (population/area) * 10000.

3.3. Data quality

Four perspectives are considered in the evaluation of data quality which are accuracy, precision, completeness, and classification uncertainty. In the assessment of accuracy, I check for spatial alignment by zooming in to the west of Wellington and comparing the location of features in the NZ parcel layer and OpenStreetMap layer. There is a slight spatial misalignment among these maps maybe because of the differences in the coordinate reference systems, as shown in Figure 1. The OpenStreetMap is based on the World Geodetic System 1984 ensemble (EPSG:6326), which has a limited accuracy of at best 2 meters, while the NZ parcel layer's Coordinate Reference System (CRS) is EPSG:2193 - NZGD2000 / New Zealand Transverse Mercator 2000. As for the aspect of precision, the NZ parcel layer has two fields displaying a precision of 15 and 4, but OpenStreetMap does not display the precision information. When checking the completeness, I use the "Select Features by Expression" button to select features where the specific attribute field is NULL. The OpenStreetMap layer has no null values, while the NZ parcel map has almost 20% null values in the "survey_area" field but it does not matter since this attribute has no influence on the following analysis. Finally, classification uncertainty is checked by using the "Property >Symbology >Categorized" tool to differentiate between different classes of land use and compare the classification with ground observation. As a result, both maps provide high-quality data.

Fig 3: Comparison between parcel layer and OpenStreetMap

3.4. Privacy and ethical issues

The exponential growth in the use of data has brought an unprecedented level of insight and innovation as well as significant risks such as breaches of privacy, identity theft, and surveillance if we do not pay attention to data collection, access, and utilization. Through learning the Privacy Act 2020 set by the New Zealand government, the dataset used in this study does not exist privacy and ethical issues as all the information is highly aggregated without showing any individual-level information.

4. Perform analysis

4.1. Common spatial analysis methods

The most commonly used spatial analysis methods are analysis of attribute tables, point-in-polygon operation, polygon overlay, raster analysis, buffering, map algebra, spatial joins and multi-criteria evaluation.

Analysis of attribute tables involves exploring the characteristics, relationships, and patterns within the attribute tables of spatial datasets. It can be used when looking for possible relationships or correlations, for instance, plotting one variable against the other as a scatterplot to examine median house value and percent black for U.S. counties in 1990 (Longley et al., 2015).

The point-in-polygon operation is used to determine whether a point lies inside, outside, or on the boundary of a polygon (Longley et al., 2015). So, the research questions are like “Which country is the city in?”, “Whether the customer’s address fall within the boundaries of a specific store location?”.

Polygon overlay is similar to the point-in-polygon operation in the aspect that two sets of objects are involved, but in this case, both are polygons (Longley et al., 2015, p. 301). It is worth mentioning that polygon overlay from the continuous field (raster) and discrete object (vector) perspective has different meanings (Longley et al., 2015). Specifically, from the continuous field perspective, polygon overlay refers to the process of combining overlapping polygons to create a new polygon layer, while from the discrete object perspective, polygon overlay involves the analysis of the spatial relationships between polygons based on their geometric attributes. It includes operations such as intersection, union, difference, and symmetric difference.

Raster analysis is the process of performing various calculations, manipulations and operations on raster data which is structured as a grid of cells and each cell represents a value related to a specific location on the Earth's surface (Longley et al., 2015). It is widely used in various scenarios, including land cover classification, habitat suitability modelling, site selection, or climate change impact analysis.

Buffering is usually used to create a certain specified distance around spatial features such as points, lines, or polygons (Longley et al., 2015). It is useful for assessing proximity, identifying areas of influence, or delineating zones based on specific criteria and can be used in both raster and vector formats.

Map algebra involves performing analysis with rater grids, also known as grid processing. It is widely used in terrain analysis, such as calculating slope and aspect.

Spatial joins involve combining attribute data from two spatial datasets based on their spatial relationship. In the simple case, we can join datasets at a similar level that are in the same location to combine their attributes.

4.2. Methods used in the study and analysis steps

As a result, in the case of selecting an insurance agency, I choose the analysis methods of polygon overlay, buffering, and spatial joins and conduct them in vector layers. The following descriptions are the detail steps.

Step1: Reproject all imported layers' coordinate reference system to EPSG:2193 - NZGD2000 / New Zealand Transverse Mercator 2000 to make them consistent with each other.

Step 2: Select Wellington object areas in the parcel base map layer using an attribute query.

Step 3: Concentrate on the population density criterion to delineate the densest districts. Firstly use the attribute query to create a new attribute population density. Then draw a choropleth map to check the densest category. Finally, use the attribute query to select the densest district in Wellington.
Step 4: locating proximity to the bus station or bus stop, parking place, bus way, and complimentary places. First of all, using the polygon overlay method Intersection to narrow down Wellington in transport, traffic, road, and place layer. Next, using attribute query to select bus station in transport, parking in traffic, bus way, a motorway in the road, mall shop supermarket in place layer. Finally, using buffering to select proximity in bus stations, parking, mall, and road.
Step 5: use spatial join to add median age, and age group to the Wellington base map.
Step 6: use pairwise Intersection with these layers and locate the final site.

5. Produce Geo-visualization

5.1. Geo-visualization approaches

Geo-visualization approaches can be categorized into three groups namely pure geo-visualization, spatial analytical visualization, and transformation visualization (O'Sullivan & Unwin, 2003).

Pure geo-visualization focuses on the visualization of geographic data without any additional analytical operations. It aims to represent spatial patterns and relationships visually appealingly to enable explorers to explore and interpret spatial information. Techniques such as linking and brushing, visual highlighting, density smoothing, contour mapping, interpolation, choropleth maps, heatmaps, dot density maps, and 3D visualization fall under this category. Linking and brushing are used to highlight symbols on a map display when they have been selected for investigation (O'Sullivan & Unwin, 2003). They interactively combine multiple forms of visualization and change in one view and reflect in the other. Visual highlighting refers to the objects highlighted when the mouse moves over them and often combines with linking and brushing. Such elements can be highlighted with, color, depth of field, leader lines, transparency, contouring, saturation, and style reduction. Density smoothing, also known as heat mapping, is the method used for smoothing dot density data by creating a continuous surface. Density smoothing techniques, such as kernel density estimation, help interpretation by highlighting clusters. Contour mapping is the method used for displaying some attribute values such as density. Although it can aid in interpretation, it reduces clarity since the actual data points are not visible (O'Sullivan & Unwin, 2003). Interpolation involves estimating precise attribute values at unsampled locations based on measurements taken at control points within the same area (O'Sullivan & Unwin, 2003). It can be used to create a smooth 3D surface for visualization. Interpolation techniques such as IDW, Kriging, and Spline are commonly used. Choropleth maps are probably the most widely used maps that display intervals over natural areas and this technique is available in virtually all GISs (O'Sullivan & Unwin, 2003). For instance, in a choropleth map showing the density across approximately 13 regions in New Zealand, two types of data can be displayed: the actual population density values and the outlines of the areas over which the data has been calculated. Dot density maps use a dot to indicate the presence of a variable. They are essentially scatterplots on a map that show spatial patterns. But it has a disadvantage in that the dots' locations are arbitrary (O'Sullivan & Unwin, 2003). 3D visualizations represent the geographic data in three-dimensional space, which provide a more immersive and realistic view of the landscape.

Spatial analytical visualization combines geo-visualization with advanced analytical techniques to extract valuable insights from spatial data. It modifies the numbers to be mapped mathematically (O'Sullivan & Unwin, 2003). By utilizing techniques like spatial clustering, it uncovers concealed patterns and relationships that may not be readily evident through pure geo-visualization alone.

Transformation visualization involves reprojecting the original spatial data into a new representation that enhances its interpretability. It mainly contains cartograms, Dasymetric, hex, and schematic maps. Cartograms are map transformations that distort area or distance in the interest of some specific objective (Longley et al., 2015, p. 276). It aims to reveal patterns that might not be readily apparent from a conventional map or to promote legibility in a way that emphasizes its relative importance across different regions.

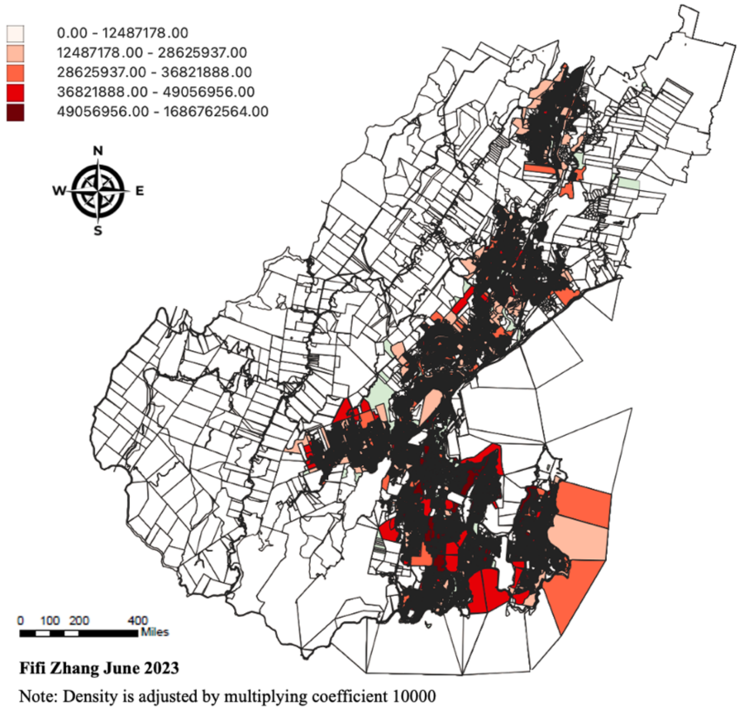
Dasymetric maps are a technique used to improve the accuracy of thematic maps by incorporating additional ancillary data such as population density to create more accurate boundaries within a map (O'Sullivan & Unwin, 2003). Dasymetric mapping helps to refine the representation of data by allocating it to more specific areas based on the underlying characteristics. Hex maps are a specialized form of thematic map that uses hexagonal-shaped bins or cells to represent data ("Hex Map," 2023). Hex maps are commonly used in data visualization, especially in fields such as crime mapping and spatial clustering. Schematic maps are designed to emphasize the relationships and connections between locations rather than their precise geographical accuracy (Administrator, 2017). Schematic maps are commonly used for public transportation systems. They remove unnecessary details, distort distances and shapes for improved clarity, and prioritize the visual communication of connectivity and direction.

5.2. Methods used in the study

In the case of insurance agency site selection, methods like choropleth maps, heat maps, and dot density maps can be used. Due to the time limit, I conduct a choropleth map alone.

Figure 4: choropleth map of population density in Wellington

Population Density Choropleth Map in Wellington



6. Outcome and Issues

The project question is choosing the optimal insurance agency locations and the deployment steps are as follows:

1) Identifying the criteria of insurance agency location allocation according to literature review. As a result, I choose eight criteria that are population density, location accessibility, proximity to a parking place, proximity to complimentary outlets, store visibility, age distribution, cost and sustainability, and proximity to competing stores.
2) Defining each criterion. For population density, I defined the densest district in the population density choropleth map. Location accessibility refers to the locations which are 100 meters from bus stations, bus stops, and taxi stops in the transport layer. Proximity to a parking place means 100 meters from the parking place in the traffic layer. Proximity to complimentary outlets represents the districts 100 meters from the mall, cloth shops, and supermarket. Store visibility means 50 meters from the primary and secondary road, motorway and busway. Age distribution focus on the group between 20 and 65 years old. Cost and sustainability refer to the rental fee and maintenance fee, but since I didn't acquire the relevant dataset, I use the relative rental fee to substitute

such as the closer to downtown the more expensive the rental fee would be. Proximity to competing stores equals 500 meters to AA insurance stores.

3) Develop different criteria map layers by using polygon overlay, buffering, dissolve, spatial join, attribute query, and choropleth map, as shown in Figure 6-10. Figure 6 shows the densest district in Wellington. Figure 7 indicates the area that is 100m from bus station and bus stop. Figure 8 refers to the area that is 100m from parking places. Figure 8 shows the places 100m from malls and supermarkets. Figure 9 shows the places 50m from the main roads. Figure 10 indicates the places with an age distribution of 20 to 65 years old.

Fig 5: densest population area

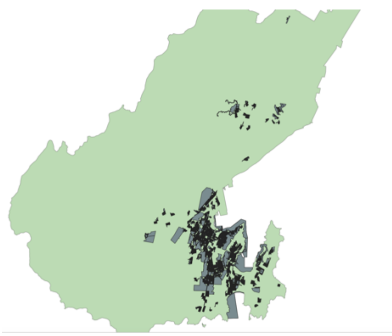


Fig6: location accessibility

Fig7: proximity to a parking place

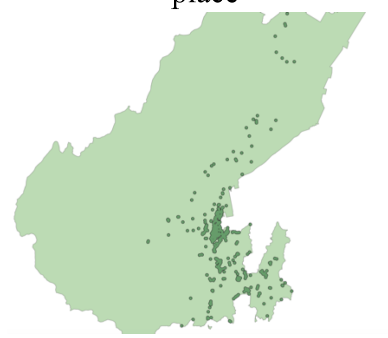


Fig8: proximity to complimentary outlets

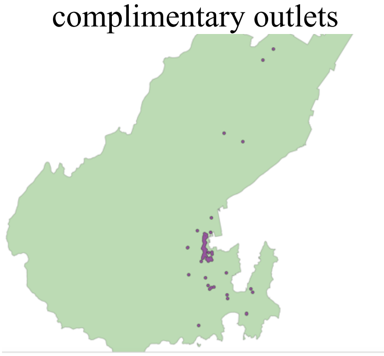
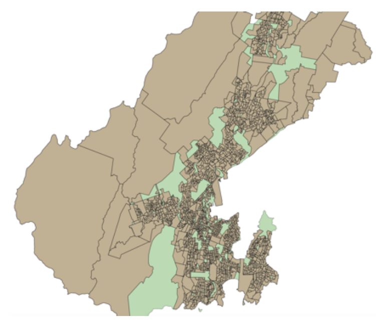


Fig9: store visibility

Fig10: age distribution 20 to 65

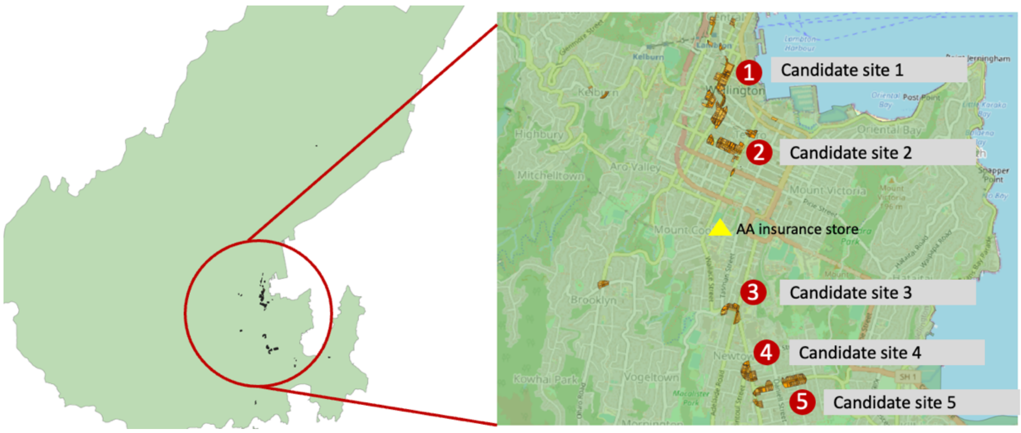


Note: green color is the base map of Wellington.

4) Pairwise intersect different criteria layers by multi-criteria evaluation, as a result, five candidate sites are selected, as shown in Figure x.
5) Evaluate the alternatives and make a decision. Considering the rental fees, candidate site 1 and candidate site 2 are in the downtown which means higher maintenance fees. Then I search the competing AA insurance stores on Google Maps, as shown yellow triangle in

Figure 11, which indicates that candidate site 3 is closer to it. Therefore, candidate site 3 is the optimal place to build an insurance agency.

Fig 11: intersection of each criteria layers



7. Reflection

The essay aims at exploring the optimal insurance agency site selection by conducting a GIS-based multi-criteria evaluation method. It develops the fundamental spatial analysis and operations on the basis of a systematic and rigorous methodology. Although the whole process is thorough, there are still three perspectives that can be refined in the future namely data collection methods diversity, various geo-visualization methods, and advanced AHP application. Firstly, the ability to acquire datasets from a diversity of sources needs to be improved. Except for OSM, LINZ, and Koordinates, other data sources need to be explored. What's more, apart from choropleth maps, other geo-visualization methods like heatmaps, and dot density maps can be applied in the research. Finally, as different criteria have differentiated importance toward location allocation, appropriate weights should be set to each criterion, thus performing AHP is more suitable for this case.

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