Huff Model & Location Allocation

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March 18, 2024

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Introduction

Location is a very important aspect of modern business strategy, urban planning, and logistics. There are many different models which are useful in terms of determining which locations are the most suitable depending on the problem that a business or organization is facing. The Huff model is a probabilistic model typically used in the analysis of consumer behavior and retail location. It predicts the probability of consumers at a particular location choosing to shop at a particular store or shopping center. The model takes into account factors such as the attractiveness of the store and the distance between the consumer's location and the store. Location allocation, on the other hand, is a process that involves determining the best places to locate facilities while considering factors such as demand, supply, and cost. It aims to minimize costs, maximize service, or achieve a suitable balance between the two. This report will implement the Huff model in order to estimate the sales potential of a shopping centre in a census tract. It will then evaluate the impact on sales potential that the addition of a new shopping center has on previously existing shopping centers. Following this, location allocation will be conducted in order to identify potential sites for 5 proposed supermarkets. The sales potential of these 5 proposed stores will then be analyzed and a competition analysis will be conducted along with site evaluation.

1. Huff Model Literature Review

The Huff model is a useful tool in spatial analysis that predicts the probability of consumers patronizing a specific location. It originated in 1963 by David Huff and is based on the assumption that a given customer does not always patronize the nearest store, but rather there is always a probability that the customer will choose to visit a further store (Huff, 1963). The probability of the customer visiting and purchasing goods at a given store is based on a variety of factors such as the distance from their home to the store, the store's attractiveness, and the distance to and attractiveness of competing stores (Huff, 1963). The probability can then be used to determine the sales potential of the store. The Huff model is as follows:

$$P_{ij} = \frac{\frac{(A_j)}{(D_{ij})^{\lambda}}}{\sum_{j=1}^{n} \frac{(A_j)}{(D_{ij})^{\lambda}}}$$

(the original Huff Model)

Figure 1: Original Huff model

Where

- P*ij* represents the probability of a consumer at location *i* travelling shopping at store *j*
- A*j* represents the attractiveness of store *j*
- D*ij* represents the distance between the consumer at location *i* and the store *j*

- λ represents an exponent applied to the distance so that the probability of distant sites is dampened (How Huff model Works, n.d)

The Huff model was then later expanded on by David Huff to allow for the use of more than one attractiveness variable and an exponent as a weight was added for these attractiveness variables (Huff, 2003).

$$P_{ij} = \frac{\dfrac{(A_j)^{\alpha}}{(D_{ij})^{\lambda}}}{\displaystyle\sum_{j=1}^{n} \dfrac{(A_j)^{\alpha}}{(D_{ij})^{\lambda}}}$$

(the extended Huff Model)

Figure 2: Extended Huff model

The Huff model has a variety of applications across many different fields such as real estate, marketing, transportation, health, etc (Huff & Black, 1997). For example, the Huff model is commonly used by retailers in order to help forecast sales. By using the Huff model, retailers are able to understand the demand for services within certain areas and the potential sales that can be generated.(Myoung-Kil, 2012). This is especially useful when determining where to open a new location as it minimises the risk involved for the retailer. Another useful benefit of the Huff model is that it can be combined with other research methods. For instance, the Huff model has been used with methods such as the two-step floating catchment (Liu et al., 2022). By combining these two methods together, researchers can better measure spatial accessibility for vulnerable populations and make more informed suggestions for policy makers.

In order to use the Huff model, there are a few requirements that must be met. First of all, the model needs to know the distances between the store locations and the consumer locations. Secondly, there needs to be an attractiveness measure for each of the stores. This attractiveness measure is usually based on variables such as store size, parking space, product pricing, etc. Lastly, an exponent value, usually ranging from 1-3, also needs to be applied to the distance variables in order to reduce the probability of distant sites (Ramanathan, 2009). When using the extended Huff model, multiple attractiveness variables can be calculated and weighted accordingly by applying an exponent to them. This allows for certain attractiveness variables to be considered more important while still being able to include other attractiveness variables that would be considered relevant (Suárez-Vega et al., 2014). Although the Huff model is a very useful tool, it is not without its limitations. The main limitation of the Huff model is that it does not consider physical barriers or road networks. As such, even though the model may say that one location has a higher probability of the customer going to it, that might not necessarily be the case when taking into consideration traffic conditions or the method of transportation that they take (Mitríková et al., 2015). The model also does not take into consideration other factors such as the social, economic, and political variation between different groups of consumers (Mitríková et al., 2015). Therefore, although the Huff model is useful in many scenarios, it is important to understand that it may not be completely accurate or representative of the population.

2. Estimating sales potential in Census Tract 535,266 for Yorkdale Shopping Centre

In order to estimate the sales potential in Census Tract 535,266 for Yorkdale Shopping Centre, we can use the following formula:

Sales Potential *= Number of Households ✖ Average Household Income ✖ Percent of income spent on consumer goods ✖ Probability population shops at shopping centre*

(Note: ✖ represents multiplication)

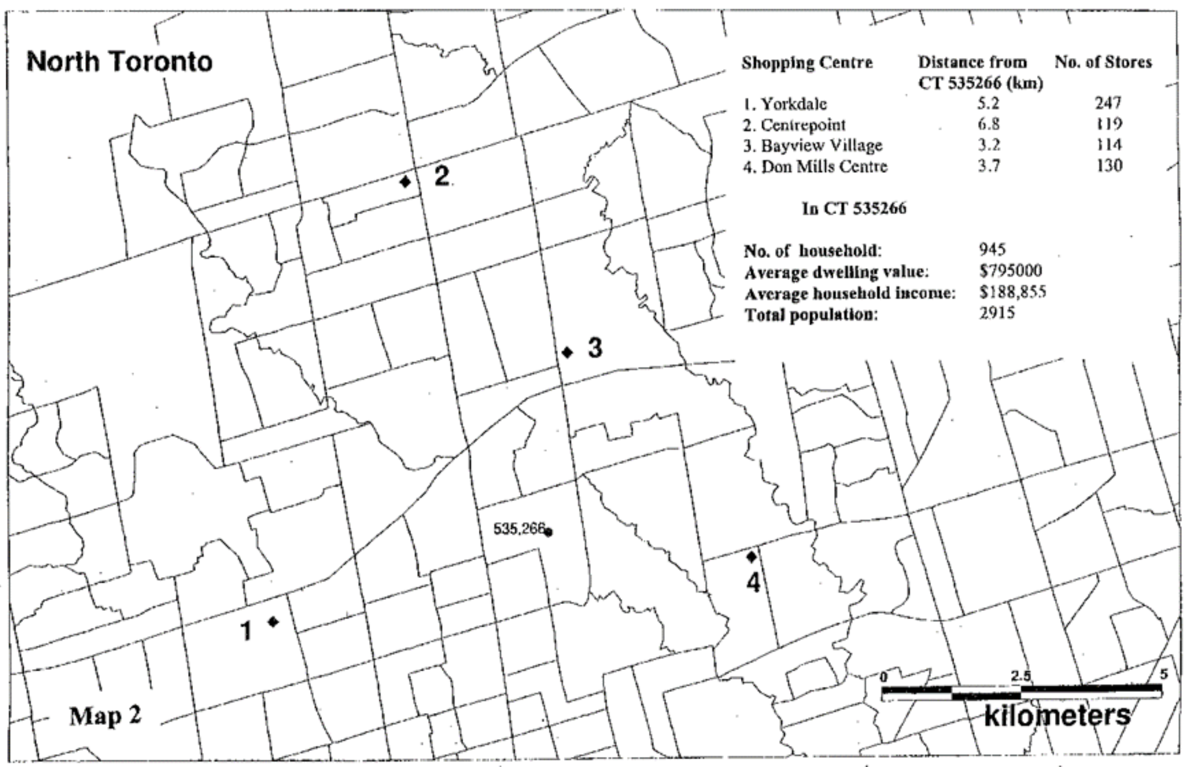

Figure 3: Map of Census Tract 535,266 and the Four Surrounding Shopping Centres

Based on Figure 3, we can see that we have information about the number of households and the average household income. We also know from a customer survey that 15% of income is spent on consumer goods in regional shopping centres. However, we must find the probability that the population shops at a shopping centre, in this case the shopping centre being Yorkdale. In order to do so, we can use the Huff model formula with the distances to each shopping centre and the following attractivness parameters based on Figure 3:

- A - 247 (Yorkdale)
- B - 119 (Centrepoint)
- C - 114 (Bayview Village)
- D - 130 (Don Mills Centre)
- λ - 2 (Lambda = 2 represents moderate distance)

$$P_{ij} = \frac{\frac{Aj}{Dij^{\lambda}}}{\sum \frac{Aj}{Dij^{\lambda}}} = \frac{\frac{247(A)}{5.2^2}}{\frac{247(A)}{5.2^2} + \frac{119(B)}{6.8^2} + \frac{114(C)}{3.2^2} + \frac{130(D)}{3.7^2}} = 0.282$$

Figure 4: Yorkdale Huff model Calculation

Based on the formula, we can see that the probability of the population shopping at Yorkdale is 0.282. We can now plug this value into the sales potential formula to find the sales potential for Yorkdale.

Yorkdale Sales Potential *= Number of HH (945) ✖ Average HH income (188,855) ✖*

% income spent on goods (0.15) ✖ Probability of shopping at store (0.282) = 7,549,195

As such, we can see that the sales potential in Census 535,266 for Yorkdale Shopping Centre is approximately $7.55 million.

3. Effect of Vaughan Mills on Trade Area

In order to evaluate how the addition of Vaughan Mills mall has impacted the market areas of Promenade, Yorkdale, and Square One mall, we need to calculate the sales potential of the primary and secondary trade areas of each mall before and after the addition of Vaughan Mills. In order to find the primary and secondary trade areas, we will need to use the Huff model which will give us the probability of customers from the census tracts shopping at each of the malls. A census tract with a probability of greater than or equal to 60% means that it is a primary trade area for the respective mall while between 60% and 40% means it is a secondary trade area. Anything less than 40% probability is considered not significant. Before applying the Huff model, we must create a composite attractiveness variable as there are multiple variables which could be used to measure the attractiveness of a mall. The variables used will be floor space, number of stores, number of department stores, and number of fashion stores. Each of these variables will be assigned a weight as some are considered more important than others. The composite attractiveness formula to be used is as follows:

Composite Attractiveness = *(Floor Space ✖ 2) + (Number of Stores ✖ 3) +*

(Number of Department Stores ✖ 1) + (Number of Fashion Stores ✖ 2.5)

The most weight was given to the number of stores as it indicates the mall has more options for customers to choose from. Floor space and number of fashion stores were given moderate weights as larger floor space indicates a larger and likely more interesting mall while fashion stores are what people are most likely to buy from at malls. Number of department stores was given the least weight as people generally do not go to malls to buy from them.

The extended Huff model with the composite attractiveness variable was then used to calculate the probability of the population at each of the census tracts shopping at each of the malls. Figure 5 shows the trade area of Promenade, Yorkdale and Square One before the addition of Vaughan Mills while Figure 6 shows the trade area after the addition of Vaughan Mills.

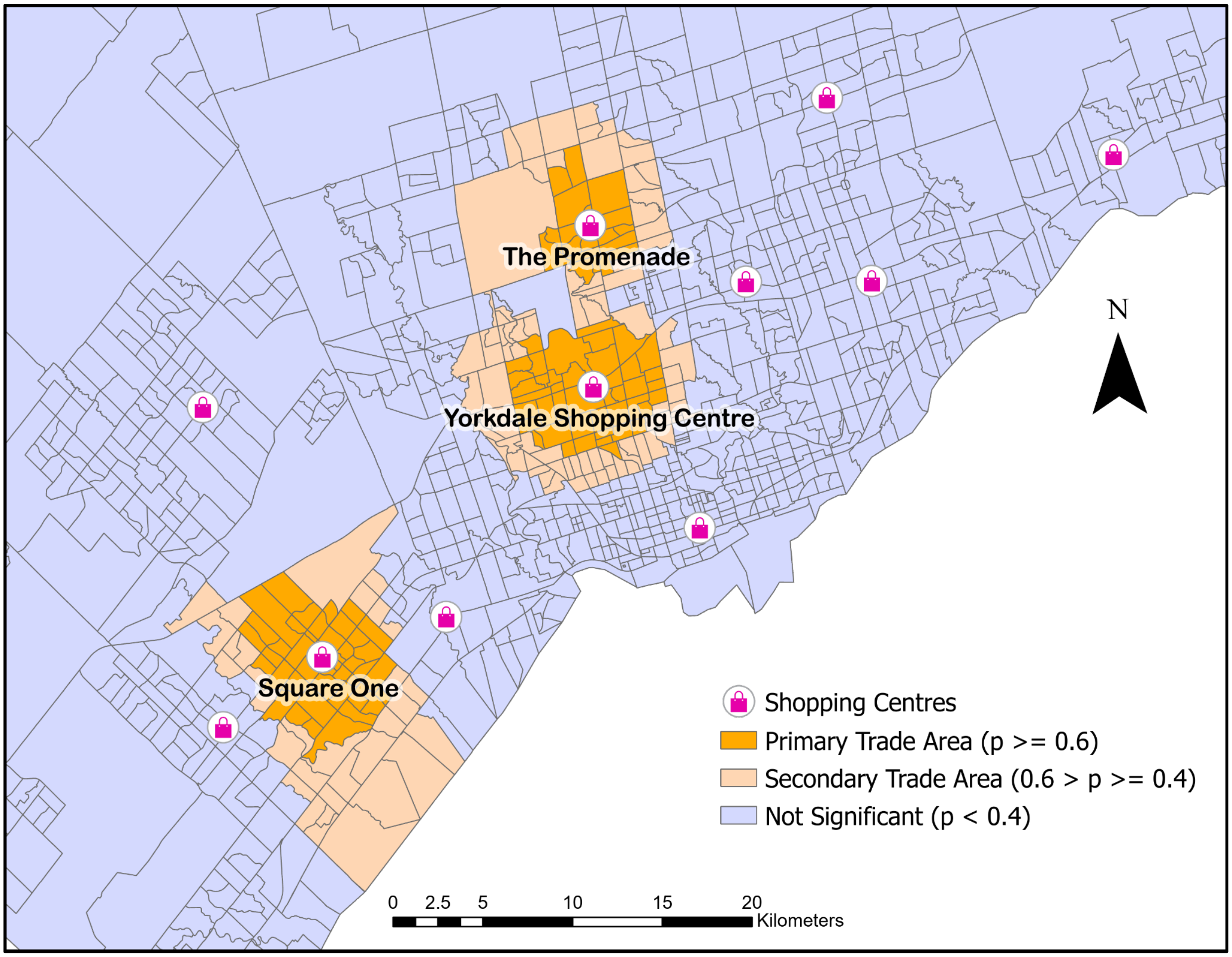

Figure 5: Trade area before addition of Vaughan Mills

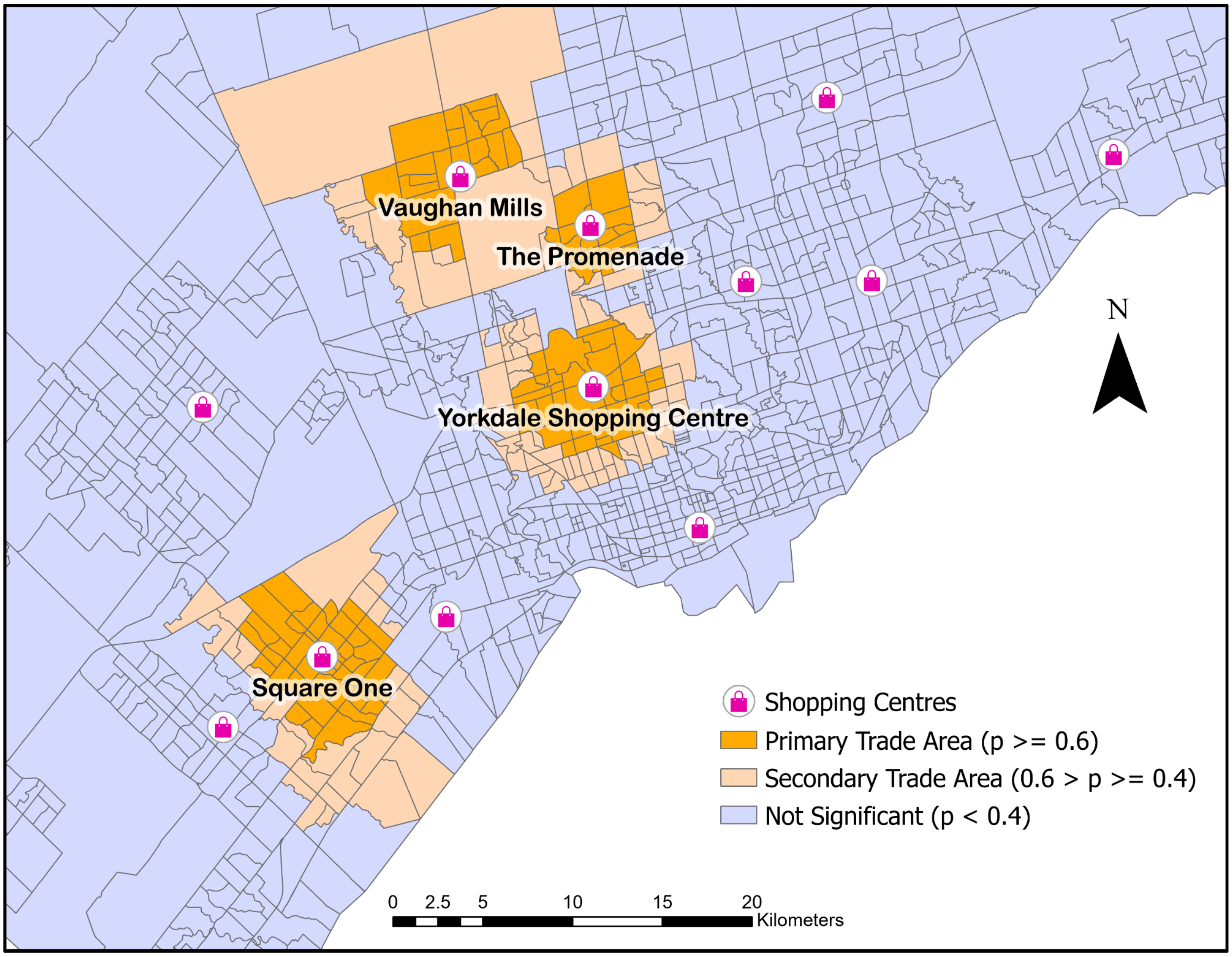

Figure 6: Trade area after addition of Vaughan Mills

Based on the two figures, we can see that Vaughan Mills has a minimal effect on Square One while mostly affecting Yorkdale and Promenade mall. This is because Square One is much farther away from Vaughan Mills than the two other malls so its trade area is less affected. To estimate the sales potential of the malls, we use the sales potential formula from earlier. The number of households and average annual income of the census tracts were given from the 2016 Canadian Census while the percentage of family income spent on goods and services at shopping centres was given from the 2019 Survey of Household Spending. Approximately 21% of family income is spent on goods and services at shopping centres. The breakdown of this percentage can be seen in the following table:

Shopping Center Category	**Amount Spent (CAD $)**
Misc. Under Education	$2,321
Food Expenditure	$10,711
Household Furnishings and Equipment	$2,712
Clothing and Accessories	$3,822
Personal Care	$1,417
Recreation	$3,658
Total Spent	$20,983
Average Household Expenditure	$101,063
Percentage Spent at Shopping Centers	~ 21%

Table 1: Breakdown of spending at shopping centres

With these three variables and the probability of customers from the census tract shopping and each of the malls, we can calculate the sales potential of each of the census tracts. These sales potentials can then be summed to find the total sales potentials of each of the malls for their primary and secondary trade area. The effect of the sales potential of the malls with and without Vaughan mills can be seen in the following table:

Trade area		Yorkdale		Promenade		Square One	
		Without VM	With VM	Without VM	With VM	Without VM	With VM
Primary	# of CT's	**43**	**37**	**19**	**16**	**42**	**41**
	Sales potential ($ million)	**1,495**	**1,271**	**703**	**578**	**1,262**	**1,237**
Secondary	# of CT's	**58**	**53**	**22**	**12**	**32**	**29**
	Sales potential ($ million)	**1,259**	**1,246**	**448**	**255**	**709**	**623**

Table 2: The effect of Vaughan Mills on sales potential

Based on table 2, we can see that the addition of Vaughan Mills has mostly impacted the sales potential of Yorkdale and Promenade shopping centres. While Square One has been affected by the addition of Vaughan Mills, it is much less impacted than the other two shopping centres were as it only lost 1 primary census tract and 3 secondary census tracts. The impact of Vaughan Mills on the sales potential of the malls can be summarised through the following table:

Shopping Centre	**Primary Trade Area % Change in Sales Potential**	**Secondary Trade Area % Change in Sales Potential**
Yorkdale	-15%	-1%
Promenade	-18%	-43%
Square One	-2%	-19%

Table 3: Percentage Change in Sales Potential of Yorkdale, Promenade, Square One

Based on table 3, we can see that Promenade shopping centre has been the most affected in terms of sales potential by the addition of Vaughan Mills as it has the largest decrease in sales potential percentage in both the primary and secondary trade area. Yorkdale is the second most affected shopping centre as it has a 15% decrease in sales potential for its primary trade area while Square One only has a 2% decrease. While Square One does have a larger decrease in sales potential for its secondary trade area, it is much more likely that customers from the primary trade area will be shopping at the mall than those in the secondary trade area.

For future attractiveness variables, there are a variety of variables that could be considered in order to improve the calculation of probabilities. One possible variable is the number of restaurants at the shopping centre as many people are likely to eat out after shopping, so having a variety of food options is likely to attract people to that location. Another possible variable is the number of parking spots as people would be more likely to go to the shopping centre if they have enough available parking. If there are not enough parking spots available and people find it hard to find a spot to park, then they would be less likely to go to that location. One more attractiveness variable could be the review score of the shopping centres such as how many stars they have on Google Reviews or Yelp. People are more likely to go to shopping centres which have higher review scores online as they would be perceived as providing a higher quality experience than other shopping centres.

4. Location Allocation Literature Review

Location allocation models are used to select sites for a number of facilities simultaneously. The purpose of location allocation is to select the most optimal sites for a given problem type as some locations are better than others for a given purpose. There are a variety of different social, political, and economic factors that can influence the most optimal sites. The main questions that location allocation seeks to answer is how many facilities are needed to support the demand in the market, how many facilities can be supported in the market, and where should these facilities be located (Cooper, 1963). Location allocation modelling has many useful applications across a variety of disciplines. It is commonly used in retail analysis in order to determine the most suitable locations for opening new stores depending on the goal such as aiming to maximize the coverage of the store or to minimize the driving distance. Location allocation is also used in fields such as health care. Location allocation in health care can help to determine where specialized health care services such as traumatic brain injury (TBI) facilities should be located depending on a variety of factors such as the degree of centralization, patient retention, and geographic density (Syam & Côté, 2010). Another interesting application of location allocation modelling is using it to analyze archaeological settlement patterns (Bell & Church, 1985). Location allocation modelling is believed to be a better tool for the analysis of settlement patterns of ancient civilizations than the geometric theorems derived from central place theory as central place theory was developed for modern market economies (Bell & Church, 1985) while location allocation modelling is applicable to pre-urban markets as well.

There are a number of different location allocation models that can be used in order to choose the most optimal facilities depending on the problem type. Some of the most common types are the following (Wang, 2024, Slide 8):

Location Allocation Model	**Function**
Minimum Impedance (p-median)	It chooses facilities such that the total sum of weighted is minimized. (impedance = distance)
Maximum Coverage	It chooses facilities such that all, or the greatest amount, of demand is within a specified distance cutoff
Minimum Facility	It chooses the minimum number of facilities needed to cover all or the greatest amount of demand within a specified distance cutoff.
Maximum Attendance	It chooses the set of facilities that maximize the total allocated demand; demand further than the specified impedance cutoff does not affect the chosen set of facilities
Maximum Market Share	This option solves the competitive facility location problem. It chooses facilities to maximize market share in the presence of competitive facilities. Gravity model concepts are used to determine the proportion of demand allocated to each facility. The set of facilities that maximizes the total allocated demand is chosen
Target Market Share	This option also solves the competitive facility location problem. It chooses facilities to reach a specified target market share in the presence of competitive facilities. Gravity model concepts are used to determine the proportion of demand allocated to each facility. The minimum number of facilities needed to reach the specified target market share is chosen.

Table 4: List of location allocation models

In order to run location allocation there are some requirements which need to be met. Firstly, the model needs candidate sites such as potential locations of supply. These are the locations that will be considered as the new places to build facilities. Next, a list of points of demand such as census tracts or dissemination areas are required. These demand points are the population that is served by the candidate sites. Lastly, a distance matrix or a road network used to calculate distance is needed. These are the main components required for location-allocation modelling (Wang, 2024, Slide 17).

As with all research methods, location-allocation has its benefits but also has a few limitations. One of the main limitations is that distance is not always a reliable variable to use as it can vary on how important it is to different parts of the population. If a census tract has a population which does not have a lot of people with cars they would prefer to go to the nearest facility but a census tract with a lot of cars might prefer to go a greater distance. Distance also does not consider travel times, as a facility that is closer might not be the fastest to travel to depending on the traffic or access to transportation which is why people might prefer to go to another facility that is farther away (Polo et al., 2015). Another limitation of location allocation is that it does not consider how the flow of the existing facilities can be channelled through the new facilities (Aykin & Brown, 1992). Since facilities act as part of the same organization, they are able to assist each other rather than acting as independent units. So although a location might be the best if the facility was acting independently, it might not be the most optimal location logistically for the location depending on where their other business operations are (Aykin & Brown, 1992).

5. Potential Sites for the 5 Proposed Supermarkets

After running the location allocation model using both Minimum Impedance and Maximum Coverage, the results of the output were identical in both cases. Figure 7 shows the outputs of both models.

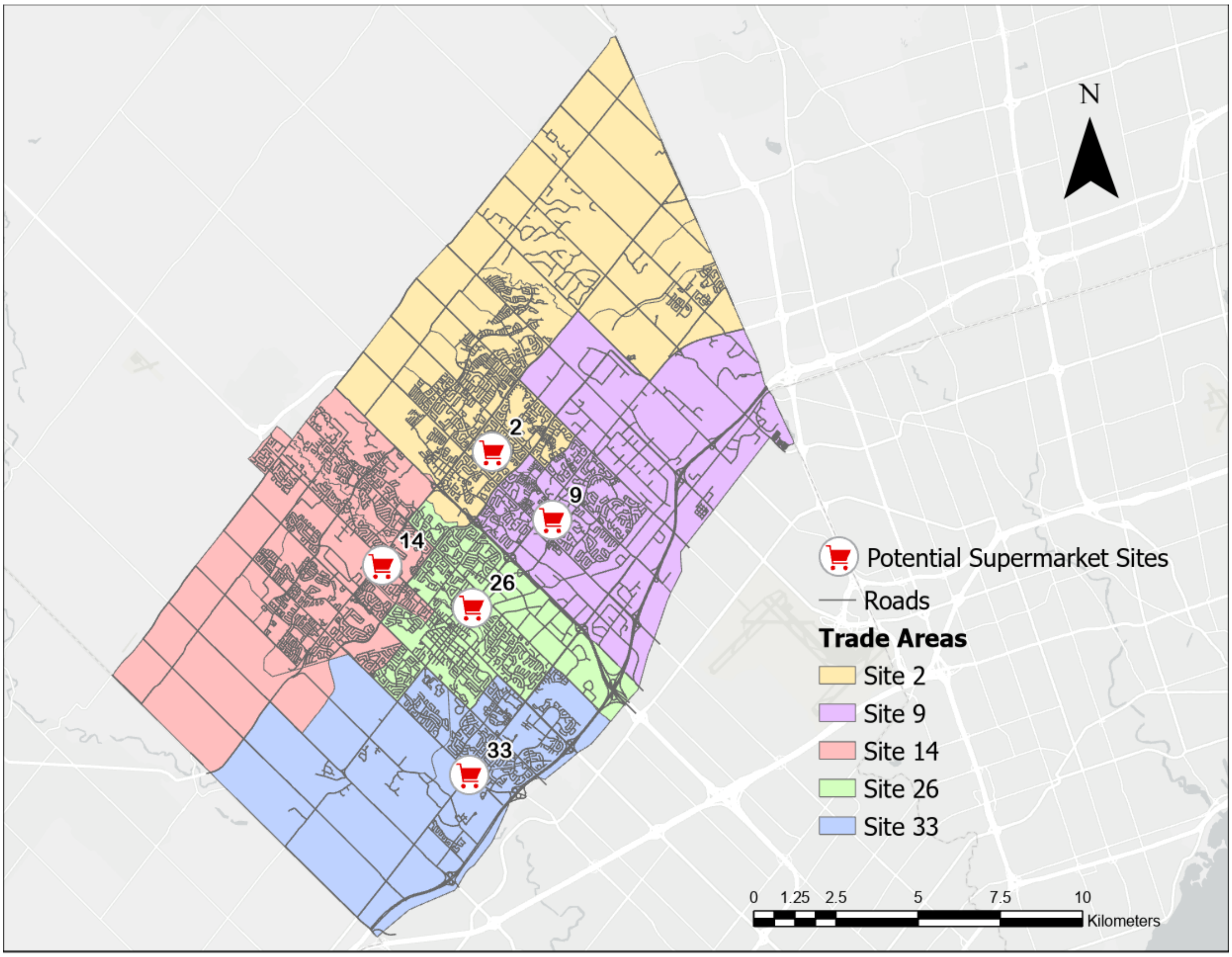

Figure 7: Potential Supermarket Sites and their Trade Area

Since both model outputs are identical, this implies that the sites selected have both the greatest amount of coverage while also having the lowest drive times.

6. Sales Potential for the 5 Proposed Supermarkets

In order to calculate the sales potential of each of the supermarkets, the sales potential formula was used to find the sales potential of each census tract belonging to a site and then summed. This gave the sales potential of each site. The sales potential formula is as follows:

Sales Potential *= Number of Households ✖ Average Household Income ✖ Percentage of Income Spent On Food From Stores ✖ Probability of Shopping at Supermarket*

Supermarket Site	Number of Census Tracts	Number of Households	% Income Spent on Food from Stores	Probability of Shopping at Supermarket	Estimated Sales Potential (CAD $ Millions)
2	34	51,670	7%	100%	390
9	12	19,955	7%	100%	110
14	25	43,560	7%	100%	320
26	13	25,385	7%	100%	150
33	14	27,460	7%	100%	190

Table 5: Sales Potential for 5 proposed supermarkets

The number of households and average household income for each census tract was within the census data while the percent of income spent on food from stores was acquired from the 2019 survey of household spending. This was roughly 7%. The probability that the people in the census tract shop at the respective supermarket is considered 100% as that is the site that the census tract belongs to. This formula was applied to all the census tracts for each of the supermarket sites, which then gave us the estimated sales potential for each supermarket site. We can see from table 4 that site 2 has the highest estimated sales potential at $390 million, followed by site 14 at $320 million. Site 9 has the lowest estimated sales potential at $110 million. The reason for this is because site 2 and 14 have a greater number of households that their trade area covers while site 9 has the least.

7. Competition Analysis

Competition analysis was conducted for each of the site locations using 1 kilometer, 5 kilometer, and 10 kilometer distances. Buffers for each of the distances were created around each site and then the competing supermarkets that fell within those distances were extracted. Table 6 shows the results of this analysis. Site 26 seems to have the most competing supermarkets within a 2.5 kilometer and 5 kilometer radius while site 33 seems to have the least within those same distances. Based on the estimated sales potential and competition analysis, site 2 seems to be a good candidate for a new location as it has the highest sales potential while having a moderate amount of competing supermarkets.

Site Number	1 km		2.5 km		5 km	
	No. of Stores	Name of Stores	No. of Stores	Name of Stores	No. of Stores	Name of Stores
2	1	Sobeys	4	Foodland, Metro, Nila's Supermarket, Sobeys	12	Leela Supermarket, Metro (3), Foodland, Nila's Supermarket, Food Basics, Sobeys, Freshco, No Frills (3)
9	2	Metro, Nila's Supermarket	6	Metro, Nila's Supermarket, Leela Supermarket, No Frills (2), Foodland	13	No Frills (4), Metro (3), Sobeys, Nila's Supermarket, Foodland, Food Basics, Leela Supermarket, Durcaa Supermarket
14	0		4	No Frills, Ample Food Market, Food Basic, Brinthavan Supermarket	18	Metro (3), Sobeys (2), No Frills (3), Food Basics (2), Freshco (2) , Ample Food Market, Brinthavan Supermarket, Fortinos, Freshco, Durcaa Supermarket, Leela Supermarket
26	0		8	No Frills (2), Food Basics, Foodland, Durcaa Supermarket, Freshco, Metro	18	No Frills (3), Metro (2), Food Basics (2), Nila's Supermarket, Brinthavan Supermarket, Leela Supermarket, Ample Food Market, Oceans Fresh Food Market, Sobeys, Foodland, Real Canadian Superstore, Freshco, Longo's, Durcaa Supermarket
33	1	No Frills	2	No Frills, Freshco	11	No Frills (2), Freshco (2), Metro, Oceans Fresh Food Market, Real Canadian Supermarket, Food Basics, Longo's, Loblaw Companies, Durcaa Supermarket

Table 6: Competing Supermarkets Competition Analysis

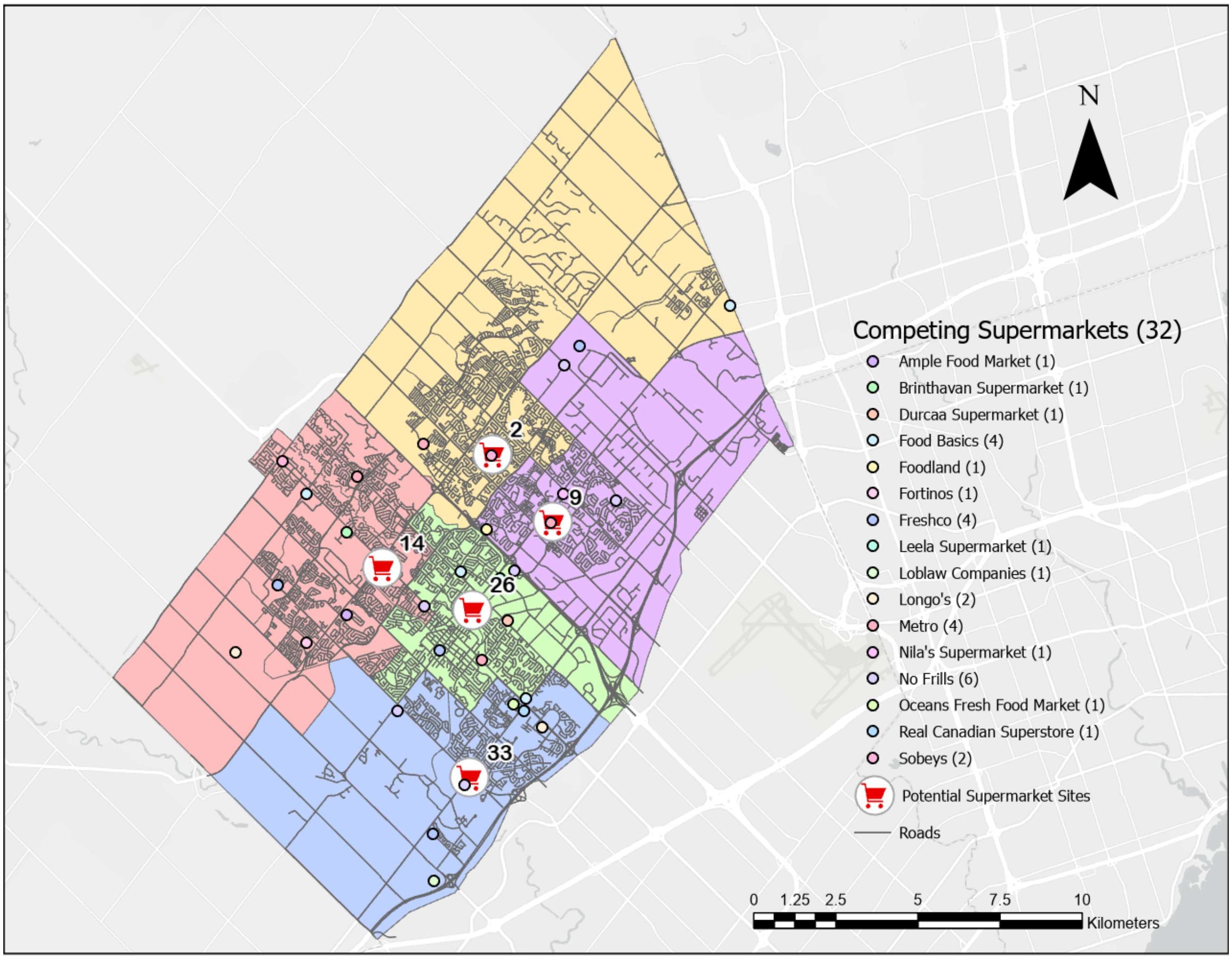

Figure 8: Competing Supermarkets Map

8. Site Evaluation of the 5 Proposed Supermarkets

Site 2:

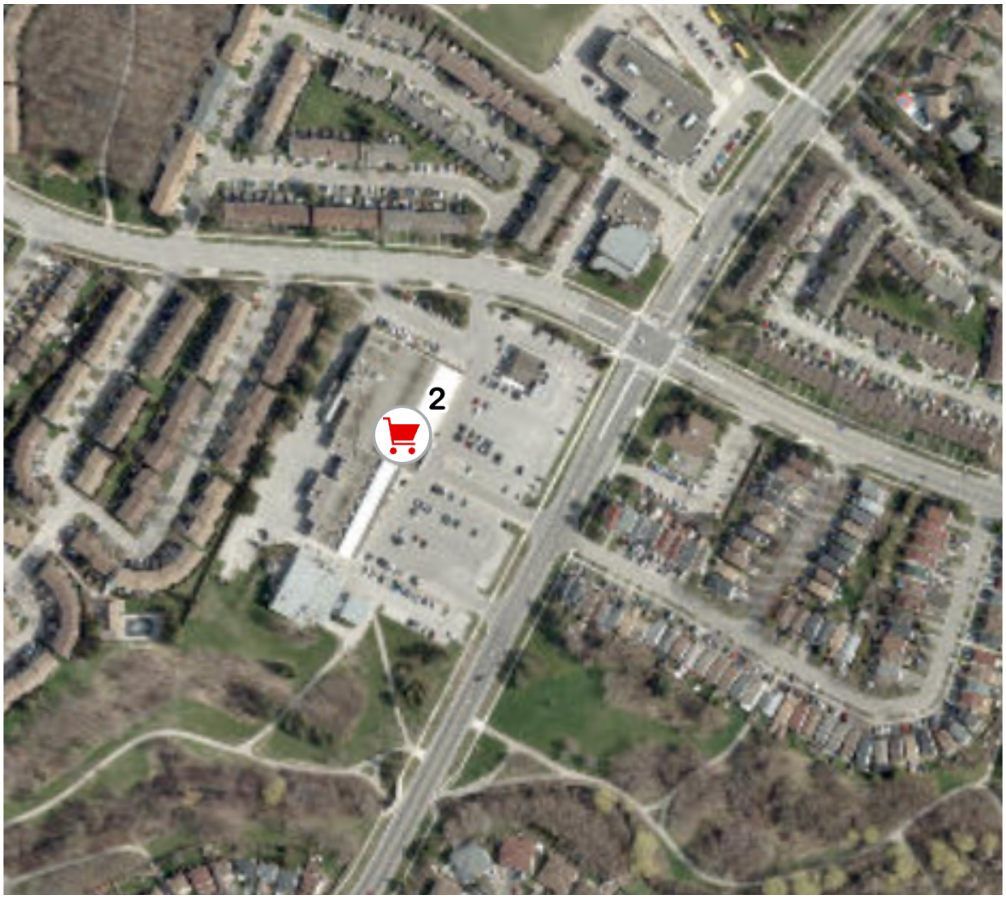

Figure 9: Site 2 Potential Supermarket Location

This site is located at the intersection of Mackay Street and North Park Drive. The site seems to be accessible to the local community around it as there is not much distance from the nearby houses and could be reached from just walking. It also seems to have good visibility as it is right next to the road and could be seen by passing cars. However, it will have strong competition as there is a Sobey’s already located in the same plaza.

Site 9:

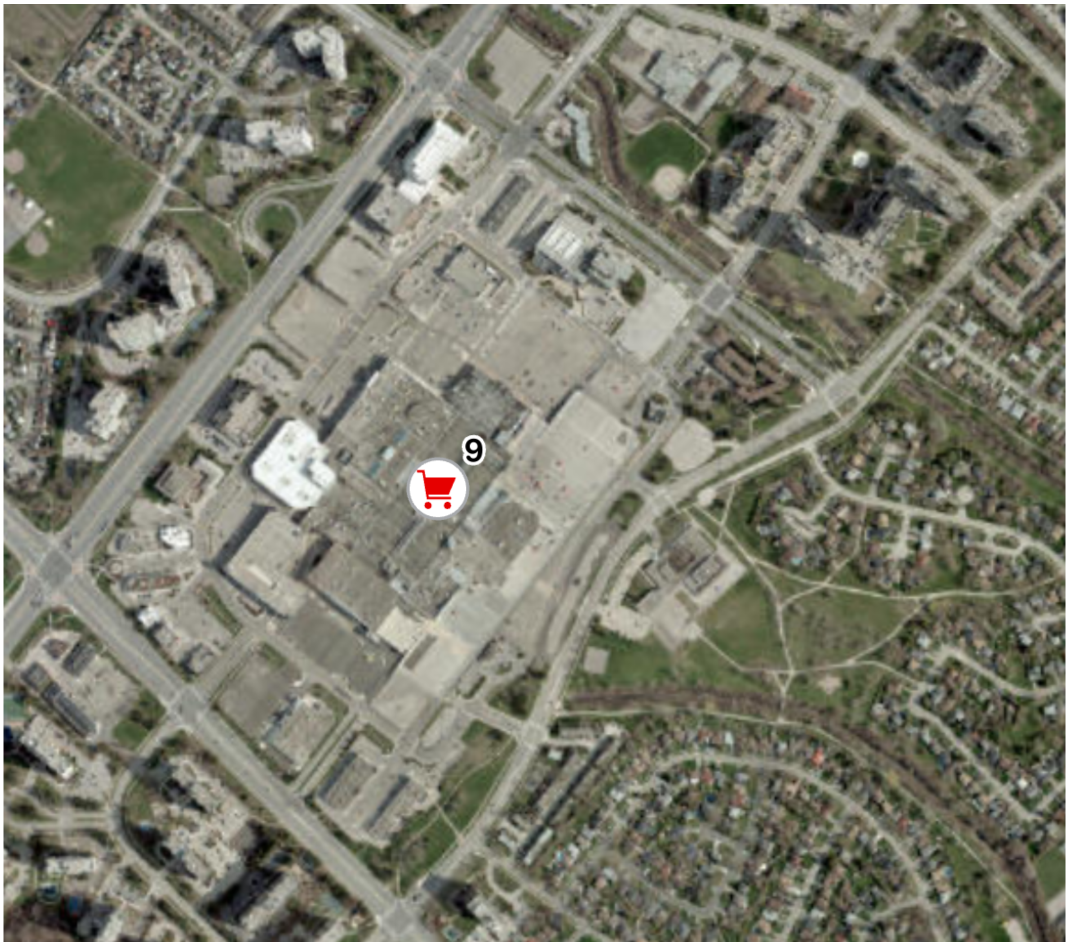

Figure 10: Site 9 Potential Supermarket Location

This site is located near the intersection of Queen Street East and Central Park Drive. It might be difficult in terms of accessibility as there is quite a bit of distance away from the nearby community of houses unless they were to take a car. It also has poor visibility as it is in the center of a large lot which is not easily seen by passing traffic. There is also already a Metro at this location which means it would also have a lot of competition.

Site 14:

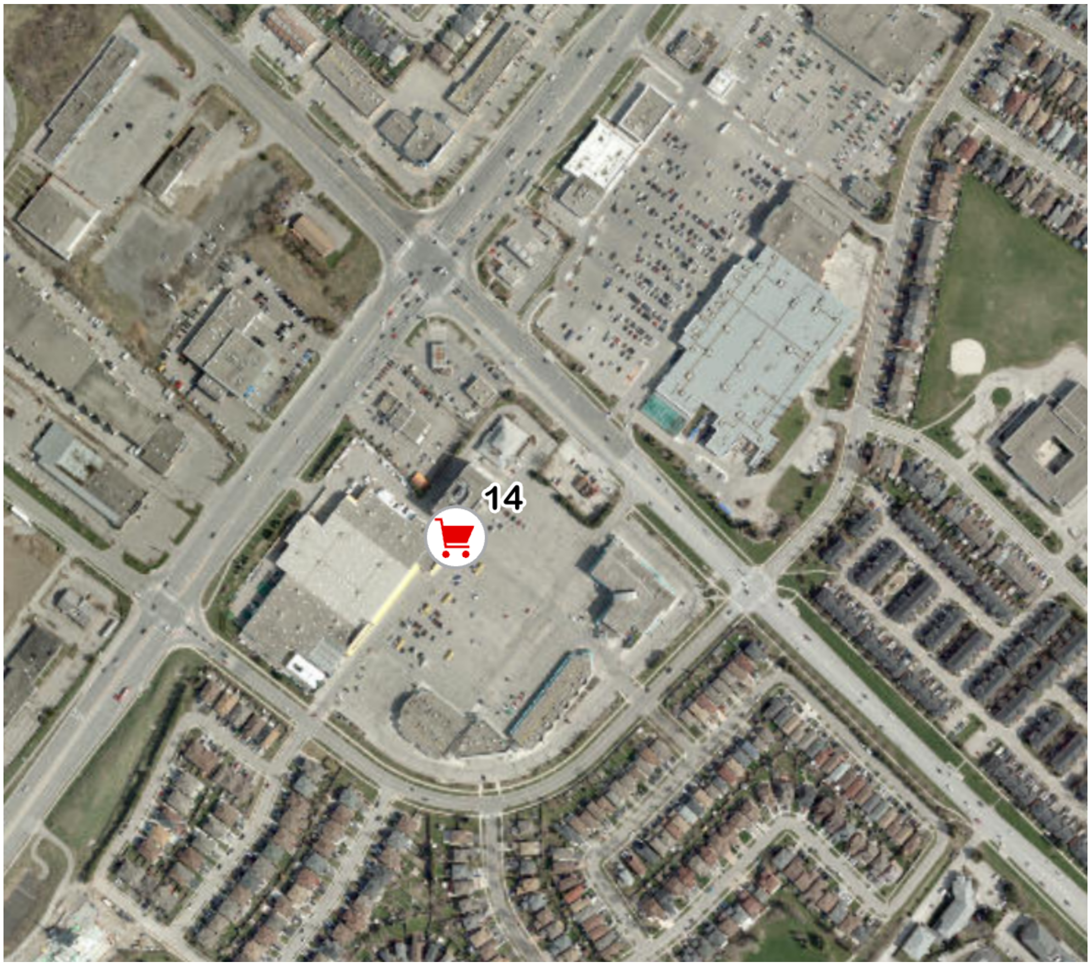

Figure 11: Site 14 Potential Supermarket Location

This site is located near the intersection of Main Street North and Bovaird Drive West. It seems to have good accessibility to the nearby houses located to the south as there is not much distance between them. Visibility seems to be poor as the lot is fairly large and the store might be difficult to see for nearby passing traffic. However, there are no competing supermarkets in the direct vicinity so it would not have much competition.

Site 26:

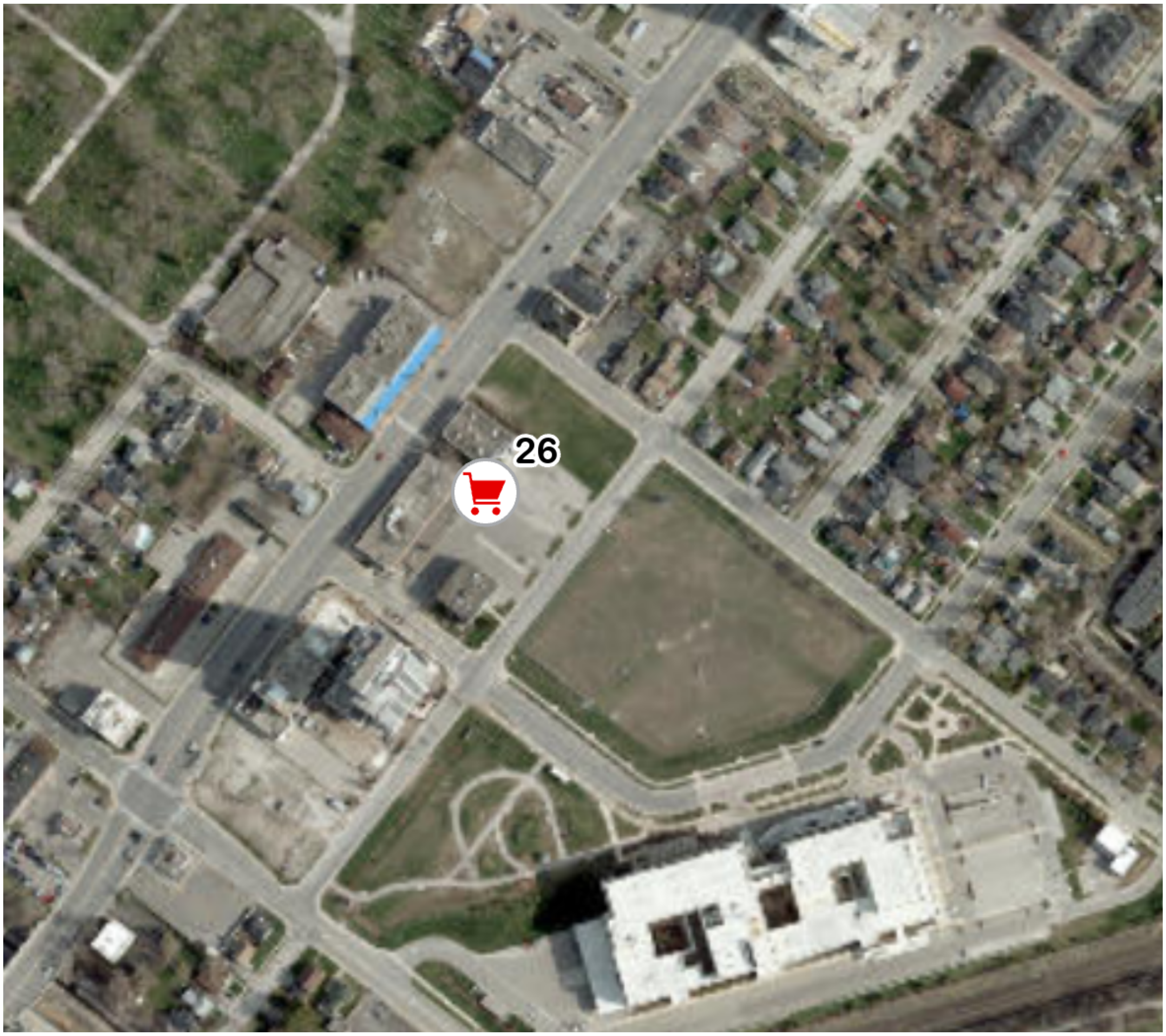

Figure 12: Site 26 Potential Supermarket Location

This site is located near the intersection of Queen Street East and Trueman Street. It is easily accessible to the local community as there is little distance to the nearby houses. Visibility is also good as it is right next to the road and could be seen by passing traffic or pedestrians. There is also little competition as there are not any nearby competing supermarkets.

Site 33:

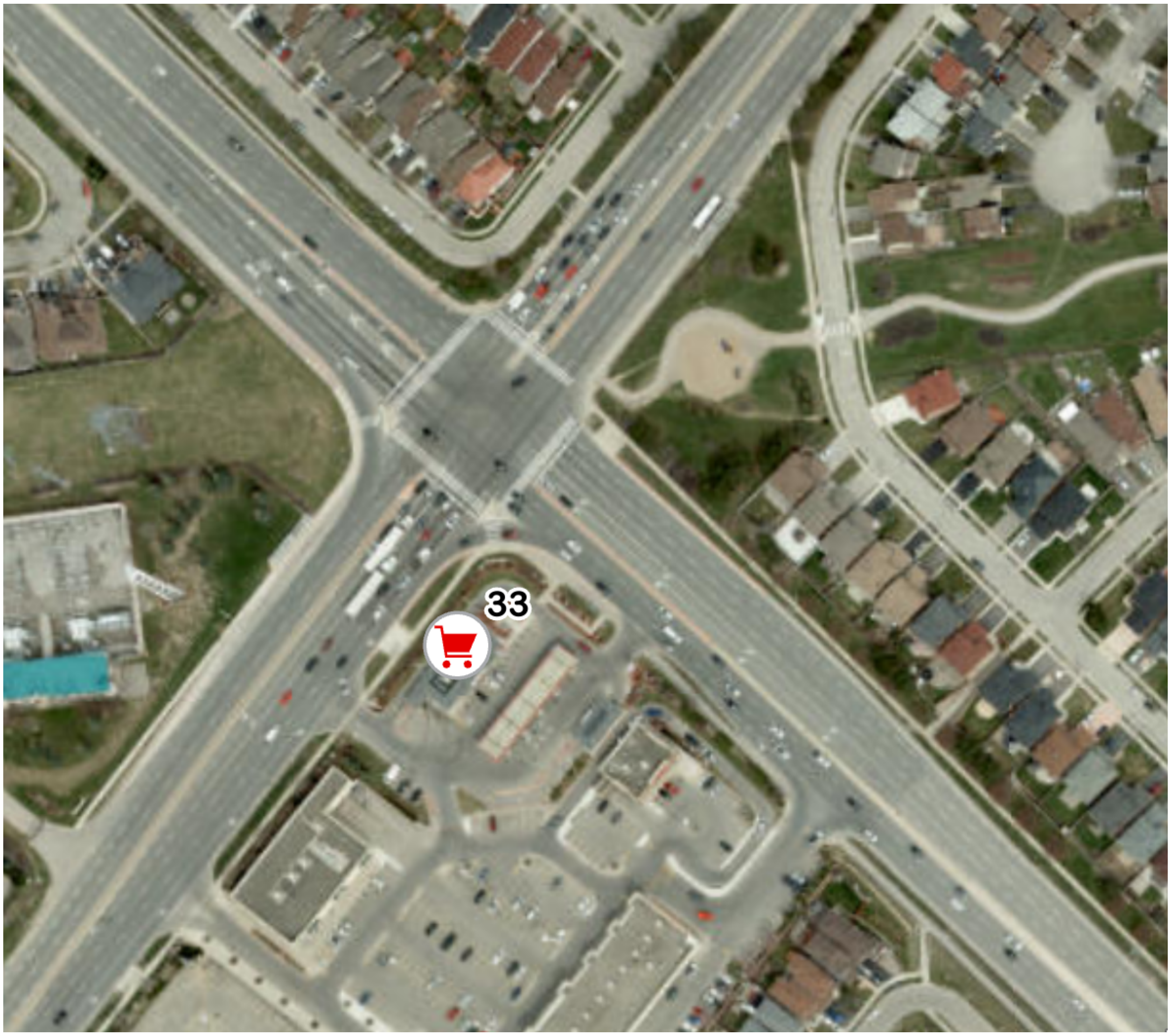

Figure 13: Site 33 Potential Supermarket Location

This site is located near the intersection of Steeles Avenue West and Mavis Road. It is fairly difficult in terms of accessibility as you need to cross a major intersection and there is a fair distance from the nearby houses. The visibility is good as it is right next to the road and could be seen by the passing cars. There would be stiff competition however as there is a NoFrills in the same lot.

Conclusion

In conclusion, it can be seen how the Huff model and location allocation are both very useful tools in helping to determine optimal site locations and estimating sales potential of these sites. The Huff model is able to provide us with the probability that consumers shop at a specific location which allows us to understand whether the location has a suitable market. Location allocation is able to provide the most optimal sites based on the type of problem that needs to be solved such as if coverage needs to be maximized or distance needs to be minimized. By integrating these tools into their decision making and analysis, businesses and other types of organizations can make better informed decisions rather than relying on gut feeling. Although they have their flaws such as the Huff model not considering physical barriers or road networks in its probability calculation or location allocation not considering that less distance does not always mean less travel time, they are still very practical and useful tools that can be applied to many different industries and scenarios as demonstrated by their long history of usage.

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