# A FACILITY LOCATION DECISION: THIBODEAU-FINCH TRANSPORT LTD.



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## ABSTRACT

This paper applies a single-facility location model to the distribution network covered by the Brantford, Ontario branch of Thibodeau-Finch Transport Ltd. The model is used to determine whether or not the existing terminal location should be maintained for the present demand structure and for a projected demand structure. Optimal locations are obtained for both demand structures using a distance function that is tailored to the actual road network over which the firm's vehicles travel. It is found that the optimal solutions are sufficiently close to the existing solution to conclude that Thibodeau-Finch should not consider relocation among its strategic options.



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## INTRODUCTION

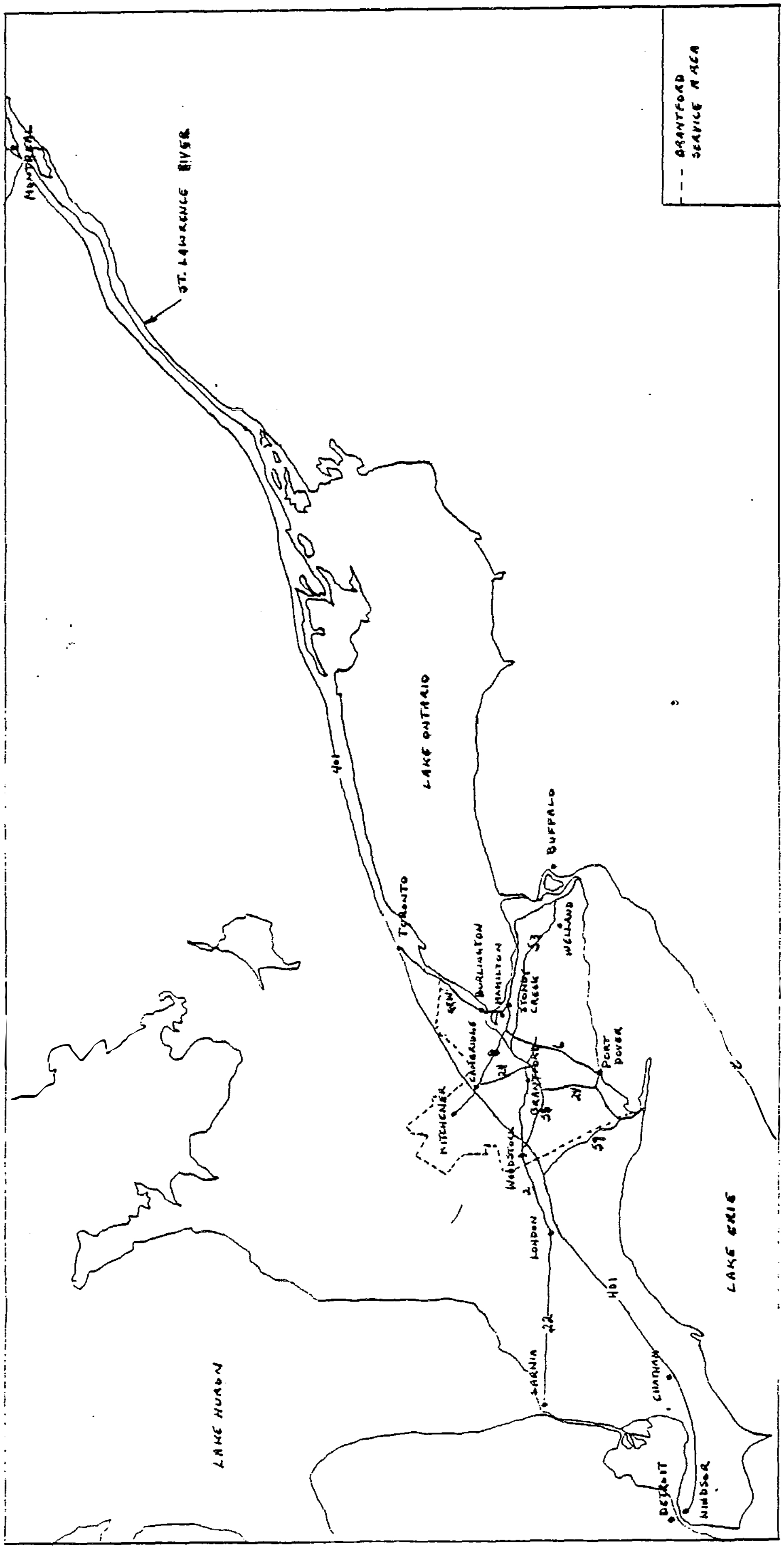
Thibodeau-Finch Transport Ltd. has been in operation for over fifty years. The trucking fleet presently covers points along the Highway 401 corridor from Detroit to Montreal, with terminals in industrial centres such as Windsor, London, Buffalo, Brantford, Toronto and Montreal.

The company operates over 300 tractors and 800 trailers for highway freight movement. The trailers are triple and double axled, 13.72 meters long, 2.74 meters high and 2.69 or 2.44 meters wide. These dimensions meet both provincial and state requirements. (New York State and Michigan State, which are in Thidbodeau-Finch's area of operation, limit trailer width to 2.44 meters.) These highway trailers have a capacity of 31,752 kilograms, which is a limit imposed by Thibodeau-Finch's licence and insurance coverage. For intercity travel within terminals' regions, smaller vehicles, called "Pups", may be used. Their capacity is 13,608 kilograms.

The problem at hand focuses on the Brantford terminal of Thibodeau-Finch which is a modern, fully-capitalized, facility. This terminal location had been chosen when Thibodeau and Finch amalgamated seven years ago. Thibodeau had an office in Cambridge, but this was closed in favour of the Head Office of Finch in Brantford. Finch had a more modern terminal and more office space.

The primary area covered by the terminal and the demand points that are served are shown in Figure 1, which is a conical projection map (a flatened map of the globe): therefore, distances are not to scale. The terminal operates five days per week for 16 to 24 hours per day. Presently the terminal has a very broad customer base which ranges from large consumer goods manufacturers to automotive parts manufactures. Two mechanics perform maintenance and repairs on the 26 tractors based in Brantford. Terminal operations include unloading and loading for delivery to various customers,

Figure 1


BRANTFORD SERVICE AREA
MONTREAL
ST. LAWRENCE RIVER
LAKE ONTARIO
401
TORONTO
BURLINGTON
HAMILTON
STONEY CREEK
WELLAND
BUFFALO
PORT DOVER
BRANTFORD
CAMBRIDGE
KITCHENER
WOODSTOCK
LONDON
LAKE ERIE
401
SARNIA
CHATHAM
LAKE HURON
DETROIT
WINDSOR

preparing full loads and multiple-customer loads for inter-terminal movement, radio dispatching, document preparation and order taking. On any given day 26 drivers are on duty; 14 are involved in daily runs within the terminal's service area, while 12 are used for loading/unloading or long-distance hauls.

## THE PROBLEM

Mr. J. Thibodeau, the General Manager of Thibodeau-Finch's Brantford Region, wished to determine whether or not the firm should be considering a relocation of its local terminal in order to reduce transportation costs incurred in serving present demands. Also, he was concerned with the effect of potential changes in the demand distribution on the location decision. The data in Table 1 were developed from company records and discussions with Mr. Thibodeau. This table gives the number of vehicle loads (i.e. one way trips) per year moving between the terminal and each demand point, for various classifications of loads. Each of these loads requires vehicle movement from the terminal to the demand point, and then back to the terminal. In addition to the data in Table 1, 260 loads per year move via trailer (T) from Burlington to Welland. For these loads, the route is "terminal to Burlington, to Welland, to terminal." Mr. Thibodeau projected the following changes in demands in the future: a 50 percent increase in demand for Pups (P) and bonded trailers (TB) in Kitchener; a 15 percent decrease in Hamilton's demand; and a change in Woodstock's demand from 520 trailer loads per year to 520 Pup loads per year.

Pup and trailer drivers are paid $15.28 per hour whereas long-haul drivers receive their wages on the basis of $0.22 per kilometer travelled. Both of these wage rates include benefits and are specified in collective agreements. On long hauls (LH) the average vehicle speed is approximately 100 kilometers per hour, whereas vehicles average 75 kilometers per hour on short hauls. Also, fuel, which costs $0.35 per litre, is consumed at the following

Table 1: Movement of Vehicle Loads

| Demand Point | Load Type* | No. Loads per year | Demand Point | Load Type* | No. Loads per Year |
|---|---|---|---|---|---|
| Brantford | P | 1,560 | Kitchener | P | 1,040 |
| | TM | 520 | | TB | 520 |
| Burlington | P | 520 | | TM | 104 |
| Buffalo | LH | 452 | London | LH | 492 |
| Cambridge | P | 520 | Montreal | LH | 1,955 |
| | TM | 104 | Port Dover | T | 520 |
| Chatham | LH | 226 | Sarnia | LH | 253 |
| Detroit | LH | 106 | Stoney Creek | P | 520 |
| Hamilton | P | 520 | Toronto | LH | 1,862 |
| | TB | 520 | Windsor | LH | 1,609 |
| | TM | 104 | Woodstock | T | 520 |

*LH: Long Haul (highway travel between terminals)

P: Pup Trailer

T: Trailer

TB: Trailer Bonded (international destination)

TM: Trapmen (heavy freight; forklift loaded)

average rates for the various types of loads: 35.32 litres/100 km.(P); 40.37 litres/100 km.(LH,T,TB,TM). Maintenance costs for vehicles are approximately $0.31 per kilometer.

## ANALYSIS

We wish to determine the terminal location which minimizes the total transportation cost. Costs of transportation between the terminal and the demand centres are proportional to the distances between these points. This problem can be represented by the following model:

Find x which

$$\text{Minimizes } W(x) = \sum_{j=1}^{n} w_j \; \ell p \; (x, a_j)$$

where:
- $n$ = the number of demand centres
- $w_j$ = a weight that converts the distance between the terminal and demand centre j into cost
- $x$ = $(x_1, x_2)$ = the location of the terminal
- $a_j$ = $(a_{j1}, a_{j2})$ = the location of demand centre j

$$\ell_{k,p}(x,a_j) = k[\,|x_1-a_{j1}|^p + |x_2-a_{j2}|^p]^{1/p};\; p \geq 1$$

In this model, k and p are parameters which are fitted to the geographical area being studied.

Further,

$$w_j = \sum_{i=1}^{n_j} D_{ij}\, K\, R_i$$

where:
- $D_{ij}$ = the number of loads per year of Type i going to demand centre j
- $K$ = a scale factor (number of kilometers per centimeter)
- $R_i$ = the transportation cost per kilometer for load Type i
- $n_j$ = the number of different Types of loads moving to demand centre j

Input data that are used for the model under current demand conditions are given in Table 2. The following points should be noted:

(i) The locations of demand centres are as shown in Figure 2. This figure is a detailed map, showing the coordinates of the demand centres which are taken from government documents [5,6]. The scale in this figure is such that K = 8.33 kilometers per centimeter.

Table 2: Input Data for Model (Current Demand)

| Demand Centre ($j$) | Location ($a_{j1}, a_{j2}$) | Load Type ($i$) | Loads/ Year ($D_{ij}$) | Transport. Cost ($R_i$) | Weight ($w_j'=w_j/K$) |
|---|---|---|---|---|---|
| Brantford | (28.75, 12.30) | P | 1,560 | 0.63 | |
| | | TM | 520 | 0.65 | 1,320.80 |
| Burlington | (34.05, 14.95) | P | 520 | 0.63 | |
| | | T | 260 | 0.65 | 496.60 |
| Buffalo | (43.20, 9.85) | LH | 452 | 0.67 | 302.84 |
| Cambridge | (28.80, 15.00) | P | 520 | 0.63 | |
| | | TM | 104 | 0.65 | 395.20 |
| Chatham | (9.50, 2.40) | LH | 226 | 0.67 | 151.42 |
| Detroit | (0.80, 1.95) | LH | 106 | 0.67 | 71.29 |
| Hamilton | (34.15, 13.35) | P | 520 | 0.63 | |
| | | TB | 520 | 0.65 | |
| | | TM | 104 | 0.65 | 733.20 |
| Kitchener | (27.00, 16.20) | P | 1,040 | 0.63 | |
| | | TB | 520 | 0.65 | |
| | | TM | 104 | 0.65 | 1,060.80 |
| London | (19.40, 9.95) | LH | 492 | 0.67 | 329.64 |
| Montreal | (85.68, 54.96) | LH | 1,955 | 0.67 | 1,309.85 |
| Port Dover | (29.80, 7.00) | T | 520 | 0.65 | 338.00 |
| Sarnia | (7.90, 10.35) | LH | 253 | 0.67 | 169.51 |
| Stoney Creek | (34.75,12.80) | P | 520 | 0.63 | 327.60 |
| Toronto | (37.85, 20.10) | LH | 1,862 | 0.67 | 1,247.54 |
| Welland | (39.35, 9.60) | T | 260 | 0.65 | 169.00 |
| Windsor | (1.00, 1.00) | LH | 1,609 | 0.67 | 1,078.03 |
| Woodstock | (24.30, 11.80) | T | 520 | 0.65 | 338.00 |

(ii) All $D_{ij}$ values, with the exception of those attributable to the Burlington/Welland movement, come directly from Table 1. The Burlington/Welland route consists of three segments; however, the costs associated with only two of these (terminal to Burlington and Welland to terminal) depend on the location decision. Accordingly, Table 2 includes 260 loads per year (type T) for Burlington and Welland.

(iii) The transportation costs, $R_i$, include drivers wages, fuel costs and maintenance costs. They are developed as follows:

$$R_P = \frac{\$15.28/\text{hour}}{75 \text{ kilometers/hour}} + \frac{\$0.35/\text{litre}}{2.83 \text{ kilometers/litre}} + \$0.31/\text{kilometer}$$

$$= \$0.63 \text{ per kilometer}$$

$$R_{LH} = \$0.22/\text{kilometer} + \frac{\$0.35/\text{litre}}{2.48 \text{ kilometers/litre}} + \$0.31/\text{kilometer}$$

$$= \$0.67 \text{ per kilometer}$$

$$R_T, R_{TB}, R_{TM} = \frac{\$15.28/\text{hour}}{75 \text{ kilometers/hour}} + \frac{\$0.35/\text{litre}}{2.48 \text{ kilometers/litre}} + \$0.31/\text{kilometer}$$

$$= \$0.65 \text{ per kilometer}$$

(iv) In order to determine the terminal loocation, x, $w'_j$ is used in place of $w_j$ since the constant scale factor, K, does not affect the choice of location. However, the cost obtained from the model when this substitution is made must be multiplied by K to obtain the total cost.

Figure 2

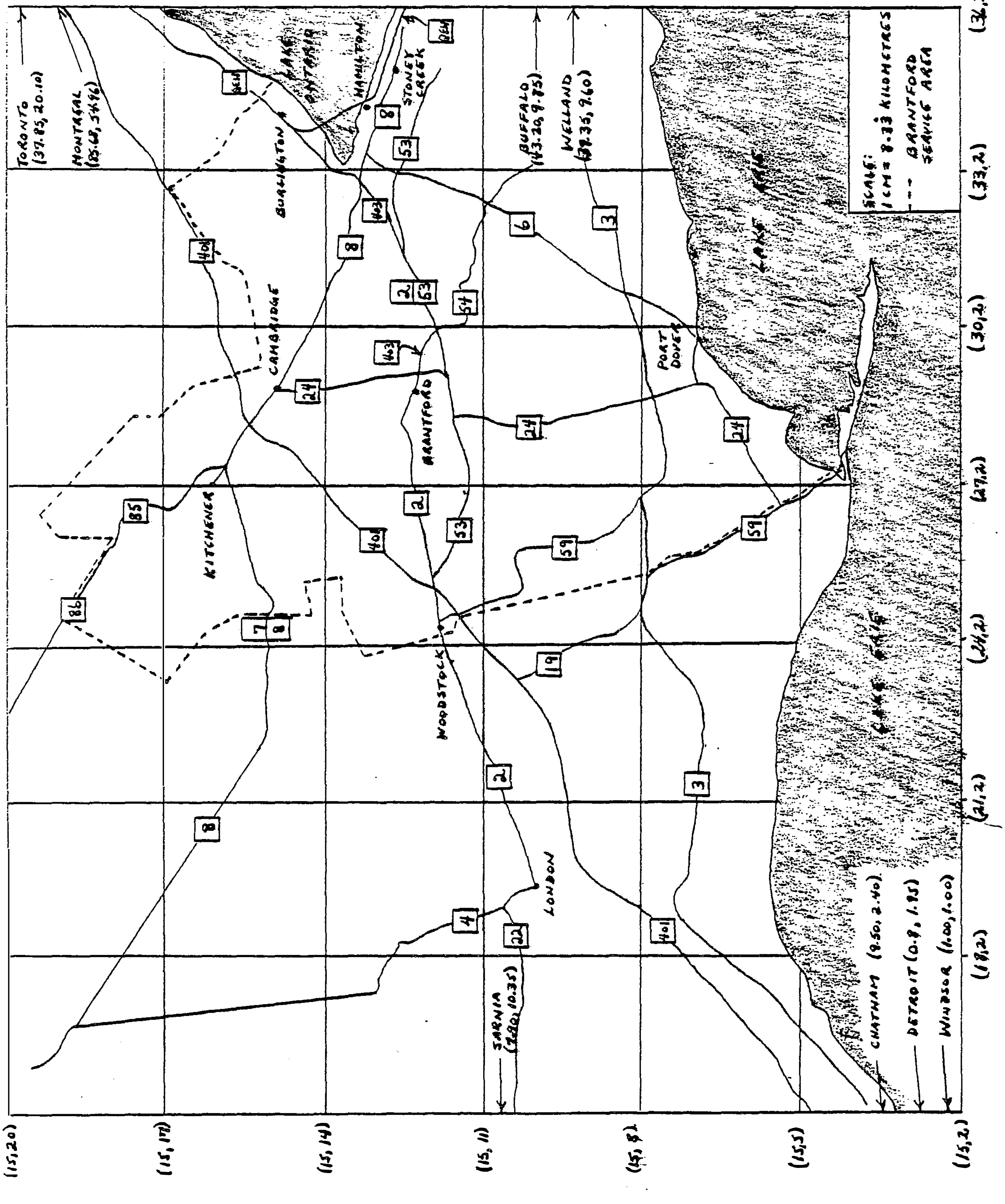

TORONTO
MONTREAL
BUFFALO
WELLAND
SARNIA
CHATHAM
DETROIT
WINDSOR
LAKE ONTARIO
LAKE ERIE
HAMILTON
STONEY CREEK
BURLINGTON
CAMBRIDGE
KITCHENER
BRANTFORD
WOODSTOCK
LONDON
PORT DOVER
SCALE:
BRANTFORD SERVICE AREA

Table 3 specifies changes that are made to the data in Table 2 when using the model for the projected demand conditions. The weights for Hamilton, Kitchener and Woodstock are revised as shown.

Table 3: Changes in Input Data for Projected Demand

| Demand Centre (j) | Load Type (i) | Loads/ Year ($D_{ij}$) | Transport. Cost ($R_i$) | Weight ($w_j^!$) |
|---|---|---|---|---|
| Hamilton | P | 442 | 0.63 | |
| | TB | 442 | 0.65 | |
| | TM | 88 | 0.65 | 623.20 |
| Kitchener | P | 1560 | 0.63 | |
| | TB | 780 | 0.65 | |
| | TM | 104 | 0.65 | 1,557.40 |
| Woodstock | P | 520 | 0.63 | 327.60 |

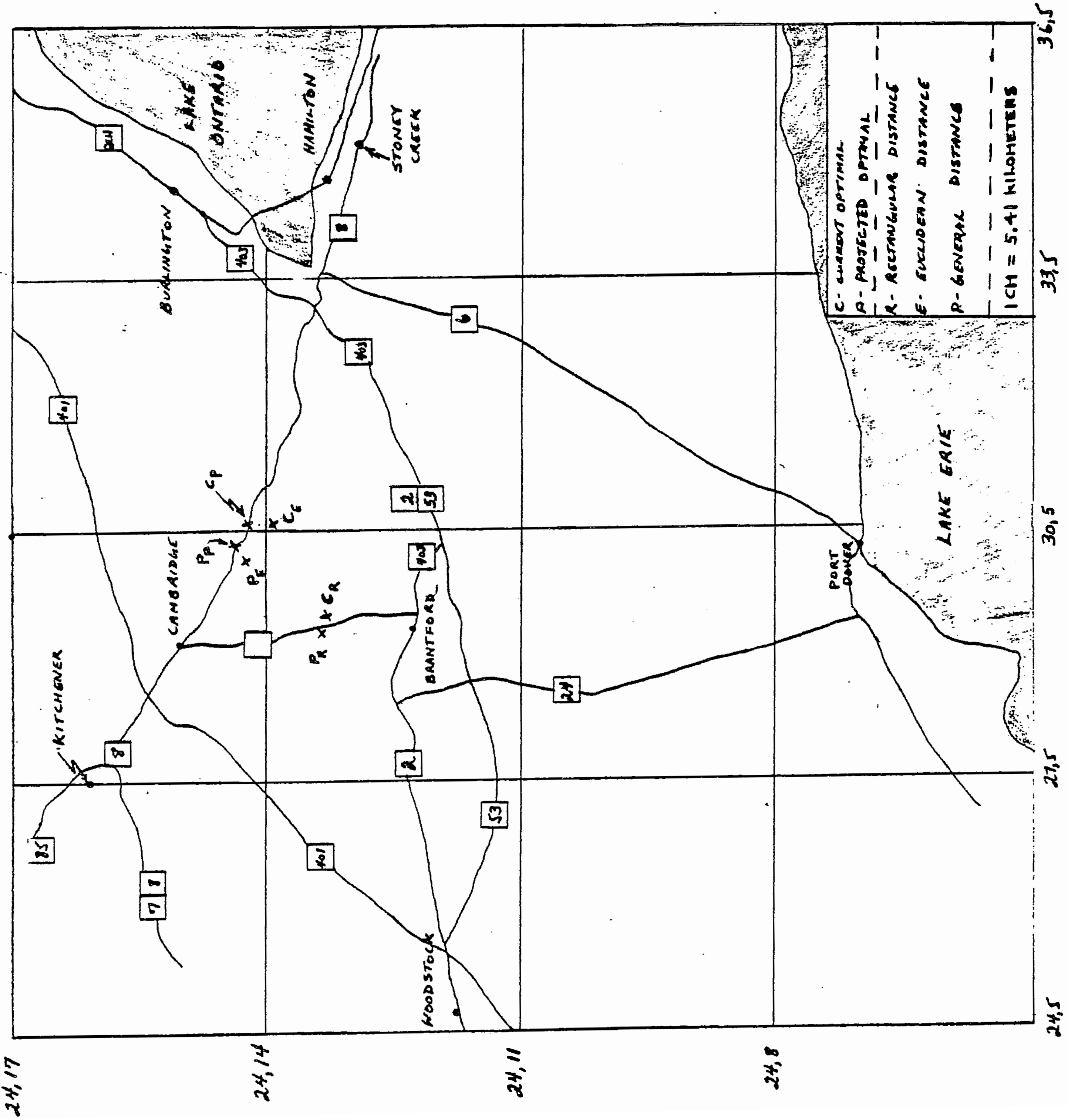
Table 4: Solutions

| Demand Distribution | Terminal Location ($x_1, x_2$) | Transportation Cost ($ per year) |
|---|---|---|
| Current | Brantford (28.75, 12.30) | 1,590,422 |
| | Optimal (30.16, 14.02) | 1,582,549 |
| Projected | Brantford (28.75, 12.30) | 1,604,033 |
| | Optimal (29.44, 14.46) | 1,584,612 |

Table 4 presents solutions to the problem for both current and projected demand distributions, using $k = 1.10$ and $p = 2.22$ as derived in the appendix. Figure 3 shows these optimal locations. The following points should be noted:

(i) Transportation costs include the effect of the scale factor, K, and a constant cost of $10,248 for movements between Burlington and Welland.

Figure 3


LAKE ONTARIO
HAMILTON
STONEY CREEK
BURLINGTON
CAMBRIDGE
KITCHENER
BRANTFORD
WOODSTOCK
PORT DOVER
LAKE ERIE
C - CURRENT OPTIMAL
P - PROJECTED OPTIMAL
R - RECTANGULAR DISTANCE
E - EUCLIDEAN DISTANCE
P - GENERAL DISTANCE
1CM = 5.41 KILOMETERS
24,17
24,14
24,11
24,8
24,5
27,5
30,5
33,5
36,5

(ii) The costs for the existing terminal location (Brantford) are determined by performing calculations as specified in the statement of the model.

(iii) The optimal locations are those obtained from program MULTIF, which is a software package on the H.P.2000 computer system at McMaster University. This program is based on an algorithm developed by Juel and Love[1] and Love and Yeong[2] and is described below.

MULTIF first checks demand centre locations for the minimization of $W(x)$. $W(x)$ is minimized at the $r^{th}$ demand point $(a_{r1}, a_{r2})$ if and only if

$$CRP = [\,|R_{r1}|^{p/p-1} + |R_{r2}|^{p/p-1}]^{(p-1)/p} \le w_r, \text{ for } p>1,$$

and $\max(|R_{r1}|, |R_{r2}|) \le w_r$, for $p=1$.

where

$$R_{rk} = \sum_{\substack{j=1 \\ (j\neq r)}}^{n} \frac{w_j \operatorname{sign}(a_{rk} - a_{jk})\,|a_{rk} - a_{jk}|^{p-1}}{(\ell p(a_r, a_j))^{p-1}} \text{ for } k = 1,2$$

In essence, this criterion is being used to determine if the sum of the vertical and horizontal forces of the other demand centres multipled by their respective weights is less than the weight at the $r^{th}$ demand centre. If this is true, the $r^{th}$ demand centre is the optimal location.

If the above criterion does not hold, an iterative procedure is used. A starting point is the centre of gravity solution where:

$$\bar{x}_{01} = \frac{\sum_{j=1}^{n} w_j a_{j1}}{\sum_{j=1}^{n} w_j} \quad ; \quad \bar{x}_{02} = \frac{\sum_{j=1}^{n} w_j a_{j2}}{\sum_{j=1}^{n} w_j}$$

The iterative procedure is specified as follows:

$$x_k^{(\ell+1)} = \frac{\sum_{j=1}^{n} \frac{a_{jk}\, w_j}{d'(x^{(\ell)}, a_j) \cdot d''(x_k^{(\ell)}, a_{jk})}}{\sum_{j=1}^{n} \frac{w_j}{d'(x^{(\ell)}, a_j) \cdot d''(x_k^{(\ell)}, a_{jk})}}$$

where

$$d'(x,a_j) = [((x_1-a_{j1})^2 + \epsilon)^{p/2} + ((x_2-a_{j2})^2 + \epsilon)^{p/2}]^{1-1/p}$$

$$d''(x_k,a_{jk}) = [(x_k-a_{jk})^2 + \epsilon]^{1-p/2}$$

$\epsilon$ is a small number to insure that discontinuity of the function does not occur where $x = a_j$

The iterative procedure is continued until the following holds:

$$\frac{\text{Actual Cost - Lower Bound on Cost}}{\text{Lower Bound on Cost}} \leq E,$$

where E is the allowable percentage error. The lower bound is calculated according to the first criterion developed by Love and Yeong.[2]

## CONCLUSIONS

In both cases, the optimal terminal location is quite close to the present location in Brantford. Also, transportation cost savings are very small. The following are the specific results upon which these general conclusions are based.

Summary of Results

| Demand Distribution | Distance from Current to Optimal Terminal Location | Annual Cost Savings $ (% of Brantford Cost) |
|---|---|---|
| Current | 19.76 kilometers | 7,873 (0.50) |
| Projected | 20.48 kilometers | 19,421 (1.21) |

Clearly, the terminal should remain at its current location. The small transportation cost savings are not sufficient to justify a move which would involve more substantial costs. Changing locations would require large capital outlays for land and for building a new facility. Also, the workforce would have to be relocated, and convenient access to major highways might not be available.

## Appendix

In actual practice, it may not be appropriate to assume a simple distance metric such as rectangular or Euclidean. The road network of the region may not be represented with sufficient accuracy by these special cases of the following general $\ell p$ metric model:

$$\ell p(a_j, a_t) = [\,|a_{j1} - a_{t1}|^p + |a_{j2} - a_{t2}|^p]^{1/p} \; ; \; p \geq 1$$

where: $a_j$, $a_t$ are points in the two dimensional plane.

As shown by Love and Morris[3], if p is tailored to actual travel distances in a region, the resulting distance function must be at least as accurate as the special cases.

While a number of models have been formulated for the distance function (e.g. Love and Morris[4]), the predicting function that is used most frequently is:

$$d_3\ (a_j, a_t; k, p) = k[\sum_{i=1}^{n} |\ a_{ji} - a_{ti}|^p]^{1/p}$$

$$= k\,\ell p(a_j,\ a_t);\ k > 0,\ p \geq 1$$

where: $a_j$, $a_t$ are points in the two dimensional plane

Two goodness of fit criteria are used to evaluate the $d_3$ function. The first is the minimization of a sum of absolute deviations which is given by:

$$AD_3 = \sum_{j=1}^{V-1} \sum_{t=j+1}^{V} |d_3(a_j, a_t) - A_{jt}|$$

where: $A_{jt}$ is the actual travel distance between points $a_j$ and $a_t$

V is the number of points chosen for estimation.

The second criterion is the minimization of a sum of squares which is given by:

$$SD_3 = \sum_{j=1}^{V-1} \sum_{t=j+1}^{V} [d_3(a_j,a_t) - A_{jt}]^2 / A_{jt}$$

Division by $A_{jt}$ normalizes the squared deviation and makes this criterion more sensitive than the first to large errors in relation to $A_{jt}$.

A software package, called LPDIST, at McMaster University was used to solve for p and k iteratively. This package is based on the methodology developed by Love and Morris.[3]

The intercity road distances shown in Table 5, and the previously determined demand locations on the rectangular grid were the required inputs. The intercity road distances were measured using a planimeter and a Government of Canada map of the study area.[5] All distances and locations were expressed in kilometers. (The demand locations were multiplied by the scaling factor, K.) With a random sample of 75 pairs of demand centres chosen by the program, the following results were obtained:

| k | p | $AD_3$ | $SD_3$ |
|---|---|---|---|
| 1.100 | 2.220 | $6.413 \times 10^2$ | - |
| 1.100 | 2.090 | - | $8.032 \times 10^1$ |

Therefore, for the $AD_3$ criterion the best value of p was 2.220; for the $SD_3$ criterion the best value of p was 2.090.

Table 5: Intercity Road Distances in Kilometers

| Montreal | Buffalo | Stoney Creek | Port Dover | Burlington | Hamilton | Brantford | Cambridge | Kitchener | Woodstock | Welland | London | Chatham | Sarnia | Windsor | Detroit | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 540 | 160 | 83.3 | 141.6 | 59.2 | 75 | 115 | 91.7 | 101.7 | 140 | 146.7 | 186.7 | 292 | 283 | 367 | 375 | Toronto |
| | 676 | 601 | 646 | 580 | 596.7 | 620 | 606 | 620 | 650 | 668.4 | 696.7 | 800 | 800 | 893 | 901.3 | Montreal |
| | | 81.7 | 133.3 | 104.2 | 91.7 | 137.5 | 135.8 | 152.5 | 169.2 | 35 | 215.8 | 333.3 | 312.5 | 400 | 408.3 | Buffalo |
| | | | 81.7 | 19.2 | 4.2 | 54.2 | 54.2 | 74.2 | 91.7 | 67.5 | 140 | 247.5 | 237.5 | 320.8 | 329.2 | Stoney Creek |
| | | | | 83.3 | 66.7 | 54.2 | 80 | 98.3 | 75 | 91.7 | 104.2 | 195.8 | 208.3 | 266.7 | 275 | Port Dover |
| | | | | | 16.7 | 50 | 50 | 66.7 | 87.5 | 88.4 | 133.3 | 246.7 | 237 | 320.8 | 329.2 | Burlington |
| | | | | | | 50 | 50 | 70.8 | 84.2 | 71.7 | 129.2 | 241.7 | 233 | 304.2 | 312.5 | Hamilton |
| | | | | | | | 25 | 41.7 | 37.5 | 92.5 | 81.7 | 193.3 | 183.3 | 268.3 | 276.7 | Brantford |
| | | | | | | | | 16.7 | 50 | 121.7 | 94.2 | 208.3 | 195.8 | 281.7 | 290 | Cambridge |
| | | | | | | | | | 54.2 | 142 | 100 | 212.5 | 200 | 287.5 | 295.8 | Kitchener |
| | | | | | | | | | | 147.5 | 46.7 | 158.3 | 142.5 | 233.3 | 241.6 | Woodstock |
| | | | | | | | | | | | 195 | 270 | 295 | 339 | 347 | Welland |
| | | | | | | | | | | | | 116.7 | 100 | 191.7 | 200 | London |
| | | | | | | | | | | | | | 77.1 | 79.2 | 87.5 | Chatham |
| | | | | | | | | | | | | | | 150 | 158.3 | Sarnia |
| | | | | | | | | | | | | | | | 8.3 | Windsor |

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