Production Facility Optimization

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Executive Summary

A company in Edmonton (who will remain unnamed for the sake of anonymity) is in search of a solution to a distribution problem. This company currently operates four production facilities; one in Leduc, one in Strathcona and two in west-Edmonton. This client, however, feels that the current layout is inefficient and is seeking a recommendation as to how they can more optimally locate their production facilities in order to minimize delivery costs. They are content with the Strathcona plant and one of the west-Edmonton facilities, but are looking to potentially close the Leduc facility, close the other west-Edmonton plant, and open a new facility in a location that will minimize delivery times based on demand throughout the region.

To handle this issue, our team created a model capable of calculating the total delivery costs associated with closing existing plants and opening new facilities in various “candidate locations” (based on restrictions provided by the client) throughout Edmonton. Our process in constructing this model involved segmenting our clients demand geographically, calculating travel distances between each demand region and each current and candidate plant location, converting the calculated travel distances into travel time, applying our client’s costs to the associated travel times, and lastly selecting the optimal facility layout that successfully minimized these total costs.

In addition to our relocation analysis, the client was also provided with a graphical user interface to easily manipulate the model. This interface will allow the client to “turn on or off” any of their existing facilities as well as any potential plant within the candidate locations. As different plant allocations are selected by the user, they are shown the total delivery costs and plant utilization rates associated with that particular facility mix. Further to that, as different plant locations are selected, a dynamic colour coded map of Edmonton and surrounding areas shows the user which plant is servicing which demand region. This interface equips the client with a powerful decision making tool, allowing them to easily distinguish which facility should provide product to which region, as demand may shift in the coming years.

After examining, evaluating and analyzing our model we recommend that the client close both their Leduc and west-Edmonton facilities and open a new plant within a region that will be referred to as candidate location 4 (CL4). By implementing these changes, the client’s delivery costs will be reduced by over $120,000 per year. The present value of these annual savings in perpetuity, using the clients weighted average cost of capital is over $1.6 million. It should also be noted that the savings associated with moving from a 4 plant production layout to only a 3 plant production layout will vastly increase the overall savings from this strategy.
**Problem**

Our client is seeking a more efficient layout for their production facilities in and around Edmonton. Their current facility allocation includes one plant in Leduc, two plants in West-Edmonton, and one plant in the Strathcona area. Under this current facility layout our client is experiencing a number of significant inefficiency issues. To name a few, our client is facing high maintenance and upkeep costs for all the aging equipment because three of the flour plants the company owns are 23 years or older. This issue may require a large amount of capital from the client in order to replace the aging equipment in a few years; inherently affecting the facility layout. In addition, the client’s plants are either frequently overloaded or frequently underutilized when it comes to production due to conflicting capacity constraints of the plants. Furthermore, the client feels that the average travel time for deliveries, as well as inbound and outbound transportation costs, are currently much more than necessary. Although all these inefficiencies are relevant issues, the company has asked our group to focus strictly on a better facility allocation to specifically minimize outbound transportation costs; equivalently reducing average travel time for deliveries.

Ultimately our client was seeking a recommendation on three key issues:

1. Should the company continue to operate in its current state, with the four existing facilities, or should the company relocate their Leduc plant?
2. If Leduc is to be relocated, where should it be situated so that delivery costs are minimized?
3. Contingent on the reallocation of the Leduc facility should the client continue to run their two plants in West-Edmonton, or should they close one of the plants and continue production with only three facilities?

**Problem Breakdown**

After analyzing and interpreting the client’s requests, our team was able to break the problem down into six steps that allowed us to get from point A, current facility layout, to Point B, an optimal facility layout.

These steps will be outlined as follows:

1. Determining Demand Locations
2. Determining potential candidate locations
3. Distance calculation (Between all candidate locations and all demand locations)
4. Converting distance to a time measurement (Between all candidate locations and all demand locations)
5. Optimization (Determining the facility allocation that minimizes our clients total transportation costs)
6. Model Creation (Developing an excel user interface to visually represent which plants are responsible for which demand locations by using visual basic for applications programming)

Our thought process behind these steps essentially involved a procedure that calculates a transportation cost, based strictly on a time measurement. This way, new potential plant locations that our team selected for our client could be quantitatively compared to one another depending on their distance to and from our clients current demand locations.

The next few sections of the report will walk through a detailed analysis of each step our team took towards solving and answering the above client’s requests as well as the reasoning behind each step.

1) Determining Demand Locations

Our first step involved dividing the city of Edmonton and the surrounding areas into certain demand locations. This was necessary in order to have the basis for our potential candidate location comparisons later on.

Our team was able to emulate the structure of our client when it came to this step; previous to our involvement with our client, they had been dividing their customer’s demand into 159 different geographical regions. These areas consisted of 110 in-Edmonton locations and 49 out-of-city locations. This segregation provided us with the framework for the rest of the analysis of the problem.

2) Determining Potential Candidate Locations

The next step required our team to determine all potential candidate locations in which our client could relocate the Leduc facility. In order to most effectively select potential candidate locations for our client our process involved limiting the selection based on; industrial zones, qualitative assumptions, intuitive assumptions regarding time, and current facility locations.

Throughout Edmonton and surrounding area, there are obviously limitations on where a cement mixing facility can be located. For this reason we had to determine which of the 159 regions were suitable candidates for the new plant. The first step we took was determining all regions
that are zoned as “medium industrial” (the minimum requirement for a plant of this size). This restricted us to areas in the south, north-west and north-east of Edmonton, as well as out-of-town locations. Since there are existing plants in the north-west and very near the north-east of Edmonton, combined with the fact that it would be counterintuitive to locate a new plant in a town too far from the city, we limited the model to the industrial regions of south Edmonton as well as Nisku, and Devon.

3) Distance Calculation

After having segmented the demand regions into the provided 159 locations, our team needed a way to calculate the distances from each of these points to all other points. This required generating a 159 X 159 distance matrix (a total of 12,561 different distances). The first step in this process involved finding the exact longitude and latitude of the centre of each demand region. To accomplish this we used Google Earth to find the longitude and latitude of the four intersections of each region. Once these were found we used simple averages to formulate the midpoint.

**Example:**

**Midpoint Calculation for Demand Location ED9**

<table>
<thead>
<tr>
<th>Intersection A:</th>
<th>Intersection B:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude</td>
<td>-113.590</td>
</tr>
<tr>
<td>Latitude</td>
<td>53.619</td>
</tr>
<tr>
<td>Intersection C:</td>
<td>Intersection D:</td>
</tr>
<tr>
<td>Longitude</td>
<td>-113.590</td>
</tr>
<tr>
<td>Latitude</td>
<td>53.599</td>
</tr>
</tbody>
</table>

**Intersection A:**

Longitude = -113.590  
Latitude = 53.619

**Intersection B:**

Longitude = -113.541  
Latitude = 53.619

**Intersection C:**

Longitude = -113.590  
Latitude = 53.599

**Intersection D:**

Longitude = -113.541  
Latitude = 53.599

**Midpoint Calculation**

Midpoint (Latitude, Longitude)  
= (Average(53.619,53.599),Average(-113.590,-113.541))  
= 53.609, -113.566

After longitude and latitudes were calculated for each midpoint of the 159 nodes, we needed to calculate the rectilinear lengths of each of 12,561 point-to-point distances in the matrix.
Rectilinear distance implies that the length between two points is not a straight line, rather the total distance between two points measured along axes at right angles. This is an appropriate approximation for vehicle travel because road systems are set up in grids consisting of right angled intersections.

**Example:**  
**Rectilinear Distance Calculation Between ED9 and EF6**

<table>
<thead>
<tr>
<th>Avenue</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>157 Ave</td>
<td>ED9</td>
</tr>
<tr>
<td>137 Ave</td>
<td></td>
</tr>
<tr>
<td>118 Ave</td>
<td></td>
</tr>
<tr>
<td>101 Ave</td>
<td>EF6</td>
</tr>
</tbody>
</table>

ED9 Location = \((X_1, Y_1) = (53.609, -113.566)\)
EF6 Location = \((X_2, Y_2) = (53.527, -113.463)\)
Km/Latitude Degree = Constant 1 = 111.0447
Km/Longitude Degree = Constant 2 = 67

**Rectilinear Distance Formula:**

\[
= |X_1 - X_2| \times \text{Constant 1} + |Y_1 - Y_2| \times \text{Constant 2}
\]

\[
= |53.609 - 53.527| \times 111.0447 + |-113.566 + 113.463| \times 67
\]

\[
= 16.0364 \text{ Km}
\]

4) **Converting Distance to Time**

Once we were able to formulate a distance matrix of all of our clients demand and facility locations, our next step consisted of converting the complete distance matrix into a time matrix based on the same coordinate locations; this was necessary because our client’s distribution of their product was contingent on the basis of time. (This was also necessary because our end model consisted of minimizing time travelled as the basis for our facility recommendation)

**Data**

The client supplied our team with a data set consisting of actual travel time (in minutes) between their current facility locations and all of their current demand locations; these times were tracked by their in house GPS system. Because our client only recorded travel times to and from their existing facilities, our team needed to calculate all the travel times between the previously mentioned candidate locations and each and every demand point. In essence, we needed to compute all the travel times for all the same locations we had previously calculated distances for.
Our procedure involved a series of steps:

1. Given that we had data for the actual travel time (in min), as well as distance (in km) for the same trips, we were able to plot these two data sets on a “distance vs. time” graph. Intuitively we expected to see a positive linear relationship between distance and time, seeing as how one would expect that longer travel distances would amount to a longer travel time. Unfortunately, what we found after plotting our data on a time vs. distance graph was that the distribution of variables seemed to fluctuate excessively and no real pattern was observable. After analyzing the data further, we discovered that trips within the city were relatively “slower” than trips outside the city. Thus, we split the actual data into two sets: “within city travel” and “outside city travel”. When we went back and re-plotted the variables onto the two times vs. distance graphs, we found that a more observable linear positive relationship existed for the two data sets

<table>
<thead>
<tr>
<th>Within City Travel</th>
<th>Outside City Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

2. Once we were able to acquire two positive linear relationships between time and distance, our next step involved calculating the slope of the two linear equations. (Note: slope is equivalent to the speed travelled during the deliveries (km/min)). A depiction of the relationship between “time” and “distance” can be best represented by the equation:

\[
y = \beta x + \varepsilon
\]
Where:
\( y \) = dependent variable (time)
\( x \) = independent variable (distance)
\( \beta \) = slope coefficient (speed)
\( \varepsilon \) = residual error

Residual Error measures everything that affects “\( y \)” that we don’t have information on. Ex. Stop lights, weather, construction, route selection

The basis to determining the slope (speed) revolved around minimizing the residual error term to the smallest amount possible in order to ensure accuracy; we were able to attain those results by using an excel based minimization application called solver.

Our “within city travel” slope (speed) amounted to 0.75 km/min or 45.12 km/hour and our average “outside city travel” slope (speed) amounted to 1.07 km/min or 64.28 km/hour.

The errors associated with these slopes were 1.70 min (5%) for our “within city travel” locations and 3.06 min (6%) for our “outside city travel” locations.

Step three involved multiplying the distances calculated in step one, by the slopes (speeds) calculated from the two linear equations in step two. This simple calculation allowed our team to convert each distance measurement (km) into a time measurement (min). Following the conversion process, our team had a complete and accurate time matrix.

5) Optimization

With 16 potential plant locations identified, as well as having calculated a matrix of travel times from those 16 locations to all of the client’s demand points, the final step was to find an optimal location for the new plant to be situated. To demonstrate the methodology behind this optimization, a simplified example will be used. This example uses 4 demand locations, rather
than 159 which the full model uses; has two existing plant locations, rather than 4 which the full model does; and only tests two candidate plant locations, rather than the full 16 that the actual model uses. (Note: Travel times, demand and costs in this example have been arbitrarily generated).

**Time Matrix:**

<table>
<thead>
<tr>
<th></th>
<th>Existing Plants</th>
<th>Candidate Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Demand Node 1</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Demand Node 2</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Demand Node 3</td>
<td>33</td>
<td>9</td>
</tr>
<tr>
<td>Demand Node 4</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

Depicted above is a matrix showing the travel times from the two existing plants (x, y) and the two candidate plants (A,B) to all four demand locations (Node 1-4). For example, it takes 24 minutes to travel from existing plant X to demand location 1. Similarly, it takes 11 minutes to travel from candidate location B to demand location 4.

**Conditional Time Matrix:**

<table>
<thead>
<tr>
<th></th>
<th>Existing Plants</th>
<th>Candidate Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Demand Node 1</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Demand Node 2</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Demand Node 3</td>
<td>33</td>
<td>9</td>
</tr>
<tr>
<td>Demand Node 4</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>
The conditional time matrices above show how, when a plant is turned off (binary digit set to zero), the model removes the associated travel times for that plant. We have applied this concept to our entire model in order to select which candidate locations should be in operation.

**Least Time Matrix:**

<table>
<thead>
<tr>
<th>Demand Node 1</th>
<th>Demand Node 2</th>
<th>Demand Node 3</th>
<th>Demand Node 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>10</td>
<td>33</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>22</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>33</td>
<td>12</td>
<td>18</td>
<td>11</td>
</tr>
</tbody>
</table>

The least time matrices above show how, when a plant is turned off (binary digit set to zero), the model removes the associated travel times for that plant. We have applied this concept to our entire model in order to select which candidate locations should be in operation.
Using a “Min()” function, the model examines each demand location in conjunction with the binary constraint in the conditional time matrix and returns only the travel time that is the smallest. In effect, the model is assigning demand to the active plant (binary digit =1) that is closest in proximity. For example, taking a look at the “Conditional Time Matrix” for Plant A we can see that the shortest travel time between the three plants (X,Y,A) to Demand Node 1, is 8 minutes. Thus the min() function would select plant A to take the demand at Node 1; hence in the “Least Time Matrix - Plant A” table, plant A takes on demand node 1 with a travel time of 8 minutes.

**Cost Calculation:**

*Assume a cost of $10 per 5 units of demand per 10 minutes of travel time*
**Assumptions**

Inherent in any model are underlying assumptions. The following will outline our assumptions throughout the analysis and explain the reasoning, and limitations behind each of them.

1) **Midpoint Calculation for all Demand and Candidate Locations**

As previously mentioned our client currently divides their demand into 159 different areas. For our analysis we assumed that, of these 159 areas, all demand comes from the exact centre of the area. Furthermore, when formulating our time and distances matrices we assumed that the respective time and distances between each of the demand points was from centre to centre.

The reasoning behind this decision was quite intuitive. Firstly, it seemed appropriate to mimic our clients break down of the city into the 159 areas. We took this one step further by calculating one central location within each of the 159 areas that would represent all the
demand for a given area. The centre was an obvious choice, seeing as how it was within equal
distance from any of the boundary lines of the selected area; thus the most reasonable location.

Note- Our team considered the possibility that the client may want to reposition the central
location for the candidate areas. (Ex. If our client did in fact choose to purchase a new facility
within an area and the facility did not happen to be situated in the centre of the given area). In
order to facilitate this we incorporated user friendly input cells that would reposition the centre
of the demand to any coordinates our client entered.

2) Perfect Rectilinear Distances

When formulating the distances from point to point, our calculation assumed that the distances
of vehicle travel within Edmonton are perfectly rectilinear. Although there are some cases that
this does not hold true, for instance the river in Edmonton does not allow some routes to follow
a perfect rectilinear grid, rectilinear approximation is generally accepted as sufficient for
calculating vehicular travel distances. Thus we felt this was a reasonable assumption for
calculating all our point to point distances.

3) Sample Perfectly Represents Entire Population

As previously mentioned, our team had access to our clients travel times (in min) between their
current facilities and their current demand points; what we were missing was the travel times
(in mins) between the future potential candidate locations and the clients current demand
points.

In order to calculate these values, our team treated the “actual” time data that we were
provided with, as a sample population. We then assumed that this sample population perfectly
represented/correlated the entire population (aka all desired time calculations). Thus, when we
formulated our two linear equations (see page 8) we were able to, with confidence, multiply the
provided distances by the coefficient (speed) to the entire population set.

Since our client was quite confident with the accuracy of their travel times, our team felt it was a
reasonable to assume that the same times would apply for different routes of the same
distance.
4) Calculated Speed Equivalent for all Trips

When converting distances to travel time, we assigned two specific speeds between the demand locations and the candidate location routes. We were able to minimize the error on travel times by differentiating between “within city travel” and “outside city travel”. This assumes that any route within city limits the average travel speed is identical. Similarly this follows for outside the city limits. After separating the speed into two groups the average error was reduced to between 5% and 6% (3 – 5 mins). We felt with such a small error, no further speed differentiation was necessary.

Note- Our team considered that the City of Edmonton would continue to grow in subsequent years and add extensions to the road network; these road networks would most likely increase the ease of travel. (For example the Anthony Henday) With these new networks “within city travel” and “outside city travel” speeds would be expected to decrease; thus the speeds that we calculated would alter slightly over time. In order to include this adaptability into our model, our team included additional user friendly input cells capable of changing the two travel speeds.

Analysis and Recommendations

With a fully functioning model in place, our team was able to analyze the problem and come up with a recommendation for the client. The graph below depicts the total delivery cost associated with various plant locations. The x-axis displays the 14 in-city candidate locations (CL4-CL18) as well as two out-of-city candidate locations. The vertical bars represent the total delivery costs associated with opening a new facility in each of the respective candidate locations. The orange bars show the delivery cost of running a 3 facility operation (Strathcona, west-Edmonton and 1 candidate location), while the blue bars represent the total delivery cost of running a 4 facility operation (Strathcona, 2 west-Edmonton plants and 1 candidate location plant. Finally, the red line shows delivery costs as they currently are.

As can be seen, opening a new facility in CL4 is the optimal decision. It should also be noted that although the total delivery cost is less with a 4 plant operation, it is only less by approximately $100,000 per year. It is obvious that the ongoing expenses of operating an extra production facility far exceed the
savings in delivery costs. For this reason our ultimate recommendation is to close the facility in Leduc, open a new plant in location CL4 and close one of the west-Edmonton facilities.

Qualitative Considerations

Further to minimizing delivery costs for the client, our proposed location is also the beneficiary of other qualitative advantages. The most significant of which is that the Queen Elizabeth Highway runs directly through the region. A plant located near this major roadway will allow for quick access to the rural road network that connects to out-of-town locations as well as providing easy access to the Anthony Henday, which provides efficient travel within the city. Additionally, after consulting the City of Edmonton’s “Municipal Development Plan”, it was evident that the vast majority of planned and developing neighborhoods in the city are located in the far south. This is advantageous for our proposed location, as it is situated in the far south of Edmonton as well. Finally, our client has done much work for Edmonton Transit in the form of LRT expansion within Edmonton. The “Municipal Development Plan” also outlines future LRT expansion further to the south. Resultantly, our proposed plant location will be situated conveniently for access to these large future deliveries in the coming years.
**Interface Functionality**

Our client requested we construct an interactive map based software tool to analyze their facility mix. They wanted to be able to designate different candidate locations as inputs into the model and have it output a financial evaluation of those locations so a cost benefit analysis could be performed. In the “Problem Break Down” section we developed 159 different demand areas and overlaid them on a map of Edmonton. We then used an overlay of an Edmonton zoning map (on top of our 159 demand locations) and altered the transparency in order to see the potential candidate plant locations that were in medium industrial zones within Edmonton. To link our user interface to our optimization model we used visual basic macros and excel lookup functions. When a candidate location rectangle is clicked, it activates the binary cell assigned to the respective plant. As a candidate location is activated, the model recalculates which active plant would be handling the demand specified for each point (see “Optimization” for further details on this step). Each active plant is then assigned a color by the model to relay back to the interface to color the demand location serviced by that plant. We also assembled a way in which the model is able to read the specific quantity of demand data in each individual demand location and change the transparency of the rectangles based on the specific quantity. This makes the locations with a higher demand less transparent (darker in color) to differentiate high from low demand areas. The interface page also references the optimization model and automatically updates transportation costs, demand handled per plant, and plant utilization as the user selects different candidate locations. Furthermore, the input page of the model allows the user to change factors such as individual plant output, operating periods, and average delivery size. The interface also gives the user the option to select between historical demand data from 2007 or 2008 to see how the efficient plant layout may have been altered. This selection option provides a large added value for our client seeing as how 2007 and 2008 were economically significantly different for the client. The user also has the flexibility to add demand forecasts or data in future years; in other words this model can be updated after every year of production. In addition to our quantitative analysis, the user can select from a series of map overlays to view qualitative factors such as developing neighborhoods and accessibility to truck routes in Edmonton.
The following images will provide a brief overview of a few scenarios our interface is capable of generating as well as an explanation of the significance of the output.

**Scenario 1: Interface with single plant open**

In this snapshot, one of four plants is in production (binary digit=1). As one can see, this plant is covering all of our clients demand; the blue color represents this. Under this scenario a number of observations are evident. Firstly, the dark blue sections are those that require the highest demand. Secondly, the transportation costs for having a single plant running amounts to $2,499,716. Thirdly, the utilization is surpassing 100% at 114.92%. Realistically, this plant layout would not be feasible due to overutilization.
Scenario 2: Interface with four plants open; client’s current plant layout

In this snapshot, all four plants of our client's current facility layout are in production (all plants binary digits=1). As one can see, all the plants are covering different demand areas; the Strathcona facility is represented by blue, one of the west Edmonton facility is represented by olive, the other west Edmonton facility is represented by coral, and Leduc is represented by light purple. It can be seen that the darker quadrants of each color are those quadrants that require the highest demand. Additionally, it is evident that the transportation costs for having our client’s current plant layout run around $1,288,794. (This is already half the costs of scenario one). Thirdly, the utilization of all four plants is below 100%. Realistically, this plant layout could be feasible however the total transportation costs could be lowered by opening other candidate locations instead.
Scenario 3: Interface with four plants open; New Candidate Location (CL4) replacing Leduc

In this snapshot, four plants are in production; three of which are our clients current facilities and one of which is a more efficiently located facility that is replacing the Leduc plant. Similarly to the previous scenario, one can see which demand locations are being serviced by which plants; Strathcona facility is represented by blue, one of the west Edmonton facilities is represented by olive, the other west Edmonton facility is represented by coral, and CL4 is represented by dark purple. Once again, a number of observations are prevalent. The transportation costs have further decreased from $1,288,794 in scenario 2 to $1,114,641. Also, the utilization of all four plants is below 100%. Realistically, this plant layout is even more feasible and efficient than scenario 2.
Scenario 4: Interface with three plants open; New Candidate Location (CL4) replacing Leduc and inefficient plant in west Edmonton is closed.

Finally, this snapshot represents the client’s most efficient plant layout. Three plants are in production; two of which are our clients current facilities and one of which is a more efficient candidate location, CL4. In this scenario, one of the west Edmonton plants has been shut down completely. As highlighted again, one can see which demand locations are being serviced by which plants; the Strathcona facility is represented by blue, the west Edmonton facility is represented by olive, and CL4 is represented by dark purple. It should be noted that although transportation costs have increased by approximately $100,000 this costs is much less than the operation costs to keeping an extra plant (for more in depth analysis of this refer to analysis and recommendations). Furthermore, the utilization of all three plants is below 100% and each plant is being used more efficiently under this scenario than with four plants in scenario 3. Ultimately, this layout was able to successfully answer all three of our client’s requests.