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A FACILITY LOCATION CASE TO STIMULATE CLASSROOM INTERACTION

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ABSTRACT

This paper presents the use of a facility location case to stimulate the class experience. This case includes the quantitative topics of regression analysis, experimental designs, ANOVA, sensitivity analysis, cost analysis, and above all the use of a computer program to solve a very sophisticated and large warehouse location problem. The simulation can be executed on a mainframe or a personal computer.

This paper will present the research setting, the cost functions, and the use of the case in the classroom as a stimulus for extensive interaction between the students. Finally, this paper will relate this professor's teaching philosophy to the inclusion of this type of case in the course curriculum.

INTRODUCTION

One of the most interesting and important issues which a multi-echelon corporation faces today is deciding where to locate warehouses in a two- or three-echelon setting. The research setting in this paper presents a two-echelon situation where the first echelon includes unlocated warehouses and the second echelon consists of fixed markets with forecasted demand. The student's objective is to determine how many warehouses to locate and where to locate them in order to minimize the total logistical cost function.

Facility Location Cost Model

The objective of this facility location problem is to minimize the following cost function:

$$TC = \sum_{i=1}^{I}\sum_{j=1}^{J} C[ij]X[ij] + \sum_{i=1}^{I} F[i]Y[i] + \sum_{i=1}^{I} W[i]\sum_{j=1}^{J} X[ij]$$

$$(1)$$

where: TC   is the total cost made up of three basic cost components: transportation cost, fixed warehouse operating cost, and variable warehouse operating cost.

C[ij]   is the unit transportation cost to ship a unit from warehouse i to market j.

X[ii]   is the number of units moving from warehouse i to market j during a certain year.

F[i]   is the fixed cost to open and operate a warehouse for one year.

Y[i]   is a 0/1 variable. Y[i] = 1 when a warehouse is opened at location i. Y[i] = 0 when no warehouse is opened at location i.

W[I]   is the variable warehousing move one unit into, around, and out of the warehouse. These costs include cost of materials handling, holding cost, and other costs which vary with the size of the throughput.

I   is the total number of possible warehouse location sites.

J   is the total number of markets (cities) where the product must be delivered.

Basic Details of the Facility Location Problem

As the student works to determine where to locate warehouses, they try to meet three objectives:

(1)   satisfy forecasted demand for a one-year planning horizon at the sales markets;

(2)   remain within the product handling capacity limits of the warehouses; and

(3)   minimize total warehouse operating plus transportation costs for the one-year period.

There are some initial assumptions, which make it easy for the student to achieve the first and second goals. First, the case assumes that the entire forecasted demand at the sales outlets is delivered from the warehouses. The computer program will "deliver" the entire market demand from the designated warehouse-- probably the closest warehouse. Second, assume that there is no handling capacity limitation at any warehouse. This means that, theoretically, we could open just one warehouse in the middle of the country and service the total system demand from this warehouse. Practically speaking, students realize this is an unacceptable solution.

Given the two simplifying assumptions, the key goal is to open some number of warehouses so as to minimize the total cost equation presented previously.

Cost Analysis

Cost information and sales data was furnished by a Fortune 500 company. The name of the firm and its product are not mentioned to maintain confidentiality. Despite these limitations, students realize that the data and relationships are real and that the problem to be solved is quite similar to the actual problems facing firms today.

Cost information was gathered from corporate records. The transportation cost--rates and distances--were determined from the actual rates paid and routes used during the recent past. The actual transportation cost function was stepwise linear. The students "help" develop the regression equation below during a classroom discussion to determine the cost of shipping one unit of product from a warehouse to a given sales market. Since they have previously been introduced to linear regression earlier in this course, the pertinent use of regression analysis is reinforced.

$$C[ij] = 0.00601 + .00003d[ij]$$

<div align="center">(2)</div>

where: C[ij]   is the cost to ship one unit from warehouse i to market j.

       d[ij]   is the distance in miles from warehouse i to market j.

The total warehouse operating cost f or each warehouse for each of several previous years was determined by gathering information from the traffic and accounting departments. The throughput of

$$'wc[i] = F[i] + (W[i] * \sum_{j=1}^{J} X[ij])$$

each warehouse was determined by adding up the shipping invoices. The costs associated with each warehouse were calculated by adding up the appropriate salary and expense accounts for each warehouse.

A plot is presented with total warehouse throughput on the X-axis and the associated total warehouse operating cost on the Y-axis. Once again students "help" develop a regression equation using the total warehouse operating cost as the dependent variable and the throughput volume of each warehouse as the independent variable as shown in the equation below:

<div align="center">(3)</div>

where: WC[i] is the total warehouse operating cost for a given warehouse.

      F[i]   is the fixed warehouse cost for each of the firm's open warehouses. It corresponds to the constant term, B(O), in the standard linear equation Y = B(O) + B(1)X. From the empirical data the fixed warehousing cost for this company is $43,000 per warehouse.

      W[i]   is the variable warehouse operating cost per unit or, in this case, per 1,000 units of throughput. It corresponds to the coefficient, B(1), in the standard linear regression equation. The empirical data showed that the variable warehousing cost is $44.10 per 1,000 units of throughput.

      X[ij]   is the number of units of product moving from warehouse i to market j during the time period.

      J   total number of market outlets in the problem.

Determining a Location-Allocation Pattern

The computerized simulation was developed to aid in solving the location-allocation problem. There are specific "rules of the game" that students must follow while experimenting with various solutions. They are presented to the students as follows:

(1)   You may open a warehouse at any of the sales outlets, but only at the sales outlets. You can open a maximum of 50 warehouses.

(2)   You must ship the forecast level of product to each sales

market. Although this may be multiple small shipments evenly spread through the year, the simulation model will portray the shipment as one large shipment satisfying the total year's demand. Although you may wish to ignore demand at a small sales outlet in some far corner of the United States, you cannot do so. The program will assign some warehouse to ship product to each market

(3)   The distance between warehouses and sales outlets is measured "as the crow flies." That is, it equals the distance along a straight line between them. Otherwise, we would face the foreboding task of trying to find the actual highway mileage for a very large number of warehouse to sales outlets combinations. This also creates a problem when water is between the two cities. The simulation program assumes that the truck can drive on the water. This creates very few problems as compared to the complexity that would have to be put on the computer software to check for lakes and oceans.

(4)   The cost of moving goods from an open warehouse to a sales outlet in the same market is not zero even though the travel distance is close to zero. The transportation cost model imposes a cost to delivery product from the warehouse to the local job sites.

(5)   The location simulation software uses the "shortest distance rule" to decide which warehouse will serve a specific sales outlet. This is a valid rule because (a) the transportation costs are linear; and (b) there is no throughput limitation at the warehouses. We should ship to each market from the closest open warehouse. Students have an opportunity to reallocate, which would be useful if there was a capacity limit imposed or if the costs were not linear.

Development of an Experimental Design

Getting the class excited about learning is aided by the realistic nature of this case. Further, each student will have a unique set of cost functions. To make this unique feature of the case work in the professor's favor, an experimental design is presented in Exhibit 1.

<div align="center">

EXHIBIT 1
EXPERIMENTAL VARIABLES AN!) FACTOR
LEVELS IN LOCATION SIMULATION

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Experimental Variable		**Factor Level**	
1.	Size of the problem	1.	23 sales
		*2.	36 sales
		3.	49 sales
		4.	86 sales
2.	Service level-- maximum	1.	400 mile maximum
	travel distance between	2.	700 mile maximum
	warehouse and sales	3.	1,000 miles maximum
	outlet	*4.	no distance limit
3.	Magnitude of the fixed	1.	$7,000 per warehouse
	warehouse operating cost	2.	$21,000 per warehouse
		*3.	$43,000 per warehouse
		*4.	$64,500 per warehouse
		*5.	$86,000 per warehouse
4.	Magnitude of the variable	*1.	low level, actual cost
	warehouse operating cost	*2.	high level, actual * 2
5.	Magnitude of the	*1.	low level, actual cost
	transportation cost	*2.	high level, actual cost * 2

After using the experimental design in Exhibit 1, several of the experiments were dropped because of great difficulty in finding a good solution. A smaller group, marked with asterisks, was deemed "fairer" for student assignments. Thus with 36 students in the class, a complete three-replication experimental design can be completed. Each student receives a handout of exhibit 2 and chooses an index card with a particular experiment --for example, one student's draw might be: 2, 4, 3, 1, 2. This represents the factor level for each of the five experimental variables.

Executing the Simulation Program

If the student drew, for example, the card mentioned above, he would input the specific experimental variable factor levels during the first pass through the simulation program. During each pass through the program the student will be required to input two very important pieces of information:

(1)   The first request is for the number of warehouses to open. Using these reports students develop a set of their own heuristics to help in the solution process. Two might be:

(2)   The program will then ask for the ZIP codes of those warehouses.

The computer software can display a series of reports during each trial to help the student solve the problem. These reports include information on allocation pattern, distance from each warehouse to the is serving, the throughput of each warehouse, the total transportation cost out of each warehouse, and the cost of each of the 36 delivery

EXHIBIT 2
CITIES FOR 36 MARKET PROBLEM

Number	ZIP	City, State	Demand
1	010	Springfield, MA	3850
2	088	New Brunswick, NJ	1230
3	120	Albany, NY	1181
4	150	Pittsburgh, PA	3085
5	189	Philadelphia, PA	2285
6	218	Salisbury, MD	1050
7	230	Richmond, VA	2213
8	278	Rocky Mount, NC	1482
9	280	Charlotte, NC	1646
10	296	Greenville, SC	1139
11	310	Macon, GA	1954
12	326	Gainesville, FL	1295
13	335	Tampa, FL	3785
14	355	Jasper, AL	2125
15	400	Louisville, KY	801
16	430	Columbus, OH	4603
17	450	Cincinnati, OH	1022
18	465	South Bend, IN	2771
19	493	Grand Rapids, MI	1370
20	553	Minneapolis, MN	2541
21	600	Chicago, IL	1727
22	630	St. Louis, MO	1706
23	640	Kansas City, MO	1793
24	670	Wichita, KS	1793
25	760	Fort Worth, TX	2915
26	800	Denver, CO	2361
27	836	Boise, ID	3403
28	850	Phoenix, AZ	2114
29	870	Albuquerque, NM	1141
30	900	Los Angeles, CA	5662
31	926	Santa Anna, CA	3738
32	94S	Oakland, CA	3436
33	950	San Jose, CA	2615
34	966	Sacramento, CA	2498
35	970	Portland, OR	3671
36	980	Seattle, WA	5106

Using these reports students develop a set of own heuristics to help in the solution process. Two might be:

(1)   Open a warehouse at the longest route length in present solution; or

(2)   Close the warehouse that has the smallest throughput.

At the end of each simulation trial the student has several options including adding, dropping, or moving warehouses. They can also loop to the top of the program and enter an entirely new group of warehouses. Students quickly learn that changing more than one or two locations per trial leads to not knowing which change helped or hurt the final total cost solution. Using ideas discussed when they investigated sensitivity cost analysis in inventory control--change only one thing at a time--is even more important in the location case because of the greater number of alternative solutions.

Teaching Pedagogy

Since there are many different sets of experimental variables among the students' assignments, they are encouraged to discuss solutions and the solution processes with one another. This will help them understand how the individual cost factor levels of the total cost equation interact.

Students are asked to find the "best" location-allocation solution. They must decide on the number of and location of warehouses. They are required to have a printout of their best solution when the case is due. Since there are multiple-million alternatives, they are helped in the beginning to get a good start on the solution process. A presentation of a regional optimization approach usually makes students realize that covering the nation regionally is the key to both meeting a low transportation cost and keeping the number of open warehouses manageable.

Students are required to keep a diary of their trials and try a minimum of forty. This helps them to organize their work and lets the faculty member see that they really have worked with the problem at hand and not just "lucked out" at finding a good solution. If students really attack the problem and work in small groups with different experimental variables, they realize several "axioms." For example, they realize that if the fixed warehouse cost goes up, they must consolidate the number of warehouses.

They are also required to draw an allocation map each of the 36 transportation routes identified. the many different sets of costs, these maps are different, but several warehouses are "universal winners."

The assignment is due in one week and each student is expected to present orally in front of the class his or her solution. The smart faculty member has arranged the cards in a particular order such that each next presentation has one factor level different from the previous one. About forty percent of the students have only fair solutions. If the "universal winners" are not part of a student's solution, the class realizes that this is not the best possible solution.

Student Learning

The learning process for students, especially in a business core course not in their major, can be difficult, almost arduous in a quantitative course.

Even with two strikes against quantitative methodology in a business core course, this case has always been a favorite of students. Even after three or four years when students come back to campus for graduate work, they always comment about the location case. First, and not the least important, students re-learn their U.S. geography and the ZIP codes attached to the 36 cities in the case. Needless to say, many, many corporations use three digit ZIP codes in their everyday business. This gained knowledge, although seemingly simplistic, is real.

Even more important students can now understand how a simulation can help solve a large and intricate business problem. Unlike a mathematical programming solution, where the inputs are keyed into the terminal and the "black box" does its magic, a simulation program, if programmed properly, can lead the user through the solution process. The intermediate allocation and cost reports can aid the user in deciding what changes and hopefully improvements to make on the next simulation trial.

The understanding of the relationships between the cost elements of the total logistical cost equation is also important. Many business problems from forecasting, to inventory, to aggregate planning, are tradeoffs of various costs. The location simulation is no different. Students learn to "trade" fixed warehousing costs for transportation costs. By working in small groups, students also learn how the increase or decrease in one of the cost elements will alter the overall location-allocation solution.

Further Extensions

A further extension of the learning process is to develop a database of the experimental variable factor levels and the total cost. An ANOVA can be performed on the database to determine which experimental variables are statistically significant. with 36 students, there would be three replications of each of the twelve unique experiments. If the faculty member had two or three sections of the same class, then there would be six or nine replications. SAS or SPSS, for example, could be used by the students or the faculty member and the statistical inferences analyzed.

Granted, the significance of the variables would be hypothesized easily before the program was executed, but the process of setting up the database and executing the statistical package may be the only opportunity the students will have during their undergraduate careers. Further, they will have not only participated in the statistical analysis, but would have in fact been the "managers" who contributed the solutions that made up that database. They would see the problem from the perspective of both the experimenter and the "guinea pig."

Benefits for the Faculty Member

Teaching is a game of marketing. If a faculty member truly wants students to learn useful knowledge that can be used in their future business careers, not just having the opportunity to listen to lectures, this case is a perfect vehicle. It is not overly burdensome to the teacher because exact solutions are not required nor a complete answer key necessary. Students are told that the "boss does not have the answer in his desk drawer." It is a real world problem and the stopping rule is "when you feel that you have a good answer." Students can "feel" when they are very close to the optimal mathematical solution. This merely adds to the realism. When students make their oral presentations, the other

class member can immediately draw a conclusion as to whether the solution is good, bad, or in the middle of the pack.

Conclusion

I have used the location case, which has its roots in my dissertation, for eight years. I enjoy it as much as the students. I have made a point of not memorizing the optimal solutions for each experiment so that during the oral presentations I can enjoy the students arguing over the "goodness" of each other's solutions. The case is a great learning experience. A complementary copy of the software can be obtained by contacting: Harms Publishing Co.; 1701 Forest Avenue; Neptune Beach, FL 32233.

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