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# EVALUATING WAREHOUSE EFFICIENCY USING RESIDUAL ANALYSIS

By

Vaughn Roller  
Northeastern University  
and  
William Lesser  
Cornell University

## Problem Addressed

In recent years, food distribution executives have become increasingly concerned with cost efficiency in the distribution center. The best estimates place the costs of these operations at 2.5 percent of retail food expenditures (Kaylin, p. 13). With high short-term interest rates, this estimate probably substantially understates the actual operating costs in the 1980's.

Until recently, efficiency improvement programs have relied on either consultants' estimates of achievable costs, or comparative physical productivity reports such as those prepared by NAWGA and at Cornell. Neither approach was complete as they lacked comparisons with actual performance and cost components other than labor. Moreover, the degree of operating inefficiency must typically be determined judgmentally by the manager or consultant. What is required is a composite report containing all of the cost components in the distribution center and providing a relative efficiency ranking across a sample of centers.

In a previous issue of the Journal, we described the applicability of frontier function analysis to analyzing warehouse efficiency (Lesser and Roller). In this paper, we report on the first attempt to carry out this analysis. With a sample of 39 warehouses across the U.S. and Canada, an industry frontier cost function was fitted. Relative to this theoretical 100% efficient cost surface, the degree of operating effi-

ciency of the sample firms ranged from 49 to 95 percent. On average, the potential savings ranged from 2 to 47 cents per case. The results, which must be considered preliminary at this early stage, are reported below, following a discussion of the methodology, data collection procedures and sample. These results have previously been made available to the distribution industry in the 1981 Cornell Report on Productivity in Grocery Distribution Centers.

## Methodology

The procedures employed in this research were drawn principally from the microeconomic theory of production-cost duality (Diewart) and from recently developed econometric techniques for cost function analysis and frontier surface estimation. Employing the concept of duality, it is possible to model the economically relevant portion of grocery distribution center production in terms of total cost as a function of the level of output (goods shipped) and the prices paid for factor inputs (i.e., labor, inventory, buildings and equipment).

Frontier function models, in essence, statistically control the influence of factors such as size of the operation, wages, inventory levels, rent, and equipment used. There is typically substantial variability among these factors from warehouse to warehouse. Once these costs have been accounted for, the analysis projects a

minimum attainable cost curve--the frontier function. By construction, all observed costs must lie on or above this curve. The proximity of the observed costs (as measured by the size of the residual) to the curve may then be interpreted as a measure of the degree of operational efficiency of each distribution center. Conversely, the residual is an indication of the potential cost savings for each firm. In addition, the shape of the curve can be used to measure the size economies of food warehousing and the decline in average costs associated with increasing the size of the operation, all other factors held constant.

Given the dearth of previous empirical work on warehousing, and thus little evidence available upon which to hypothesize a best functional form for distribution centers, we chose the flexible translog cost functional form as the basis for our model. The translog cost function has the advantage of minimizing restrictive assumptions about the underlying technology associated with the industry cost function. Although simplified versions of the functional form were estimated and tested, it was found that these restricted versions lacked the explanatory power of a full translog formation to a statistically significant degree. Thus, an unrestricted translog industry cost function was retained as the most representative model.

Following Christensen and Green, we obtained maximum likelihood estimates of cost function parameters using an iterative Zellner procedure employing the cost function and its derivative share equations. The intercept term was adjusted by adding the largest negative fitted residual, in effect shifting the estimated surface to a minimum cost frontier position and forcing all residuals to be positive. Each residual was then interpreted as potential savings equal to the difference between the total of annual costs of labor, inventory, occupancy and equipment and

the minimum possible cost of these items predicted by the model. This potential cost reduction was then divided by total costs (including miscellaneous additional inputs such as support labor, supervision and supplies) to arrive at a conservative estimate of potential savings in percentages.

#### Data Source

Data were collected from 39 distribution centers in the United States and Canada using a mail questionnaire. Of these, 32 are retailer owned, five are independent wholesaler operations, and two are retailer-owned cooperative centers. The questionnaire was divided into two sections. Section one addressed to the comptroller's office included questions on occupancy, operations and input costs, and investments in equipment. The remaining questions, constituting the second section, related to distribution center operations such as labor hours, inventory levels and product movement. These data were supplied by the warehouse manager (or assistant) for a one-year study period.

The completed questionnaires were returned from a mailing to 200 of the larger food distribution firms. As with any self-selected sample of this type, the included firms are not necessarily representative of the entire industry. Hence these results must be considered as preliminary. In addition, the accuracy of the supplied data has been problematic in the past. In this case, an extensive screening and validation process, including telephone calls to the firms, was used to identify and clarify any potential errors. Nevertheless, inaccuracies potentially remain and could affect the results.

#### Results and Significance for Food Distribution

The frontier function analysis used here is suited to the measurement of two forms of inefficiencies. First is the costs of operating below (or above) the

most efficient size, or scale. The analysis showed that the size economies of distribution center operations are quite substantial. With a minimum efficient scale (MES) estimated to occur beyond the range of most existing operations of 50 million case units, the cost penalty of operating at one-half MES is about 8¢ a case, or 24% of the cost of 50 million unit operations. At 10 million annual units, the costs are 40% above MES costs. According to Bain's classification of costs, these are substantial. They are also notably larger than those estimated in previous studies (Pierson; Grinnell and Crawford). Of course, a complete analysis of distribution center size economies would have to include the assembly and particularly the distribution system. As larger centers distribute over greater distances, the evaluation of in-center size economies only probably overstates true size economies.

The second and far more significant form of efficiency analyzed here is operational efficiency, previously described as the "distance" of observations from the frontier function. These distances as measured by the estimated residuals are shown in Table 1 where they are ranked in ascending order of potential savings. Potential savings range from 5 to over 50% with a mean of approximately 30%. These results agree closely with estimates of engineering consultants who report the potential for cost savings from 10 to 40% with no major investments in equipment (Grocery Distribution, Grinnell and Friedman).

Table 2 contains a break-down of costs per case shipped into seven accounting categories: direct labor, inventory, occupancy, equipment, warehouse supervision, support labor and miscellaneous (second level management, utilities, and supplies). This information substantiates the significance of direct labor (mean 25.8¢ per case) and inventory (mean 12.9¢ per case) as respectively 45 and 24% of total warehousing costs.

The data in Tables 1 and 2 may be used by the industry in several ways. The participant can determine from Table 1 the relative ranking of his operation to the attainable level and by using Table 2 can get an indication of the major operating area where the excessive costs are incurred. Use by non-participants requires an additional step. The user must first identify using the remaining tables in the Report a similar warehouse operation to his. Then he can compare his estimated per-case cost with the frontier value (Table 1) and the costs of each major component (Table 2).

The application of frontier function analysis to food distribution centers is a good example of how sophisticated empirical analysis can be presented in a way which is beneficial to the industry. The results to date must be considered preliminary, but they contribute to the mounting evidence that there are significant technical inefficiencies within our food distribution system. Some efficiencies are apparently achievable by construction larger warehouses and taking advantage of size-related cost-savings. But equally important in terms of costs, yet more readily achievable, are improvements in operating efficiencies. A key research need now is in identifying the sources of those operating inefficiencies and developing remedies.

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Table 1. Unit Costs, Potential Savings and Labor Productivity

ID <sup>1/</sup>	Cost per Case Shipped (c/case)	Potential Savings (%)	Potential Savings (c/case)	Minimum Possible Unit Cost (c/case)	Cases Shipped/ Direct Labor Hr.
08	40.3	5.0	2.0	40.3	102
35	45.3	7.8	3.5	41.8	82
61	34.0	10.2	3.4	30.5	114
03	43.7	10.3	4.5	39.2	68
24	29.8	12.2	3.6	26.1	77
58	49.7	16.6	8.2	41.4	69
15	55.9	17.9	10.0	45.9	82
09	45.6	19.0	8.6	37.0	73
62	40.4	19.8	8.0	32.4	71
49	38.8	21.7	8.4	30.4	87
12	47.6	24.2	11.5	36.1	62
13	42.8	24.9	10.6	32.1	69
10	60.3	25.9	15.6	44.6	61
21	44.7	26.2	11.8	33.0	69
28	67.6	27.3	18.4	49.1	63
56	61.2	28.9	17.6	43.5	51
20	66.8	29.6	19.8	47.0	52
02	47.3	29.7	14.0	33.2	57
18	53.0	30.4	16.0	36.8	56
37	56.2	30.4	17.1	39.1	55
16	63.8	32.1	20.5	43.4	61
42	38.8	34.1	13.2	25.6	65
51	77.1	34.4	26.5	50.6	52
33	51.6	34.4	17.8	33.8	41
22	50.2	34.7	17.4	32.8	51
50	81.2	35.7	29.0	52.2	49
48	50.4	36.4	18.4	32.0	47
54	59.0	36.6	21.6	37.4	46
23	59.8	37.4	22.4	37.4	61
39	71.6	37.6	26.8	44.6	51
41	45.2	37.6	17.0	28.2	56
63	84.0	39.5	33.2	50.8	41
59	63.0	39.6	25.0	38.0	33
25	63.2	40.6	25.6	37.5	48
40	47.5	42.8	20.4	27.2	56
60	73.2	45.0	33.0	40.2	40
55	71.2	45.4	32.3	38.9	33
29	61.4	47.6	29.2	32.2	41
57	92.3	51.0	47.1	45.2	25
Mean	55.8	29.8	17.7		59
Min.	29.8	5.0	2.0		25
Max.	92.3	51.0	47.1		114
Noncomparable Operations					
43	75.7				52
44	30.0				98
45	12.2				180
46	28.6				82
47	38.5				71
52	138.1				32
53	77.7				51

<sup>1/</sup> Ranked in order of increasing potential savings.

SOURCE: 1981 Cornell Report, p. 6.

Table 2.

Unit Cost by Accounting Category  
(c/case shipped)

ID <sup>1/</sup>	Direct Labor	Inventory	Occupancy	Equipment	Warehouse Supervisors	Support Labor	Other
08	17.4	11.2	3.2	1.0	2.2	2.4	2.6
35	18.8	12.5	3.0	3.8	3.8	0.2	3.0
61	13.2	7.0	6.8	0.6	1.8	2.7	1.8
03	15.2	12.0	2.9	1.3	2.9	5.4	4.0
24	13.3	8.4	0.8	1.8	0.8	1.8	2.5
58	27.8	8.6	2.2	0.7	2.4	5.7	2.1
15	23.5	13.0	5.2	2.4	2.3	6.2	3.3
09	9.7	14.2	9.6	1.2	2.0	3.0	6.7
62	16.4	10.6	5.0	1.4	4.0	1.8	1.2
49	18.4	7.9	3.6	2.3	0.9	3.8	1.8
12	24.1	8.0	3.1	3.0	3.0	2.2	4.0
13	18.3	13.8	2.2	0.3	1.2	2.4	4.4
10	35.8	6.5	1.6	1.0	3.4	7.4	4.8
21	17.0	12.6	1.6	3.0	3.2	4.1	3.1
28	26.6	21.0	3.0	3.2	2.8	6.8	4.2
56	29.8	11.8	3.4	0.9	2.8	7.9	4.4
20	34.0	16.1	3.6	1.2	3.2	5.6	2.9
02	22.0	12.9	2.6	0.2	1.3	5.6	2.4
18	17.6	15.9	5.4	1.8	2.8	6.0	3.4
37	24.1	11.7	4.8	2.4	2.4	5.4	5.2
16	31.0	18.4	6.8	0.9	2.2	1.0	3.5
42	16.0	9.1	3.8	1.6	2.1	3.2	2.8
51	38.4	14.8	3.6	1.2	4.3	11.8	2.8
33	16.6	19.8	3.8	3.2	2.2	2.1	3.8
22	23.8	12.6	1.8	1.0	2.6	5.2	3.2
50	41.0	14.8	2.4	1.6	4.2	12.5	4.5
48	23.2	11.9	4.1	2.0	3.1	1.3	4.6
54	30.8	11.3	3.4	0.8	3.6	5.7	3.1
23	18.8	19.0	7.0	3.2	2.8	4.5	4.3
39	35.0	15.0	4.0	1.4	2.7	9.1	4.2
41	16.4	10.8	6.0	1.2	2.9	3.4	4.4
63	54.4	10.4	1.2	1.8	3.1	11.2	1.6
59	21.2	15.4	3.8	9.6	2.4	6.4	4.0
25	26.4	14.2	4.1	7.4	2.4	5.4	3.2
40	28.8	8.8	0.7	2.3	0.6	3.0	3.0
60	41.4	13.7	6.2	1.7	3.8	2.2	4.1
55	42.8	11.6	0.8	1.0	3.6	7.8	3.3
29	31.6	15.8	3.3	5.2	2.5	0.4	2.4
57	48.0	19.4	2.4	5.6	5.0	4.8	6.8
Mean	25.8	12.9	3.6	2.2	2.7	4.8	3.6
Min.	8.8	6.5	0.7	0.2	0.6	0.2	1.1
Max.	54.4	21.0	9.6	10.0	5.0	12.5	6.8
Noncomparable Operations							
43	20.2	8.4	16.7	13.0	1.9	4.1	11.4
44	9.6	3.0	5.5	3.8	1.6	2.0	2.4
45	5.4	2.6	0.9	0.6	0.6	1.1	0.8
46	12.5	2.2	3.5	3.2	1.7	2.6	2.9
47	14.4	6.5	5.5	3.6	1.9	3.0	3.6
52	64.8	23.8	6.6	3.1	5.6	15.1	18.9
53	40.2	7.2	1.8	2.8	4.3	17.1	4.1

<sup>1/</sup> Ranked in order of increasing potential savings.

SOURCE: 1981 Cornell Report, p. 8.

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