A PROCEDURE FOR APPLYING LINEAR PROGRAMMING TO THE FORMULA FEED WAREHOUSE COST-CENTER

by

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CHAPTER I

Introduction

The formula feed industry is considered to be the largest agricultural industry that specializes in supplying products for use by the American farmer today. The industry has grown in importance from its early beginnings. As more and more feeders began to see the advantages of using formulated feeds, the industry was faced with the challenge of continuing to formulate, manufacture, or distribute a quality feed that would enable the farmers to produce livestock at a lower cost.

The extent to which the industry has met this challenge is partially shown in Figure 1. From an early year peak production of 13.1 million tons in 1930, formula feed production has increased to approximately 44 million tons annually at the present time.[1]

Evidence of the industry's importance is also shown in Figure 2. Currently ranked Number 13 in value of shipments, the formula feed industry has ranked as one of the nation's top industries in value of shipments during the past

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[1]Feed Production School, Inc., Feed Production Handbook (Kansas City, Missouri: Feed Production School, Inc., 1961), p. 14.

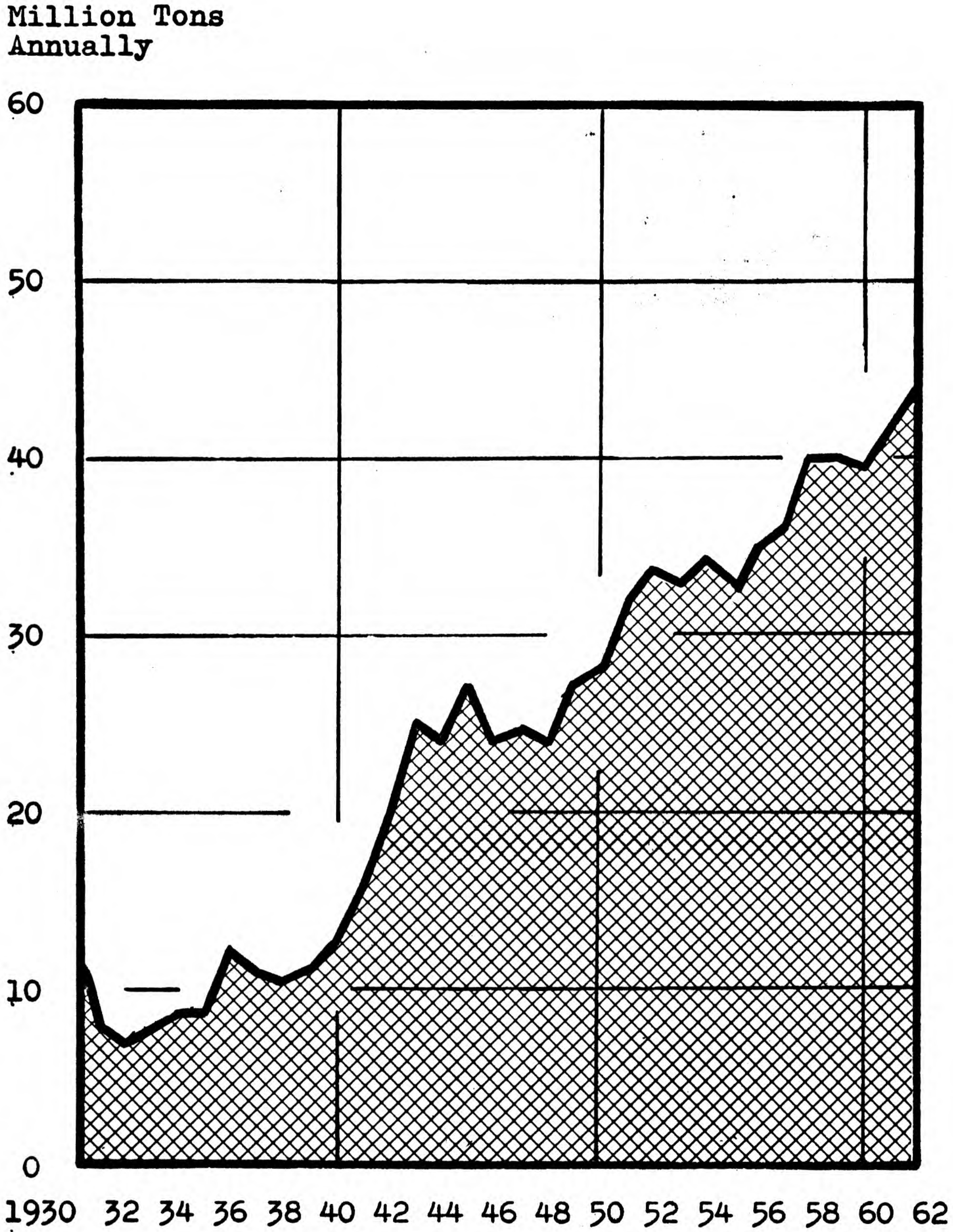

Fig. 1--Formula Feed Production in the United States 1930 to 1962[a]

[a]Source: Feed Production School, Inc., Feed Production Handbook, 1961, p. 16.

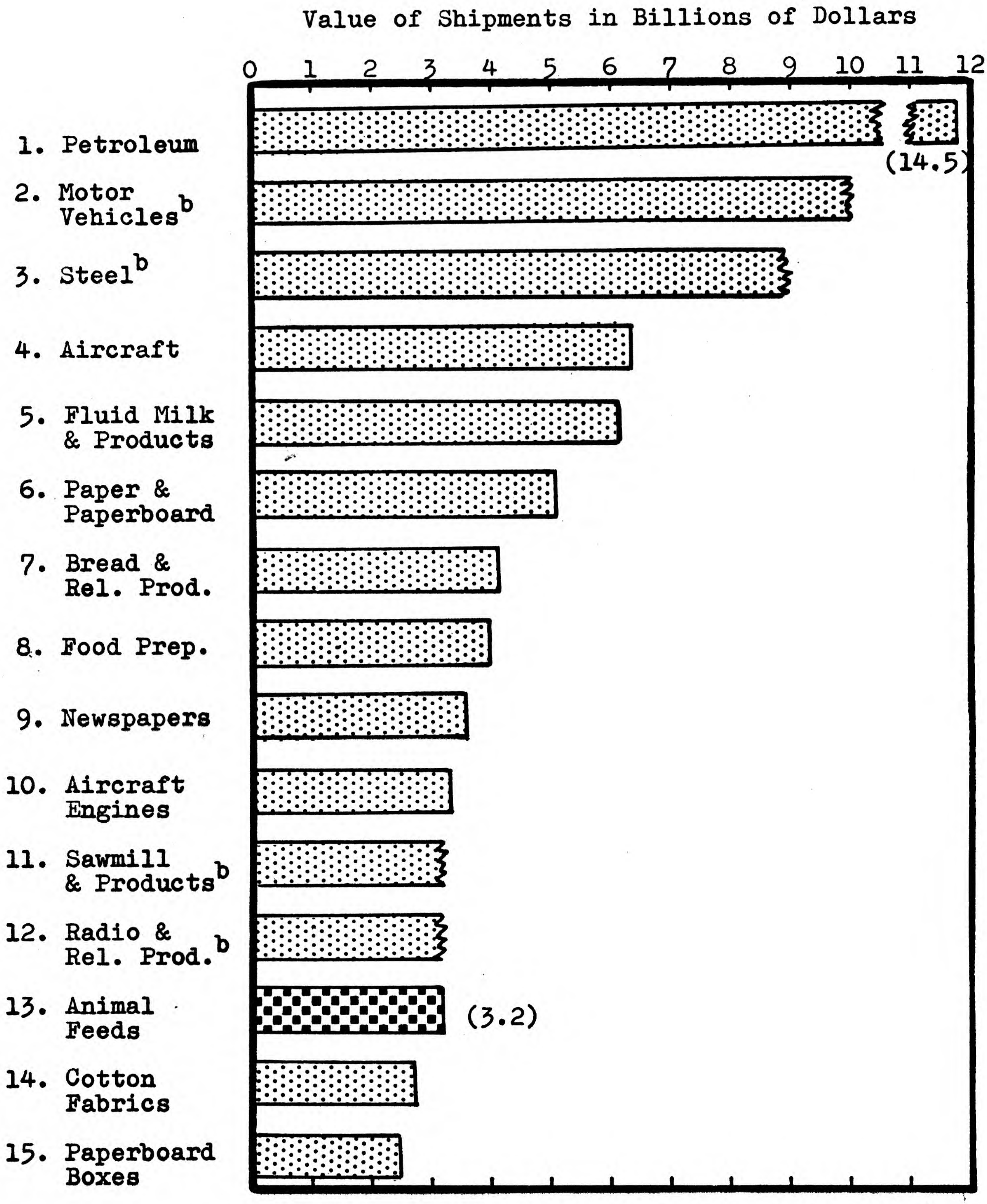

Fig. 2.--America's first fifteen industries[a]

[a]Source: Feed Production School, Inc., Feed Production Handbook, 1961, p. 13.

[b]1958 estimate not available. Rank based on 1956 data.

decade.[2]

Needless to say, the industry has made notable advances in the utilization and promotion of scientific formulation, manufacturing processes and procedures, customer services, and product lines. In order to retain their competitive position, manufacturers have been forced to analyze closely their manufacturing costs. Manufacturing costs are the third most important item of total feed costs and account for 6 to 10 percent of the wholesale formula feed price (See Table 1). Assuming

TABLE 1

BREAKDOWN IN COSTS OF COMMERCIAL FORMULA FEED[a]

Cost Item	Estimated Percent of Total Cost
Raw ingredients	65 - 75
Freight	10 - 20
Manufacturing	6 - 10
Sales	5 - 10
Gross margin	3 - 8
Administration and research	3 - 6

[a]Source: Feed Production School, Inc., Feed Production Handbook, 1961, p. 18.

that a local manufacturer is taking full advantage of all available sources of ingredients and that he can do little to influence freight costs, the logical point at which to

[2]U. S. Bureau of the Census, United States Census of Manufacturers: 1958, II, Part 1, pp. 1-6-1-23.

initiate a cost-reduction program is in the area of manufacturing costs.

Askew, Vosloh, and Brensike[3] stated that labor is 53 percent of the total mill operating costs and 69 percent of the total warehouse costs (Table 2). In addition, the warehouse alone comprises 30 percent of total direct labor and 27 percent of total mill labor expense as shown in Table 3.

Much interest has been displayed recently in the industry to reduce production man-hour requirements, the number of man-hours required to produce one ton of finished feed.[4] Table 4 offers a comparison by cost-centers of production man-hour requirements per ton.[5] It is readily apparent that the warehouse cost-center offers a large potential for an operating-cost reduction program.

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[3] William R. Askew, Carl J. Vosloh, Jr., and V. John Brensike, _Case Study of Labor Costs and Efficiencies in Warehousing Formula Feeds_, Marketing Research Report No. 205, U. S. D. A., Agricultural Marketing Service (Washington: U. S. Government Printing Office, 1957).

[4] Midwest Feed Manufacturers' Association, _Proceedings of the 1956 Midwest Feed Production School_ (Kansas City, Missouri, 1956), is a complete report of the industry's endeavor to establish In-Plant Cost Standards.

[5] The cost-center concept is designed to define eight natural cost areas within a given feed manufacturing plant. The recognized cost-centers are: (1) ingredient receiving, (2) grain processing, (3) mixing, (4) pelleting, (5) packing, (6) warehousing, (7) high molasses and (8) maintenance.

TABLE 2

DISTRIBUTION OF ANNUAL MILL AND WAREHOUSE OPERATING COSTS, BY COST ELEMENT[a]

Cost Element	Operating Costs			
	Mill		Warehouse	
	Percent		Percent	
Direct labor	34.0		47.0	
Indirect labor	7.1		5.7	
Supervision	5.6		6.9	
Other labor	6.8		8.8	
Total operating labor		53.5		69.3
Repairs, rents, and depreciation	24.2		12.4	
Other operating costs	13.8		7.2	
Management and administration	8.5		11.1	
Total - other		46.5		30.7
Total costs		100.0		100.0

[a]Source: U. S. Department of Agriculture, "Case Study of Labor Costs and Efficiencies in Warehousing Formula Feeds," Marketing Research Report 205, 1957, p. 5.

Statement of the Problem

The warehouse operation of individual mixed feed plants has been a vital service since the early days of the formula feed industry. A modern day warehouse is a complex and important operation and as such requires a great deal of managerial attention if it is to operate in an efficient and economical manner.

TABLE 3

ANNUAL MILL AND WAREHOUSE LABOR COST, DISTRIBUTION, AND RELATIONSHIP BY COST ELEMENT[a]

Cost Element	Proportion of Total Labor Cost Devoted to:		Warehouse as Proportion of Mill Cost by Classification
	Mill	Warehouse	
	Percent	Percent	Percent
Direct labor	64	69	30
Indirect labor	13	8	17
Supervision	10	10	26
Other	13	13	27
Total	100	100	27

[a]Source: U. S. Department of Agriculture, "Case Study of Labor Costs and Efficiencies in Warehousing Formula Feeds," Marketing Research Report 205, 1957, p. 5.

Through the years, finished feeds typically have been handled by the use of two-wheel hand trucks. However, in keeping with advancements in technology and automation in our society, new methods of materials handling have been introduced into the feed industry.

At the present time, three methods of handling finished feeds in the warehouse are recognized. They are: the two-wheel hand truck, the forklift pallet truck, and the belt conveyor. The new methods have been introduced in an effort to cut production costs and thus allow the individual firm to better compete in the already highly competitive formula feed industry. It should be stressed, however, that as plants

TABLE 4

PRODUCTION MAN-HOURS REQUIRED PER TON OF FORMULA FEED PRODUCED IN PLANTS WITH DIFFERENT VOLUMES, BY COST-CENTERS[a]

Cost-Center	7,500 to 10,000 tons per year			25,000 to 35,000 tons a year			50,000 to 75,000 tons per year		
	Industry Average	Better than Average Plants	Industry Cost Standard	Industry Average	Better than Average Plants	Industry Cost Standard	Industry Average	Better than Average Plants	Industry Cost Standard
Ingredient receiving	.352	.275	.162	.231	.154	.080	.154	.143	.071
Grain processing	.128	.100	.038	.105	.070	.019	.056	.052	.008
Mixing	.608	.475	.341	.357	.238	.145	.238	.221	.122
Pelleting	.160	.125	.119	.126	.084	.075	.084	.078	.046
Packing	.480	.375	.175	.336	.224	.109	.210	.195	.087
Warehousing	1.216	.950	.671	.735	.490	.309	.490	.455	.264
Maintenance	.256	.200	.160	.210	.140	.150	.168	.156	.126
Foreman	b	b	.133	b	b	.080	b	b	.080
Total	3.200	2.500	1.799	2.100	1.400	0.967	1.400	1.300	0.804

[a]Source: Midwest Feed Manufacturers' Association, Proceedings of the 1957 Midwest Feed Production School, p. 21.

[b]Included in the relevant cost-center.

increase automation, a careful analysis is required to insure that the capital outlay for automation will not result in depreciation and maintenance costs that exceed the saving in labor requirements.

It is this choice of the amount of automation to employ that is a top-management decision. In making the decision, the manager needs a procedure to follow by which he can evaluate the various methods in order to choose a handling system that will maximize his particular business objectives. The procedure will take the form of a step-by-step analysis of the current warehouse labor and equipment requirements, current costs, proposed alterations, and changes in labor and equipment requirements and costs resulting from the proposed alterations.

In every industry management is continuously expected to make decisions with respect to cost control. In the past, these decisions many times were based on a managers' experience and good judgment with the use of available data. Today, due to the increased complexity of industry, management needs analytical tools which will enable them to make decisions on increasingly complex problems that will maximize the objectives of their business. Linear programming is one such tool which management can use since management objectives can be clearly stated. It is a mathematical technique that has been found to be useful in the analysis of business and industrial problems.

In order for programming to be useful to management in the feed industry, it is necessary that a procedure be presented that explains the concepts and techniques involved.

Objectives

This study is primarily intended to demonstrate a method that could be used in applying linear programming to the formula feed industry's cost-center concept. It is believed that if linear programming can be used to analyze the relatively simple operations of a model warehouse, the technique would prove to be valuable in an analysis of more complicated operations encountered in a feed mill. Thus, the warehouse was selected as the cost-center around which this thesis has been developed.

Since no previous work has been done in applying programming to a cost-center analysis, this study is designed to provide a foundation on which can be constructed a knowledge and respect of the technique. Once this is achieved, the scope could be expanded to include other cost-centers. By including all operations of a feed plant, a model then could be formulated for use in analyzing the total operations of a firm. The present study will deal only with the warehouse cost-center.

Review of Feed Industry Programming Application Studies

A considerable volume of material has been published since the mid 1950's concerning the application of linear programming to the formula feed industry. The majority of work done, however, has been in the area of least-cost mixes or formulations.

As early as 1951, Waugh applied linear programming as a method to determine the minimum-cost dairy feed that would satisfy specified nutritive requirements.[6] In 1953, Fisher and Schruben continued Waugh's study by extending the application to the case of two or more feeds and to alternative price structures.[7]

Swanson discussed the time required to solve a minimum-cost formulation problem by use of an electronic computer.[8] In addition, he pointed out the ease of obtaining the solutions to a problem with several variations in order to compare the price effects. Katzman considered the optimum solution to a broiler ration with seven nutritive requirements and eight

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[6]Frederick V. Waugh, "The Minimum-Cost Dairy Feed," Journal of Farm Economics, XXXIII, No. 3 (August, 1951), pp. 299-310.

[7]Walter D. Fisher and Leonard W. Schruben, "Linear Programming Applied to Feed Mixing Under Different Price Conditions," Journal of Farm Economics, XXXV (November, 1953), pp. 471-483.

[8]Earl R. Swanson, "Solving Minimum-Cost Feed Mix Problems," Journal of Farm Economics, XXXVII, No. 1 (February, 1955), pp. 135-139.

feed ingredient sources.[9]

In 1957, Hutton and Allison expanded the basic formula mix problem to include various operational aspects such as provisions for bulk control, control of level of entry of individual ingredients, and milling-in-transit privileges.[10] Their study was aimed at developing a model that would make the programming technique more useful to the formula feed industry by treating both the nutritional aspects and the operational aspects of the feed mix problem. This same year found the first attempt to program an actual firm's operation by programming the product mix, a variation of the formula mix problem. Scott used the technique to determine which feed formulas should be produced by a given mill and the most profitable volume for each.[11]

Hutton and McAlexander expanded on the non-nutritional specifications work done earlier by developing a model that would consider both restricted and unrestricted ingredients.[12]

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[9] I. Katzman, "Solving Feed Problems Through Linear Programming," Journal of Farm Economics, XXXVIII, No. 2 (May, 1956), pp. 420-429.

[10] R. F. Hutton and J. R. Allison, "A Linear Programming Model for Development of Feed Formulas Under Mill-Operating Conditions," Journal of Farm Economics, XXXIX, No. 1 (February, 1957), pp. 94-111.

[11] J. T. Scott, "Application of Linear Programming for Profit Maximization in the Feed Firm" (unpublished Ph. D. dissertation, Dept. of Agricultural Economics, Iowa State College, 1957).

[12] R. F. Hutton and R. H. McAlexander, "A Simplified Feed-Mix Model," Journal of Farm Economics, XXXIX, No. 3, Part 1 (August, 1957), pp. 714-730.

In another work, they outlined several ways to set up a minimization problem and the advantage of each method.[13]

Another minimum cost feed study was done by Hutton, King, and Boucher when they applied linear programming to derive a least-cost broiler feed formula.[14] In addition, they outlined methods by which the formula might be adjusted to changes in prices, ration specifications, and composition of ingredients.

A very thorough discussion of a complete minimization problem is presented by McAlexander and Hutton in their example of a least-cost dairy ration utilizing only two feedstuffs to meet three specifications.[15] In addition to presenting their least-cost solution, McAlexander and Hutton present an easily understood explanation of the simplex method of solving a linear programming problem.

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[13] R. H. McAlexander and R. F. Hutton, "Determining Least-Cost Combinations," Journal of Farm Economics, XXXIX, No. 4 (November, 1957), pp. 936-941.

[14] R. F. Hutton, Gordon A. King, and Robert V. Boucher, A Least-Cost Broiler Feed Formula Method of Derivation, Production Research Report No. 20, U. S. D. A. in cooperation with the Pennsylvania Agricultural Experiment Station (Washington: U. S. Government Printing Office, 1958).

[15] R. H. McAlexander and R. F. Hutton, Linear Programming Techniques Applied to Agricultural Problems, Agricultural Economics and Rural Sociology Report No. 18 (University Park, Pennsylvania: Pennsylvania Agricultural Experiment Station, 1959).

CHAPTER II

Procedure For Applying Linear Programming to the Warehouse

This study applied the technique of linear programming to a model warehouse that was presented at the Midwest Feed Production School.[16] The warehouse is intended to depict a practical operation that will meet a set of requirements rather than to serve as an ideal warehouse design.

In applying linear programming to this cost-center a series of steps were utilized to obtain data essential to the analysis. These steps are:

(1) Description of the warehouse

(2) Description of jobs involved

(3) Description of alternative handling methods

(4) Determination of programming components

(5) Computation of labor requirements

(6) Computation of equipment requirements.

Upon the completion of the above steps, the necessary data are then available for completion of a linear programming analysis. With minor adaptations, these same six steps would

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[16] Richard Muther and Clifford H. James, "The Model Warehouse," Proceedings of the 1957 Midwest Feed Production School (Kansas City, Missouri: Midwest Feed Manufacturers' Association, 1957), p. 101.

be followed when applying the analysis to another cost-center.

Description of the Warehouse

The feed industry has proposed the following definition to be representative of the warehouse cost-center:

> The cost-center begins after the bags of finished feed leave the sewing machine ready for loading on hand trucks or pallets or after the bulk feed is placed into the storage bins. All movement of finished feeds from the sewing machine through warehousing including loading of the rail cars and trucks is included in this cost-center. Also, included is the work involved in resacking materials from broken bags, coopering rail defects, and checking outbound shipments. The cost-center ends after the rail cars and trucks have been loaded and are ready for transport.[17]

The warehouse measures 67 feet by 141 feet giving a total floor area of 9,447 square feet. It is serviced by an overhead belt conveyor from the bagging area to a centrally located take-off table along one wall of the warehouse.

Specifications which this model is designed to meet are:

1. Mill production, seventy-five tons per eight-hour shift.
2. Movement of feed:
    a. Seventy-five tons from the take-off table to warehouse storage.
    b. Fifty tons from the warehouse to truck shipment.
    c. Twenty-five tons from the warehouse to rail car shipment.
3. Percentage of total trips to each warehouse area:
    a. Area A, 32.52 percent
    b. Area B, 30.04 percent

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[17] Feed Production School, Inc., Feed Production Handbook, p. 179.

c. Area C, 5.28 percent
d. Area D, 3.52 percent
e. Area E, 2.36 percent
f. Area F, 2.36 percent
g. Area G, 5.04 percent
h. Area H, 18.88 percent.

Layout of the warehouse is shown in Figure 3. Storage areas are provided for each of eighty formulas produced and are designated by numbers according to their volume of movement. Number 1 is the greatest volume, number 2 is next largest, and so on. The areas were laid out on the basis of annual movement figures. Letters refer to aisle areas. Racks are provided along aisles D, E, and F to accommodate pallets of low volume formulas 33 through 80.

Tables 5, 6, 7, and 8 show the distances involved in each of the movement routes and the times, in man-hours, required for a round trip.

Description of Jobs Involved

In programming the operations of a cost-center, it is necessary to compile a complete list of job descriptions that define the work performed in the area. The following job descriptions have been advanced by the feed industry as the labor that is necessary to conduct the operations of the warehouse.

Job Functions of Warehouse Leadman

Planning Duties: Schedule the activities of the loading crew to conform with the production schedule.

Supervisory Duties: Supervise and coordinate the activities of the Warehouse Fork Truck Operator and the loading crew. The Warehouse Leadman is responsible for the

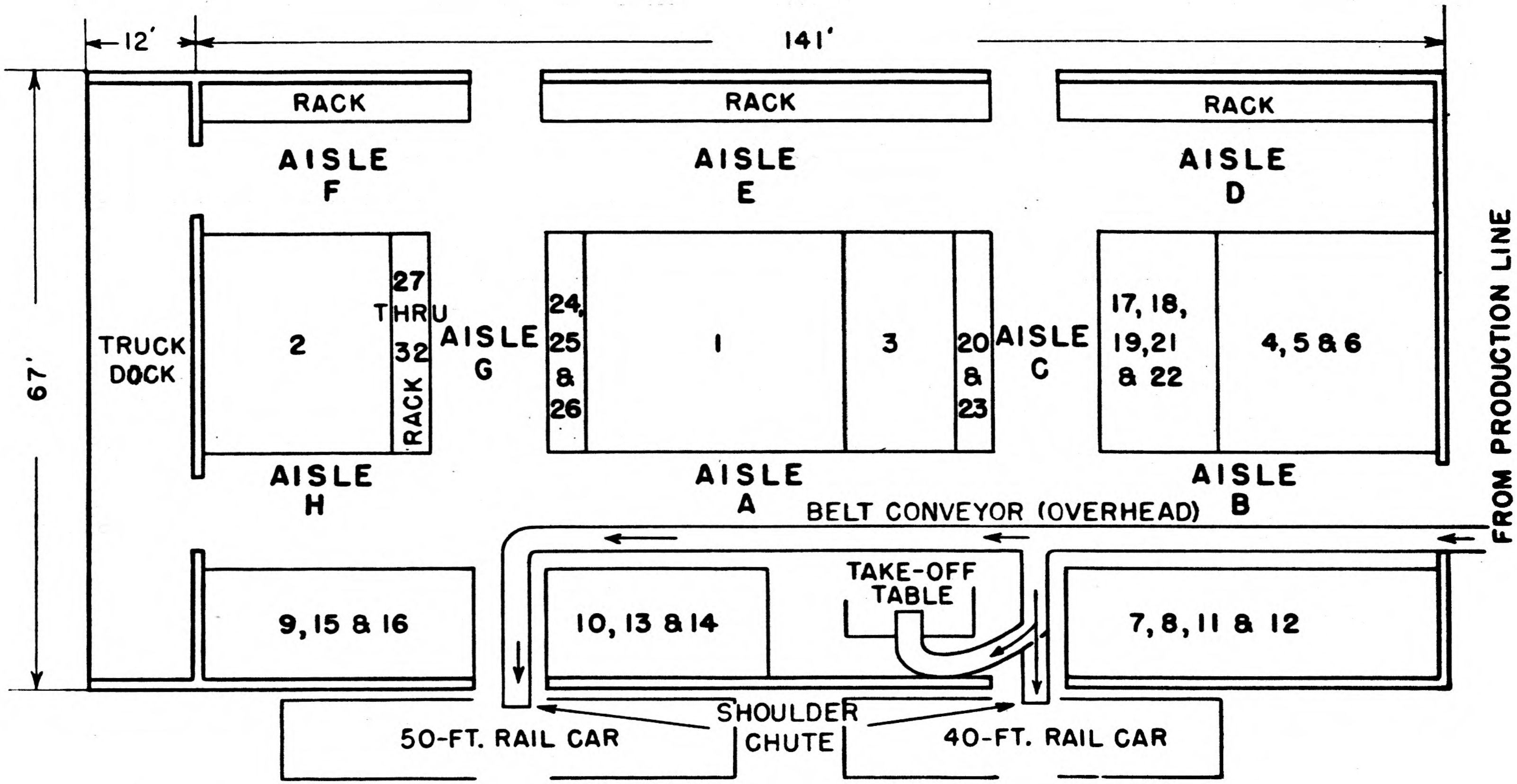

Fig. 3.--Model warehouse layout[a]

[a]Source: U. S. Department of Agriculture, "Formula-Feed Warehousing Costs," Marketing Research Report 268, 1958, p. 6.

TABLE 5

DISTANCES AND TIMES PER ROUND TRIP BETWEEN WAREHOUSE AREAS AND TAKE-OFF TABLE[a]

Warehouse Area	No. of Feet From Take-Off Table	Time per Round Trip by Forklift Truck[b]	Time per Round Trip by Hand Truck[c]
A	34	0.00544	0.00544
B	50	0.00800	0.00800
C	44	0.00704	0.00704
D	88	0.01056	0.01408
E	94	0.01128	0.01504
F	114	0.01140	0.01824
G	78	0.00936	0.01248
H	76	0.00912	0.01216

[a]Calculated from: Midwest Feed Manufacturers' Association, Proceedings of the 1957 Midwest Feed Production School, pp. 70-71, 107.

[b]Man-hours per 2000 pound load.

[c]Man-hours per 500 pound load.

loading and unloading of all bagged ingredients, bagged feeds, and bulk feeds.

Operating Duties:

1. Spot rail cars and trucks at the proper loading doors.
2. Inspect all rail cars and trucks before loading for cleanliness, damage, contamination, or insect infestation.
3. Make up loading and unloading schedule for your crew.
4. Inspect loaded trucks and rail cars for the proper loading of the proper products.

TABLE 6

DISTANCES AND TIMES PER ROUND TRIP BETWEEN WAREHOUSE AREAS AND TRUCK DOCK[a]

Warehouse Area	No. of Feet From Truck Dock	Time per Round Trip by Forklift Truck[b]	Time per Round Trip by Hand Truck[c]
A	88	0.01056	0.01408
B	150	0.01500	0.02400
C	136	0.01360	0.02176
D	150	0.01500	0.02400
E	88	0.01056	0.01408
F	45	0.00720	0.00720
G	75	0.00900	0.01200
H	45	0.00720	0.00720

[a]Calculated from: Midwest Feed Manufacturers' Association, Proceedings of the 1957 Midwest Feed Production School, pp. 70-71, 107.

[b]Man-hours per 2000 pound load.

[c]Man-hours per 500 pound load.

5. Receive the incoming shipments and sign bills of lading after the shipment is unloaded. Report any product damage or shortage to the Process Foreman.

6. Instruct the Warehouse Fork Truck Operator as to the placement of incoming ingredients in the warehouse.

Quality Duties:

1. Inspect bagged finished feed for the proper bags, tags, obvious overweight or underweight, or any unusual odor.

TABLE 7

DISTANCES AND TIMES PER ROUND TRIP BETWEEN WAREHOUSE AREAS AND RAIL CAR NUMBER 1[a]

Warehouse Area	No. of Feet From Car No. 1	Time per Round Trip by Forklift Truck[b]	Time per Round Trip by Hand Truck[c]
A	50	0.00800	0.00800
B	110	0.01100	0.01760
C	100	0.01200	0.01600
D	148	0.01480	0.02368
E	96	0.01152	0.01536
F	80	0.00960	0.01280
G	46	0.00736	0.00736
H	42	0.00672	0.00672

[a]Calculated from: Midwest Feed Manufacturers' Association, Proceedings of the 1957 Midwest Feed Production School, pp. 70-71, 107.

[b]Man-hours per 2000 pound load.

[c]Man-hours per 500 pound load.

2. Sample the incoming bagged ingredients according to the established quality control procedure. Deliver samples to the Process Foreman.

Housekeeping Duties:

1. Maintain a clean orderly warehouse by scheduling the loading crews time to allow regular sweeping of the area.
2. Instruct the loading crew to clean out every rail car and truck before loading.

Safety Duties:

1. Make certain that your loading crew conducts their work in a manner consistent with good safety practices.

TABLE 8

DISTANCES AND TIMES PER ROUND TRIP BETWEEN WAREHOUSE AREAS AND RAIL CAR NUMBER 2[a]

Warehouse Area	No. of Feet From Car No. 2	Time per Round Trip by Forklift Truck[b]	Time per Round Trip by Hand Truck[c]
A	50	0.00800	0.00800
B	42	0.00672	0.00672
C	46	0.00736	0.00768
D	80	0.00960	0.01280
E	96	0.01152	0.01536
F	148	0.01480	0.02368
G	100	0.01200	0.01600
H	110	0.01100	0.01760

[a]Calculated from: Midwest Feed Manufacturers' Association, Proceedings of the 1957 Midwest Feed Production School, pp. 70-71, 107.

[b]Man-hours per 2000 pound load.

[c]Man-hours per 500 pound load.

2. Enforce the plant safety rules in your warehouse whether the violator is an employee or not.

Training Duties:

1. Instruct the loading crew as to the proper way to load, unload, and clean rail cars and trucks.
2. Instruct the Warehouse Fork Truck Operator as to:
   a. The proper operation of the fork truck.
   b. The proper way to warehouse the various products.

Reporting and Clerical Duties:

1. Fill out loading sheets for the loading crew showing the order in which they are to load or unload.
2. Fill out receiving and quality reports on incoming bagged ingredients.
3. Take the bagged ingredients and finished feed inventory at the required intervals.

Miscellaneous Duties: Perform any and all other jobs as assigned by the Process Foreman.[18]

Job Functions of Pallet Loader

Operating Duties:

1. Load pallets with bagged feed in a neat stack with the correct number of bags per pallet.
2. Request empty pallets from the Lift Operator.
3. Check weigh one bag per pallet on the scale provided.
4. Maintain a supply of empty bags, string, and filler cord for the Packer Operator.

Quality Duties: Inspect the bags of feed for the proper bag, tag, and weight. Report any discrepancies to Process Foreman.

Maintenance Duties: Assist the Packer Operator with the maintenance of the packer and sewing machine.

Housekeeping Duties:

1. Load only clean, repaired pallets.
2. Sweep and pick up sweeping when spillage occurs.
3. Return broken bags to Mixer Operator for reblending into the same run.
4. Sweep and pick up sweepings in entire area at least twice per shift.
5. Assist the Packer Operator in cleaning the added fat applicator and the molasses blender.

Safety Duties:

1. Lift the bags in a manner consistent with good safety practices.

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[18] *Ibid*., pp. 165-166.

2. Keep your work area free of part bags, pallets, and piles of sweepings.

Reporting and Clerical Duties:

1. Report the number of bags loaded in each run.
2. Record the weights of bags you check weighed.

Miscellaneous Duties: Perform any and all other jobs assigned by the Process Foreman.[19]

Job Functions of Warehouse Forklift Truck Operator

Planning Duties: Follow loading and unloading schedule provided by the Warehouse Leadman. Schedule trips to and from the warehouse to keep the loading crew supplied with bagged feed or the unloading crew supplied with empty pallets.

Operating Duties:

1. Haul loaded pallets of bagged ingredients from the rail car or truck and stack neatly in the ingredient warehouse. In doing this:
   a. Maintain a supply of pallets for the unloading crew.
   b. Warehouse the loaded pallets in straight rows in the proper area being careful not to damage the product. Never put ingredients from one shipment in front of ingredients from a prior shipment.
   c. Warehouse only one ingredient per row.
2. Supply the loading crew with the proper finished bagged feed according to your loading schedule. In doing this:
   a. Use the finished feed on a first-in, first-out basis.
   b. Replace part pallets of feed in the warehouse in the proper place.
   c. Sort empty pallets and put damaged pallets in the pallet repair pile.

Quality Duties:

1. Check the finished feed bags for correct tags, bags, obvious overweight or underweight and report discrepancies to the Process Foreman.

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[19] Ibid., p. 164.

2. Inspect the warehouse for rodent damage, insect infestation and unusual odors, report your observations to the Process Foreman.

Maintenance Duties: Perform preventive maintenance on your fork truck at the beginning of work shift according to the manufacturers recommendations. In accordance with this:

1. Check oil level, water (antifreeze) level, and brakes.
2. Check for leaks in the hydraulic system, transmission, lift, unusual noises, etc., and report your findings in writing to the Process Foreman.

Machine Care Duties: Operate the fork truck in accordance with the manufacturers recommendations as to speed, lift height, transmission shifting, load capacity, and any other operating limitations.

Housekeeping Duties: Maintain a clean and orderly warehouse. In doing this:

1. Sweep and pick up sweepings in empty rows before refilling.
2. Clean up spillage when it occurs.
3. Restack any piles that lean or contain broken bags.

Safety Duties: Operate the fork truck in a manner consistent with good safety practices. Always:

1. Drive with the load lowered so vision is not obscured.
2. Drive at a slow speed; reduce speed at aisle intersections; sound horn at each corner.
3. Engage emergency brake whenever you leave the fork truck.
4. Fuel the fork truck outside in the prescribed location and carry your fire extinguisher with you.
5. Clean up any spilled oil or gasoline.

Reporting or Clerical Duties:

1. Report in writing any equipment problems.
2. Assist in taking the finished feed and ingredients inventory in the warehouse.

Miscellaneous: Perform any and all other jobs assigned by the Process Foreman.[20]

Job Functions of General Labor

Planning Duties: Follow unloading and loading schedule developed by the Warehouse Leadman.

Operating Duties:

1. Load and unload rail cars and trucks. Make sure you:
   a. Clean every rail car or truck before loading.
   b. Handle the bags so as not to tear or damage them.
   c. Stack the bags so they won't be damaged in transit.
   d. Load only bags in good condition; never load torn or dirty bags.
   e. Have the rail car or truck checked by the Warehouse Leadman when the shipment is loaded.
2. Assist in the loading and unloading of bulk shipments.

Quality Duties: Inspect the bags you are loading for the proper tag on the proper bag, improper weights, sour odor, damaged bags, etc. Report anything unusual to the Warehouse Leadman.

Housekeeping Duties:

1. Sweep the warehouse as required by the Warehouse Leadman.
2. Sweep up spilled product as it occurs and deposit it in the proper, labeled containers.

Safety Duties: Lift the bags in a manner consistent with good safety practices.

Miscellaneous: Perform any and all other jobs assigned by the Warehouse Leadman or the Process Foreman.[21]

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[20] *Ibid.*, p. 166.

[21] *Ibid.*

Description of Alternative Handling Methods

Forklift Truck Handling Method

In this system, finished feeds are primarily transported by means of a mechanized, four-wheel fork truck. The truck may be either gasoline, diesel fuel, or battery powered. It is equipped on the front with two metal arms that can be raised and lowered in order to place or remove a load from a stack. The load consists of a unit including the feed bags and a supporting pallet. Normally the pallets are loaded with one ton lots of feed.

One man loads the bags onto the pallet at the take-off table, then the truck operator drives to the required destination and places the pallet onto a stack. Pallets can be easily stacked two high. When moving a load from the warehouse, the truck operator will position the truck arms then drive under the pallet. The pallet is raised several inches in order to clear the stack then the operator will back away and drive to the desired loading dock.

This handling method greatly reduces the amount of transportation time as compared with the hand truck method since a larger load is involved. However, the equipment cost per ton far exceeds that of the hand truck.

Two-Wheel Hand Truck Handling Method

This method utilizes hand trucks as the principal means of transporting finished feeds from the take-off table to either the storage areas or the loading docks.

The worker loads his truck with a 500 pound load at the take-off table then proceeds to the predetermined destination. Upon arrival at the appropriate area, the worker may perform an operation called "bucking the load." This means he simply stops his forward movement and pushes ahead on the truck handles thereby unloading the sacks to a stack in one movement. If conditions prevent doing this, the worker must place the bags one at a time by hand onto a stack. He then returns to the take-off table and obtains another load. The procedure is very similar when moving from a warehouse area to one of the loading docks except that the worker might be able to "stick a load." This refers to the operation whereby an entire stack can be picked up by forcing the hand truck under the pile and pulling back on the handles.

Since all transportation is done by hand, a large amount of labor is required for travel purposes and constitutes a major portion of the costs incurred by this system. One advantage of the system is its high degree of flexibility. Any spot in the warehouse is easily accessible to a worker with a hand truck. Since this system does not involve any complex machinery, repair and maintenance allowances are negligible.

<u>Belt Conveyor Handling Method</u>

With the increased use of automation in all types of manufacturing operations, it is not surprising that much use has been made of belt conveyors to handle bagged feeds.

Several types of conveyors; such as the flat-bed conveyor, sliding-belt conveyor, and the trough-belt conveyor, are available for handling bagged feeds.

A conveyor is installed the length of the warehouse to move bags along each of the various warehouse storage areas and to the loading docks. This belt should be reversible in direction in order to facilitate moving to and from storage. A cross belt is used to transport bags along the entire length of the truck dock. Slide chutes are used to transfer bags from the belt to each of the rail car loading areas. A movable sweep is used to divert bags from the belt at a given warehouse storage area and the bags are then placed on a stack by hand.

The use of this handling method requires a supplementary method in order to move bags to distant storage areas in the warehouse. Normally, a hand truck will be relied upon for this operation.

Determination of Programming Components

As will be explained later, a linear programming problem is composed of a set of variables or activities which are subject to certain restrictions. The following discussion explains the various problem components.

Activities

The warehouse operations consist of moving finished feed tonnages along three different movement routes by each of the three alternative handling methods already described. These operations form the basis for the nine real activities considered in this analysis. The activities are:

Production to warehouse by forklift truck
Production to warehouse by hand truck
Production to warehouse by belt conveyor
Warehouse to trucks by forklift truck
Warehouse to trucks by hand truck
Warehouse to trucks by belt conveyor
Warehouse to rail cars by forklift truck
Warehouse to rail cars by hand truck
Warehouse to rail cars by belt conveyor.

Restrictions

The restrictions are the totals of tonnages that are to be transported over the various movement routes in accordance with the original warehouse study. The problem states that seventy-five tons be moved from production to the warehouse, fifty tons be moved from the warehouse to trucks, and twenty-five tons be moved from storage areas to rail cars.

Costs

Both direct labor costs and equipment costs are included in the analysis. Only direct labor was considered since it was felt that indirect and supervision labor would be relatively constant for the various handling methods.

Time allowances for labor were computed from the feed industry's Table of Standard Times and are discussed in the next section. These times were then weighted to include delay and idle time. It was believed that this would give a more realistic picture of the labor costs for each handling method. The weights that were used are the respective proportion of workers' time spent in idleness and delays for each handling system.[22]

Computation of Labor Requirements

As was stated earlier, worker time was calculated from the industry's Table of Standard Times.[23] The Tables were published by the Midwest Feed Manufacturers' Association and are based on time study observations at several selected mills in the Midwest. They represent time values for each operational element in a feed mill warehouse.

Labor was first divided into three categories: bag handling, pallet handling, and travel. The various operational elements comprising the first two categories were multiplied by the respective number of times each occurred during the handling of the required number of tons. These element totals were multiplied by their standard times to obtain the worker man-hours. Travel time was computed by multiplying the percentage of total trips, given in the warehouse specifications, by the total number of round trips required in the movement route. This product is then multiplied by the time per round trip to yield the total trip time in man-hours. Travel time computations are shown in Tables 9 and 10.

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[22] Askew, Vosloh, and Brensike, Case Study of Labor Costs and Efficiencies in Warehousing Formula Feeds, p. 20.

[23] Midwest Feed Manufacturers' Association, Proceedings of the 1957 Midwest Feed Production School, pp. 68-79.

TABLE 9

COMPUTATION OF FORKLIFT TRUCK TRAVEL TIME

Warehouse Area	Percent of Total Trips	Total Number of Round Trips	Time Per Round Trip	Total Trip Time in Man-Hours
		Production To Warehouse - 75 Ton		
A	32.52	24.3	.00544	.1322
B	30.04	22.5	.00800	.1800
C	5.28	4.0	.00704	.0282
D	3.52	2.7	.01056	.0285
E	2.36	1.8	.01128	.0203
F	2.36	1.8	.01140	.0205
G	5.04	3.8	.00936	.0356
H	18.88	14.1	.00912	.1288
Total	100.00	75.0	--	.5741
		Warehouse To Trucks - 50 Ton		
A	32.52	16.3	.01056	.1720
B	30.04	15.0	.01500	.2250
C	5.28	2.6	.01360	.0354
D	3.52	1.7	.01500	.0255
E	2.36	1.2	.01056	.0127
F	2.36	1.2	.00720	.0087
G	5.04	2.5	.00900	.0225
H	18.88	9.5	.00720	.0684
Total	100.00	50.0	--	.5702

TABLE 9--Continued

Warehouse Area	Percent of Total Trips	Total Number of Round Trips	Time Per Round Trip	Total Trip Time in Man-Hours
Warehouse to Rail Car Number 1 - 12.5 Ton				
A	32.52	4.2	.00800	.0336
B	30.04	3.9	.01100	.0429
C	5.28	0.7	.01200	.0084
D	3.52	0.5	.01480	.0074
E	2.36	0.3	.01152	.0035
F	2.36	0.3	.00960	.0029
G	5.04	0.6	.00736	.0043
H	18.88	2.5	.00672	.0168
Total	100.00	13.0	--	.1198
Warehouse to Rail Car Number 2 - 12.5 Ton				
A	32.52	4.2	.00800	.0336
B	30.04	3.9	.00672	.0262
C	5.28	0.7	.00736	.0052
D	3.52	0.5	.00960	.0048
E	2.36	0.3	.01152	.0035
F	2.36	0.3	.01480	.0045
G	5.04	0.6	.01200	.0072
H	18.88	2.5	.01100	.0275
Total	100.00	13.0	--	.1125

TABLE 10

COMPUTATION OF HAND TRUCK TRAVEL TIME

Warehouse Area	Percent of Total Trips	Total Number of Round Trips	Time Per Round Trip	Total Trip Time in Man-Hours
		Production to Warehouse - 75 Ton		
A	32.52	97.56	.00544	.5307
B	30.04	90.12	.00800	.7210
C	5.28	15.84	.00704	.1115
D	3.52	10.56	.01408	.1487
E	2.36	7.08	.01504	.1065
F	2.36	7.08	.01824	.1291
G	5.04	15.12	.01248	.1887
H	18.88	56.64	.01216	.6887
Total	100.00	300.00	--	2.6249
		Warehouse to Trucks - 50 Ton		
A	32.52	65.04	.01408	.9158
B	30.04	60.08	.02400	1.4419
C	5.28	10.56	.02176	.2298
D	3.52	7.04	.02400	.1690
E	2.36	4.72	.01408	.0664
F	2.36	4.72	.00720	.0340
G	5.04	10.08	.01200	.1210
H	18.88	37.76	.00720	.2719
Total	100.00	200.00	--	3.2498

TABLE 10--Continued

Warehouse Area	Percent of Total Trips	Total Number of Round Trips	Time Per Round Trip	Total Trip Time in Man-Hours
Warehouse to Rail Car Number 1 - 12.5 Ton				
A	32.52	16.26	.00800	.1301
B	30.04	15.02	.01760	.2644
C	5.28	2.64	.01600	.0422
D	3.52	1.76	.02368	.0417
E	2.36	1.18	.01536	.0181
F	2.36	1.18	.01280	.0151
G	5.04	2.52	.00736	.0185
H	18.88	9.44	.00672	.0634
Total	100.00	50.00	--	.5935
Warehouse to Rail Car Number 2 - 12.5 Ton				
A	32.52	16.26	.00800	.1301
B	30.04	15.02	.00672	.1009
C	5.28	2.64	.00768	.0203
D	3.52	1.76	.01280	.0225
E	2.36	1.18	.01536	.0181
F	2.36	1.18	.02368	.0279
G	5.04	2.52	.01600	.0403
H	18.88	9.44	.01760	.1661
Total	100.00	50.00	--	.5262

The totals of the three work categories for each handling method were weighted by the respective idle and delay time percentage. This total was then divided by the tonnage involved in order to put the work on a per ton basis. These computations are shown in Tables 11, 12, and 13.

The above procedure was followed to calculate the labor requirements in each of the three basic movement routes by each of the three handling systems. The labor cost per ton for each of the nine real activities of the warehouse problem is shown in Table 14.

In order for a mill manager to make comparable calculations for his warehouse it would be necessary to conduct a work sampling analysis.[24] Work sampling is a statistical procedure based on the laws of probability. It may be used to determine the percentage of time that a worker is involved in a particular work operation by observing the worker at random over a period of time. If ten hours of the worker's time is included in the study and it is determined that 10 percent of his time is spent driving a forklift truck; the conclusion may be made that he has spent one hour in the work category, travel.

After observing each of the warehouse workers, the manager would be able to compute the time required per ton and the labor cost per ton. This would complete his sampling analysis.

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[24]Ralph M. Barnes, Work Sampling (Dubuque, Iowa: Wm. C. Brown Company, 1956).

TABLE 11

FORKLIFT TRUCK LABOR COST PER TON BY MOVEMENT ROUTE

Line No.	Work Category	Man-Hours	Idleness and Delay Adjustment	Total Man-Hours
		Production to Warehouse - 75 Ton		
1	Travel	.5741	1.252	.7188
2	Pallet Handling	1.2075	1.252	1.5118
3	Bag Handling	2.5500	1.252	3.1926
4		Total Man-Hours - - - - - - - - -		5.4232
5		Total Tons Handled - - - - - - -		75
6		Man-Hours Per Ton (Line 4 ÷ Line 5) - - - - - - -		.0723
7		Wage Rate Per Hour - - - - - - -		$2.00
8		Labor Cost Per Ton (Line 6 X Line 7) - - - - - - -		$.1446
		Warehouse to Trucks - 50 Ton		
1	Travel	.5702	1.252	.7139
2	Pallet Handling	.6600	1.252	.8263
3	Bag Handling	3.0000	1.252	3.7560
4		Total Man-Hours - - - - - - - - -		5.2962
5		Total Tons Handled - - - - - - -		50
6		Man-Hours Per Ton (Line 4 ÷ Line 5) - - - - - - -		.1059
7		Wage Rate Per Hour - - - - - - -		$2.00
8		Labor Cost Per Ton (Line 6 X Line 7) - - - - - - -		$.2118
		Warehouse to Rail Cars - 25 Tons		
1	Travel	.2323	1.252	.2908
2	Pallet Handling	.4750	1.252	.5947
3	Bag Handling	1.5000	1.252	1.8780
4		Total Man-Hours - - - - - - - - -		2.7635
5		Total Tons Handled - - - - - - -		25
6		Man-Hours Per Ton (Line 4 ÷ Line 5) - - - - - - -		.1105
7		Wage Rate Per Hour - - - - - - -		$2.00
8		Labor Cost Per Ton (Line 6 X Line 7) - - - - - - -		$.2210

TABLE 12

HAND TRUCK LABOR COST PER TON BY MOVEMENT ROUTE

Line No.	Work Category	Man-Hours	Idleness and Delay Adjustment	Total Man-Hours
		Production to Warehouse - 75 Ton		
1	Travel	2.6249	1.269	3.3310
2	Truck Handling	2.1030	1.269	2.6687
3	Bag Handling	4.1700	1.269	5.2917
4		Total Man-Hours		11.2914
5		Total Tons Handled		75
6		Man-Hours Per Ton (Line 4 ÷ Line 5)		.1506
7		Wage Rate Per Hour		$2.00
8		Labor Cost Per Ton (Line 6 X Line 7)		$.3012
		Warehouse to Trucks - 50 Ton		
1	Travel	3.2498	1.269	4.1240
2	Truck Handling	1.4020	1.269	1.7791
3	Bag Handling	3.4400	1.269	4.3654
4		Total Man-Hours		10.2685
5		Total Tons Handled		50
6		Man-Hours Per Ton (Line 4 ÷ Line 5)		.2054
7		Wage Rate Per Hour		$2.00
8		Labor Cost Per Ton (Line 6 X Line 7)		$.4108
		Warehouse to Rail Cars - 25 Ton		
1	Travel	1.1197	1.269	1.4209
2	Truck Handling	.7590	1.269	.9632
3	Bag Handling	1.0000	1.269	1.2690
4		Total Man-Hours		3.6531
5		Total Tons Handled		25
6		Man-Hours Per Ton (Line 4 ÷ Line 5)		.1461
7		Wage Rate Per Hour		$2.00
8		Labor Cost Per Ton (Line 6 X Line 7)		$.2922

TABLE 13

BELT CONVEYOR LABOR COST PER TON BY MOVEMENT ROUTE

Line No.	Work Category	Man-Hours	Idleness and Delay Adjustment	Total Man-Hours
		Production to Warehouse - 75 Ton		
1	Travel	.6562	1.359	.8918
2	Bag Handling	4.7625	1.359	6.4722
3		Total Man-Hours		7.3640
4		Total Tons Handled		75
5		Man-Hours Per Ton (Line 3 ÷ Line 4)		.0982
6		Wage Rate Per Hour		$2.00
7		Labor Cost Per Ton (Line 5 X Line 6)		$.1964
		Warehouse to Trucks - 50 Ton		
1	Travel	.8124	1.359	1.1040
2	Bag Handling	3.3400	1.359	4.5391
3		Total Man-Hours		5.6431
4		Total Tons Handled		50
5		Man-Hours Per Ton (Line 3 ÷ Line 4)		.1129
6		Wage Rate Per Hour		$2.00
7		Labor Cost Per Ton (Line 5 X Line 6)		$.2258
		Warehouse to Rail Cars - 25 Ton		
1	Travel	.2799	1.359	.3804
2	Bag Handling	1.4900	1.359	2.0249
3		Total Man-Hours		2.4053
4		Total Tons Handled		25
5		Man-Hours Per Ton (Line 3 ÷ Line 4)		.0962
6		Wage Rate Per Hour		$2.00
7		Labor Cost Per Ton (Line 5 X Line 6)		$.1924

TABLE 14

SUMMARY OF LABOR COST PER TON BY HANDLING METHOD ACCORDING TO MOVEMENT ROUTE

	Forklift Truck	Two-wheel Hand Truck	Belt Conveyor
Production to Warehouse	\$.1446	\$.3012	\$.1964
Warehouse to Trucks	\$.2118	\$.4108	\$.2258
Warehouse to Rail Cars	\$.2210	\$.2922	\$.1924

Computation of Equipment Requirements

Data on equipment requirements and costs were supplied by equipment manufacturers and engineering consultants.[25]

This study relied on the judgment of the consultants as to what equipment was necessary and its total cost. These total cost figures were then prorated by the straight-line method over the engineering estimates of equipment life. This yearly cost figure was then divided by the yearly tonnage handled to obtain the equipment cost per ton for each of the handling methods. These costs are shown in Table 15 and the computations appear in Tables 16, 17, and 18.

It was necessary to contact equipment manufacturers since data is needed for all three types of handling systems. A mill manager would have access to cost data for equipment which is currently in use in his warehouse; however, he must depend on a consultant to supply data for the other equipment

[25]Interviews with Sam Gibbons, Sales Representative, Lift Truck Sales and Service, Inc., October, 1962, and Earl E. Welborn, Sales Engineer, Universal, Inc., January, 1963.

TABLE 15

SUMMARY OF HANDLING COST PER TON BY HANDLING METHOD ACCORDING TO MOVEMENT ROUTE

Item	Forklift Truck	Two-Wheel Hand Truck	Belt Conveyor
	Production to Warehouse		
Labor	$.1446	$.3012	$.1964
Equipment	$.0580	$.0020	$.0924
Total	$.2026	$.3032	$.2888
	Warehouse to Trucks		
Labor	$.2118	$.4108	$.2258
Equipment	$.0580	$.0020	$.0924
Total	$.2698	$.4128	$.3182
	Warehouse to Rail Cars		
Labor	$.2210	$.2922	$.1924
Equipment	$.0580	$.0020	$.0924
Total	$.2790	$.2942	$.2848

involved. He would, therefore, follow the same procedure used by this writer in obtaining data on alternative systems.

Assumptions and Limitations

This study utilizes an industry warehouse model for its analysis. Since the primary objective is to present a procedure for conducting the analysis, the study is necessarily limited to accepting the warehouse design and storage location as was originally presented. Therefore, the study does

TABLE 16

FORKLIFT TRUCK EQUIPMENT COST PER TON

Line No.	Item	Cost	
	Forklift Truck		
1	Purchase Price (2 trucks) - - - - - - - - -	$11,800	
2	Salvage Value (15%) - - - - - - - - - - - - -	1,770	
3	Depreciable Value - - - - - - - - - - - - - -	$10,030	
4	Estimated Life (years) - - - - - - - - - -	8	
5	Annual Depreciable Value (Line 3 ÷ Line 4)	$ 1,253.75	
6	Total Tons Handled Annually - - - - - - - -	39,000	
7	Truck Cost Per Ton (Line 5 ÷ Line 6) - -		$.0321
	Truck Repair and Maintenance		
1	Charge Per Day - - - - - - - - - - - - - - -	$ .80	
2	Total Tons Handled Daily - - - - - - - - -	150	
3	Repair and Maintenance Cost Per Ton (Line 1 ÷ Line 2) - - - - - - - - - - - - -		.0053
	Truck Battery		
1	Purchase Price (2 batteries) - - - - - - -	$ 2,660	
2	Salvage Value (5%) - - - - - - - - - - - - -	133	
3	Depreciable Value - - - - - - - - - - - - - -	$ 2,527	
4	Estimated Life (years) - - - - - - - - - -	8	
5	Annual Depreciable Value (Line 3 ÷ Line 4)	316	
6	Total Tons Handled Annually - - - - - - - -	39,000	
7	Battery Cost Per Ton (Line 5 ÷ Line 6) -	$	.0081

TABLE 16--Continued

Line No.	Item	Cost
	Battery Charger	
1	Purchase Price - - - - - - - - - - - - - - -	$ 645
2	Salvage Value (5%) - - - - - - - - - - - - -	32.25
3	Depreciable Value - - - - - - - - - - - - - -	$ 612.75
4	Estimated Life (years) - - - - - - - - - - -	15
5	Annual Depreciable Value (Line 3 ÷ Line 4)	$ 40.85
6	Total Tons Handled Annually - - - - - - - -	39,000
7	Charger Cost Per Ton (Line 5 ÷ Line 6) -	$ .0010
	Pallet Cost	
1	Purchase Price (780 pallets) - - - - - - -	$ 1,755
2	Estimated Life (years) - - - - - - - - - -	5
3	Annual Depreciable Value (Line 1 ÷ Line 2)	$ 351
4	Total Tons Handled Annually - - - - - - - -	39,000
5	Pallet Cost Per Ton (Line 3 ÷ Line 4) - -	$ .0090
	Pallet Maintenance	
1	Maintenance Charge Per Ton (10% pallet cost) - - - - - - - - - - - - -	$ .0009
	Interest Cost on Investment	
1	Total Annual Investment - - - - - - - - - - -	$ 1,961.60
2	Interest Rate (3%) - - - - - - - - - - - - -	$ 58.85
3	Total Tons Handled Annually - - - - - - - -	39,000
4	Interest Cost Per Ton (Line 2 ÷ Line 3) -	$ .0016

not imply that this is the best possible design for the warehouse in question.

A production period of 260 days per year is assumed for purposes of this analysis.

The wage rate is not intended to represent an industry average.

TABLE 17

TWO-WHEEL HAND TRUCK EQUIPMENT COST PER TON

Line No.	Item	Cost
	Hand Truck	
1	Purchase Price (10 trucks) - - - - - - - -	$ 500
2	Salvage Value (10%) - - - - - - - - - - - - -	50
3	Depreciable Value - - - - - - - - - - - - - - -	$ 450
4	Estimated Life (years) - - - - - - - - - -	5
5	Annual Depreciable Value (Line 3 ÷ Line 4)	$ 90
6	Total Tons Handled Annually - - - - - - - -	39,000
7	Truck Cost Per Ton (Line 5 ÷ Line 6) - -	$ .0020
	Interest Cost on Investment	
1	Total Annual Investment - - - - - - - - - -	$ 90
2	Interest Rate (3%) - - - - - - - - - - - - -	2.70
3	Total Tons Handled Annually - - - - - - - -	39,000
4	Interest Cost Per Ton (Line 2 ÷ Line 3) -	$ .00007
	(Negligible)	

TABLE 18

BELT CONVEYOR EQUIPMENT COST PER TON

Line No.	Item	Cost	
	Belt Conveyor		
1	Purchase Price - - - - - - - - - - - - - - -	$45,000	
2	Salvage Value - - - - - - - - - - - - - - - -	10,000	
3	Depreciable Value - - - - - - - - - - - - - -	$35,000	
4	Estimated Life (years) - - - - - - - - - -	10	
5	Annual Depreciable Value (Line 3 ÷ Line 4)	$ 3,500	
6	Total Tons Handled Annually - - - - - - - -	39,000	
7	Conveyor Cost Per Ton (Line 5 ÷ Line 6) -	$	.0897
	Interest Cost on Investment		
1	Total Annual Investment - - - - - - - - - - -	$ 3,500	
2	Interest Rate (3%) - - - - - - - - - - - - -	$ 105	
3	Total Tons Handled Annually - - - - - - - -	39,000	
4	Interest Cost Per Ton (Line 2 ÷ Line 3) -	$	.0027

CHAPTER III

The Linear Programming Problem

Mathematical Statement of the Problem[26]

In the formulation of a linear programming problem, the relationships between a set of variables are stated as a system of linear equations. The technique obtains a unique solution by considering simultaneously the equations which are subject to certain stated restrictions.

The problem being considered here is the desire to move certain quantities of feed to various areas of a warehouse. The feed may be moved by any one of three different handling methods. By considering the labor and equipment cost involved in each method, it is desired to determine the least-cost method of moving the required tonnage. Table 19 provides the necessary information for the warehouse problem.

Mathematically, the equations may be stated:

$$\sum_{\substack{i=1 \\ j=1}}^{3} a_{ij}\, x_{ij} = b_i$$

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[26] Many excellent references are available which explain the technique of linear programming. However, the author prefers one main reference:
Earl O. Heady and Wilfred Candler, Linear Programming Methods (Ames, Iowa: The Iowa State University Press, 1958).

where the a_{ij}'s are the coefficients which express the relationship between the activities x_{ij} and the restrictions, b_i. The notation "i" refers to a specific equation from the system of equations defining the problem. The "j" notation refers to one of the variables within that equation.

TABLE 19

BASIC DATA FOR SOLVING WAREHOUSE PROBLEM

	Unit	Requirement Level	Fork-lift Truck	Two-Wheel Hand Truck	Belt Conveyor
Production to Warehouse	Tons	75	1	1	1
Warehouse to Trucks	Tons	50	1	1	1
Warehouse to Rail Cars	Tons	25	1	1	1
Production to Warehouse Cost	$ Per Ton	--	.2026	.3032	.2888
Warehouse to Trucks Cost	$ Per Ton	--	.2698	.4128	.3182
Warehouse to Rail Cars Cost	$ Per Ton	--	.2790	.2942	.2848

Since the problem constraints are the three movement routes, the real activities are the operations of moving along these routes by each of the three handling methods. Mathematically, the real activities are denoted in the following manner:

x_1 = tons moved from production to warehouse by forklift truck

x_2 = tons moved from production to warehouse by hand truck

x_3 = tons moved from production to warehouse by belt conveyor

x_4 = tons moved from warehouse to trucks by forklift truck

(3.1) x_5 = tons moved from warehouse to trucks by hand truck

x_6 = tons moved from warehouse to trucks by belt conveyor

x_7 = tons moved from warehouse to rail cars by forklift truck

x_8 = tons moved from warehouse to rail cars by hand truck

x_9 = tons moved from warehouse to rail cars by belt conveyor.

In the formulation of the problem, the system of equations, which represent problem constraints, must first be defined. These equations, made up of variables termed activities, are stated as such:

$$
\begin{aligned}
& 1x_1 + 1x_2 + 1x_3 = 75 \\
(3.2) \quad & 1x_4 + 1x_5 + 1x_6 = 50 \\
& 1x_7 + 1x_8 + 1x_9 = 25
\end{aligned}
$$

The values in (3.2) are taken from Table 19. The first row may be read, "the quantity of feed moved from production to warehouse by forklift truck plus the quantity moved by hand truck plus the quantity moved by belt conveyor must equal seventy-five tons." A similar meaning may be placed on the other equations.

In order to give economic meaning to the solution, negative values are not allowed to enter into the solution. The condition that the answer must contain non-negative quantities is written:

$$(3.3)\quad \begin{array}{l} x_1 \geq o,\ x_2 \geq o,\ x_3 \geq o,\ x_4 \geq o,\ x_5 \geq o,\ x_6 \geq o,\ x_7 \geq o, \\ x_8 \geq o,\ x_9 \geq o \end{array}$$

When the system of equations is solved, it results in a set of values for x which will optimize the following objective function:

$$(3.4)\quad \sum_{j=1}^{9} c_j x_j$$

In this study c_j refers to the cost of an activity x_j and the objective is to minimize the function. This means that the total cost of performing the necessary operations is to be minimized.

The Simplex Method

The procedure used in this study to obtain the problem solution is termed the simplex method.[27] It is designed to find a feasible solution which will serve as a starting point from which an optimum solution is determined by a series of iterative calculations or tableaus.[28]

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[27] Ibid., pp. 53-108.

[28] In this problem a feasible solution is one that satisfies the set of requirements with non-negative values of the real activities.

In the formulation of a problem, a disposal activity is added to each equation in the set of equations which describe the problem. These disposal activities represent a nonfulfillment of their respective real activities and are used to form a diagonal row of 1's. The initial feasible solution is made up of this diagonal row rather than arbitrarily selecting a feasible solution of real activities. Since the diagonal row of 1's states that the solution is made up of disposal activities at levels equal to the problem requirements, the real activities are considered to be included at a zero level. From this initial situation, real activities are introduced until a condition of minimum cost is achieved that meets the set of requirements.

Artificial Activities

An artificial activity is a variable that is added to a constraint that either has no disposal activity or has a disposal activity with a minus coefficient. Since the equations in the constraint set (3.2) are equalities, no disposal activities exist in this problem. Therefore, artificial activities must be introduced in order to form the diagonal row of 1's for the starting point. The artificial has a positive coefficient for the restriction, meaning that it requires the use of the restriction.

When artificial variables are used, it is understood that they will not be allowed to enter into the final solution. This means that an optimum solution will not be obtained until after all artificial variables are eliminated. This is accomplished by assigning a large cost, termed a penalty cost, to the variable. The initial solution will be one of maximum possible cost since it is composed of the artificial activities. During successive solutions, real activities are introduced eliminating the artificials and reducing the total cost. This process continues until a least-cost or optimum solution is found. In this problem the artificial variables are denoted as Q_1, Q_2, and Q_3 in order to separate them from the real activities. The set of restrictions (3.2) is now rewritten:

$$\begin{aligned} &1x_1 + 1x_2 + 1x_3 + 1Q_1 = 75 \\ (3.5)\quad &1x_4 + 1x_5 + 1x_6 + 1Q_2 = 50 \\ &1x_7 + 1x_8 + 1x_9 + 1Q_3 = 25 \end{aligned}$$

The diagonal row of 1's is supplied by the coefficients of Q_1, Q_2, and Q_3. The non-negativity condition also applies to artificial variables, so (3.3) is now rewritten:

$$(3.6)\quad \begin{aligned} &x_1 \geq 0,\ x_2 \geq 0,\ x_3 \geq 0,\ x_4 \geq 0,\ x_5 \geq 0,\ x_6 \geq 0,\ x_7 \geq 0, \\ &x_8 \geq 0,\ x_9 \geq 0,\ Q_1 \geq 0,\ Q_2 \geq 0,\ Q_3 \geq 0 \end{aligned}$$

An obvious solution to the problem exists from (3.5). This solution is:

$$\begin{aligned} &Q_1 = 75,\ Q_2 = 50,\ Q_3 = 25,\ x_1 = x_2 = x_3 = x_4 = \\ &x_5 = x_6 = x_7 = x_8 = x_9 = 0 \end{aligned}$$

This initial solution is the one that appears in the initial section of the simplex table, Table 20.

TABLE 20

INITIAL SOLUTION SIMPLEX TABLE

		C_j →		M	M	M	.2026	.3032	.2888	.2698	.4128	.3182	.2790	.2942	.2848	
			Requirement Level	Artificial Activities			Real Activities									
			P_o	Q_1	Q_2	Q_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
Row	C_i ↓	Vector	1	2	3	4	5	6	7	8	9	10	11	12	13	R
1	M	← Q_1	75	1			1	1	1							75
2	M	Q_2	50		1					1	1	1				
3	M	Q_3	25			1							1	1	1	
4		Z $														
5		M	150	1	1	1	1	1	1	1	1	1	1	1	1	
6		Z-C$					-.2026	-.3032	-.2888	-.2698	-.4128	-.3182	-.2790	-.2942	-.2848	
7		M	150				1	1	1	1	1	1	1	1	1	

As was stated earlier, a penalty cost of M is assigned to each of the artificial variables. This cost is understood to be extremely large and is considered to be greater than any other numerical cost. (See Table 15 for Coefficients.) The penalty cost can now be added to the cost function (3.4) and is rewritten:

$$\text{(3.7)} \quad \begin{aligned} \text{Cost} = Z = & .2026\ x_1 + .3032\ x_2 + .2888\ x_3 + .2698\ x_4 \\ & + .4128\ x_5 + .3182\ x_6 + .2790\ x_7 + .2942\ x_8 + \\ & .2848\ x_9 + MQ_1 + MQ_2 + MQ_3 \quad \text{where } Z \text{ is a minimum.} \end{aligned}$$

The Simplex Table

Table 20 is the starting basis of the problem and from it is determined the initial solution. Data for the first three rows are obtained from Table 19. The c_i column represents the costs of the activities entered in the vector column. The problem requirements are placed in the P_o column. The costs for each of the activities, both artificial and real, are shown in the c_j row. The Z \$ and M rows represents the total cost in both units for performing the required operations. They also show the total costs for each activity. In the Z-C\$ and M rows are found the marginal costs for the same activities.

The succeeding solutions are derived from this initial section and are displayed in Tables 21, 22, and 23.

TABLE 21

SECOND SOLUTION SIMPLEX TABLE

		C_j →		M	M	M	.2026	.3032	.2888	.2698	.4128	.3182	.2790	.2942	.2848	
			Requirement Level	Artificial Activities			Real Activities									
			P_o	Q_1	Q_2	Q_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
Row	C_i ↓	Vector	1	2	3	4	5	6	7	8	9	10	11	12	13	R
1	.2026	→ P_1	75	1			1	1	1							
2	M	← Q_2	50		1					1	1	1				50
3	M	Q_3	25			1							1	1	1	
4		Z $	15.195	.2026			.2026	.2026	.2026							
5		M	75		1	1				1	1	1	1	1	1	
6		Z-C$	15.195	.2026				-.1006	-.0862	-.2698	-.4128	-.3182	-.2790	-.2942	-.2848	
7		M	75	-1						1	1	1	1	1	1	

TABLE 22

THIRD SOLUTION SIMPLEX TABLE

	$C_j \longrightarrow$			M	M	M	.2026	.3032	.2888	.2698	.4128	.3182	.2790	.2942	.2848	
			Requirement Level	Artificial Activities			Real Activities									
			P_o	Q_1	Q_2	Q_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
Row	$C_i \downarrow$	Vector	1	2	3	4	5	6	7	8	9	10	11	12	13	R
1	.2026	P_1	75	1			1	1	1							
2	.2698	$\longrightarrow P_4$	50		1					1	1	1				
3	M	$\longleftarrow Q_3$	25			1							1	1	1	25
4		Z $	28.685	.2026	.2698		.2026	.2026	.2026	.2698	.2698	.2698				
5		M	25			1							1	1	1	
6		Z-C$	28.685	.2026	.2698			-.1006	-.0826		-.1430	-.0484	-.2790	-.2942	-.2848	
7		M	25	-1	-1								1	1	1	

TABLE 23

FINAL SOLUTION SIMPLEX TABLE

		$C_j \longrightarrow$		M	M	M	.2026	.3032	.2888	.2698	.4128	.3182	.2790	.2942	.2848	
			Requirement Level	Artificial Activities			Real Activities									
Row	$C_i \downarrow$	Vector	P_o 1	Q_1 2	Q_2 3	Q_3 4	P_1 5	P_2 6	P_3 7	P_4 8	P_5 9	P_6 10	P_7 11	P_8 12	P_9 13	R
1	.2026	P_1	75	1			1	1	1							
2	.2698	P_4	50		1					1	1	1				
3	.2790	$\longrightarrow P_7$	25			1							1	1	1	
4		Z $	35.66	.2026	.2698	.2790	.2026	.2026	.2026	.2698	.2698	.2698	.2790	.2790	.2790	
5		M														
6		Z-C$	35.66	.2026	.2698	.2790		-.1006	-.0826		-.1433	-.0484		-.0152	-.0058	
7		M		-1	-1	-1										

Computation of the Simplex Solution

The values in the Z \$ and M rows are obtained by multiplying the cost in the c_i column by each of the values in the body of the table from that same row and summing for each column. This value is placed in the Z row that represents the same cost unit as the c_i cost. In Table 20, there are no \$ costs in the c_i column so row 4 remains blank. The value in row 5 column 2 is determined by multiplying each value in column 2 by the corresponding cost in column c_i and summing. Since column 2 has only one non-zero quantity, this quantity times its cost is then entered in the cell formed by row 5 column 2. If the cost had been \$ instead of M, it would have been entered in row 4. The value in row 6 column 5 is found by subtracting the cost in the c_j row from row 4. This value is the negative of c_j since there are no entries in row 4.

The above procedure is followed to determine each value for rows 4, 5, 6, and 7. Once this is done it is necessary to determine the master column and the master row for the next tableau.

The master column is found by selecting the most positive value to the right of the P_o column in row 7. Since the values are all equal to unity, choose the least negative value in row 6. The selection of this activity will lead to a decrease in the total cost found by (3.7). In Table 20, column 5 is the least negative and is the master column. The activity represented by this column will enter into the next tableau in place of the master row of the present tableau.

The master row is determined by dividing each non-zero number in the master column into its corresponding P_o value. This is done for rows 1, 2, and 3. The smallest value for this ratio represents the master row. Row 1 becomes the master row of tableau 1 and the activity which it represents will be replaced in the next tableau by the activity represented by the master column.

The headings for the next tableau are the same as in the original except that Q_1 in row 1 is replaced by P_1 as the result of the above computations. The values in this new row are determined by dividing each value in the old row by the value in the master column. Therefore, the value for row 1 column 2 is found by dividing the old row 1 by column 5 in the first tableau. In summary, the value for the new master row is found by dividing the old row value by the old row master column value.

The values for rows 2 and 3 are determined by a variation of this procedure. The procedure is: new master row value times old master column value for the desired new row, then subtract the quantity from the old row value for each column.

Rows 4, 5, 6, and 7 are computed by the same process as was followed for the original tableau. These procedures are continued until no activity has a positive Z-C M coefficient. When this point is reached, the artificial variables have all been eliminated from the solution and the costs are now all $ costs.

Since the desired objective of eliminating the artificial activities has been achieved, it is now necessary to find the least cost solution to the problem. This is done by continuing the above computational steps until there are no positive coefficients in the Z-C $ row for columns with zeros in the Z-C M row. When this occurs, there is no feasible way of reducing the dollar cost of the warehouse problem and the least-cost solution has been determined. Table 23 represents the optimum solution of the problem.

The Solution Tableau

The least cost solution of the warehouse problem can be read from the P_o column of the final tableau, Table 23. It states that seventy-five tons will be moved from production to the warehouse by forklift trucks; fifty tons will be moved from the warehouse to trucks by forklift; and twenty-five tons will be moved by forklift trucks to rail cars from the warehouse. These operations will be performed at a total cost of $35.66.

CHAPTER IV

Summary

Linear programming has made a notable contribution to the analysis of various business and industrial problems in recent years. At the same time, however, the technique has been shunned by many persons who felt that a broad knowledge of higher mathematics was necessary for its comprehension. This is a belief that could not be further from the truth.

This is not to say that everyone who reads a text on linear programming will be able to understand it completely at first glance. Nor will everyone be able to accurately formulate a complex problem, with many variables and restrictions, after obtaining a fundamental knowledge of the technique. On the other hand, many business managers are finding that linear programming is opening doors to new horizons in the business world.

Where decisions were once blocked by the burdensome and time consuming task of carefully weighing complicated factors, there now exists a means of swift analysis. Although specialists are available, a business executive can solve many situations by himself where he otherwise would have been forced to call for help. If a small, unsophisticated analysis resulted in the saving of a fraction of a cent per work-piece, it could mean a tremendous total saving for the company. Not all programming contributions are intricately designed studies. There is much value to be gained from a simple analysis.

This is the assumption around which this study is based. It presents a procedure for applying linear programming to a formula feed cost-center. The feed industry has utilized programming for many years to determine least-cost feed mixes. However, very little other application has been made in the industry. This study chose the warehouse cost-center for the purposes of its application.

The warehouse was chosen for several reasons. First, it represents an area made up of a limited number of operations. This meant that a simple and easily understood example was available for explaining the procedure and that the reader would not become confused with mathematical complexities. Secondly, the choice of the warehouse provided a considerable volume of data in the form of published material. Finally, it was desired to concentrate on a cost-center which could be formulated in such a manner that the answer would be obvious.

By referring to Table 15, it is easy to see that the forklift truck represents the lowest cost for each movement route. Therefore, the answer is obtained before the actual linear programming technique is applied and the solution to the problem is actually obtained by two different methods. This meant that the unfamiliar reader would be given the opportunity to appreciate the significance of the answer achieved by linear programming. Also, he would, possibly, more fully realize the potential of the technique in more complex problems.

The study attempted to set down the basic fundamentals which would be necessary for a mill manager to observe in order to apply linear programming to a cost-center in his plant. The procedure is not limited to the warehouse center. In fact, it may be applied to any other cost-center in the mill. Though the operations will vary with the cost-center, the procedure of application would remain the same.

It is important to keep in mind that this analysis has been conducted in the same manner as would be used if a feed manufacturer were to study his own warehouse operation. The only difference is that labor requirements were determined from a Table of Standard Times, whereas a manufacturer would need to utilize a work sampling analysis in his plant to determine the amount of labor that is required. Also, he would need to use his plant wage-rates in computing the labor costs. The study places emphasis on the costs incurred in a given operation at the present time in relation to the costs that would be incurred by alternative handling methods.

Suggestions for Future Study

One important aspect of warehousing that should be considered in a separate research project is the allotment of warehouse space to specific feed lines. Many times a manufacturer will stack the finished product in a certain place simply because that is where it was placed last year. Other times a partial effort may be undertaken to arrange feeds in order of their volume movement or turnover rate. However, even by relying on personal judgment and past experience, this can only be a partial effort at best.

Exactly where should the number one selling feed be placed? How much space should be alloted for each feed? What should be done with the available space when a feed line is discontinued? Is too large an expense being incurred by travel in the warehouse? Is there a more efficient arrangement possible? These are all questions which can be answered by linear programming.

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A PROCEDURE FOR APPLYING LINEAR PROGRAMMING TO THE FORMULA FEED WAREHOUSE COST-CENTER

by

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The formula feed industry is actively engaged in an attempt to reduce production costs in order to provide a more marketable product. While cost control programs are not unique to the feed industry, they are an important phase of management's responsibilities. In order to administer a cost control plan, a tool of analysis is needed on which business and industrial problems can be based. It is believed that linear programming is one such tool that would be useful in analyzing management situations.

Though linear programming has been extensively used during the past decade by the formula feed industry to formulate least-cost rations, little application has been made in the area of business operations. Research has shown that the technique is of value in maximizing a firm's profits by determining what feed formulas should be produced and the volume for each formula. This would indicate that other equally valuable applications exist where linear programming could be of service to management in the feed industry.

The purpose of this study was to demonstrate the procedure that could be used in applying linear programming to the formula feed industry's cost-center concept. A cost-center is interpreted as a natural cost area which exists in a feed manufacturing plant. This study utilized the warehouse cost-center for the purposes of its application.

The warehouse was chosen since studies have shown that labor is 69 percent of the total warehouse operating costs and that warehouse labor comprises 27 percent of the total mill labor expense. In addition, it was believed that a cost-center made up of few operations would be desirable in explaining the programming technique. After the procedure is understood, it would be possible to extend the application to other cost-centers within the plant.

The study attempted to analyze labor and equipment costs that would be encountered in fulfilling the work requirements of the warehouse. This was done for the handling method currently in use and for each alternative handling method.

Production and shipping requirements were used to determine the activities of the area. Job descriptions outlined the worker duties. Standard Times Tables and a work sampling analysis can be used to determine the man-hours per ton required by each handling method. Information on equipment requirements was obtained from equipment manufacturers and consultants.

The labor and equipment costs for each handling method were then incorporated into a simple linear programming example. The example was used to explain formulation and computation procedures. The discussion is also applicable to cost-centers other than the warehouse. These may be analyzed by making several minor adaptations of the analysis procedure.

The study makes use of industry recognized terms and definitions in an attempt to promote uniformity and to minimize the problems managers would encounter in making use of the study results. The standard definitions were applied to an industry model warehouse. The model warehouse is presented as being representative of a practical warehouse operation rather than as an ideal design.