HILGARDIA

A JOURNAL OF AGRICULTURAL SCIENCE PUBLISHED BY
THE CALIFORNIA AGRICULTURAL EXPERIMENT STATION

Volume 36, Number 4 • December, 1964

Size and Location Factors Affecting California's Beef Slaughtering Plants

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INTRODUCTION

CALIFORNIA RANKS second among the states in number of cattle slaughtered. In 1962, California registered a total cattle slaughter of 2,565,000 head, as against Iowa's 2,907,000 (U. S. Dept. of Agr., 1963).[2]

The number of slaughtering plants in California has declined over recent years; on March 1, 1960, there were 118 commercial slaughter plants in the state, but there were 131 in 1955. Despite the over-all decrease, the number of establishments slaughtering only cattle and calves increased from 22 to 26 during the same time period. Diversified plants slaughtering cattle, in addition to other species such as hogs or sheep, dropped from 109 to 91 (U. S. Agr. Mktg. Serv., 1960).

California has been a "deficit" state with regard to shipment of cattle and calves for some time. Total inshipments of cattle and calves in 1960 amounted to 1,885,000 head, of which 450,000 were for immediate slaughter. Some 56.2 per cent of the inshipments of slaughter cattle originated in Arizona, with the rest generally scattered among other western and Great Plains states. Texas is the largest single shipper of stocker and feeder cattle to California, with 496,000 head of the total 1,435,000 shipped in 1960 (Calif. Crop and Lvstk. Rptg. Serv., 1961).

The growth of specialized cattle slaughtering while over-all number of plants has decreased, plus the strong dependence on inshipments of live animals, makes the problems of optimum size and optimum location of slaughter plants particularly relevant to California. At present, the size and location of cattle slaughtering plants is highly varied. Daily kill rates vary from less than 25 to 450 head.

Approximately 50 per cent of the state's slaughter is centered in the Vernon area of Los Angeles County, but plants are scattered throughout the state. The present location pattern reflects decisions made over many years, and reasons for particular plant locations may no longer be valid. For example, plants were located near terminal markets receiving animal inshipments by rail. The increased use of truck transportation for live animals and for meat has contributed to the decline of central markets in California and elsewhere. Another change is the growth of concentrated feedlot areas. Thus, decisions as to new plant location would now

[1] Submitted for publication April 15, 1964.
[2] See "Literature Cited" for publications referred to in the text by author and date.

be based on a different set of criteria than those which were relevant when present plants were established.

The object of this analysis is to estimate the optimum number, size, and location of cattle slaughtering plants in California, and the optimum shipment patterns for live animals and carcass beef, given: (1) regional levels of live animal supply and consumer demand for meat, (2) assembly and distribution cost functions, and (3) processing costs. The level of cattle feeding in California and the inshipments of slaughter weight animals and dressed beef are, therefore, considered as given. The analysis relates to 1960 conditions, and the solution is applicable to the long-run location pattern only if supply and demand conditions were to remain unchanged. However, if cattle feeding increases, more (or larger) plants would be justified. Conversely, if fewer slaughter weight animals are shipped into California, the solution overstates the required slaughter capacity for the state. The analysis does provide a bench mark as to plant location, size, and shipment patterns consistent with a minimum cost assembly of live animals, slaughter, and shipment of meat to consuming regions. The results should be of interest to individual firms in the slaughter industry in planning possible adjustments in size and location. In addition, the study provides a methodological approach that may be of value to research workers concerned with efficiency in marketing.

FRAMEWORK OF ANALYSIS

THEORETICAL CONSIDERATIONS

The location of economic activity under a competitive system depends upon product demand, supply, and transfer costs among regions. Here, attention is focused on factors affecting the location of processing plants for a single agricultural product. The framework will be that of partial equilibrium and will be concerned with raw product as well as final product transfer costs. The relevant theoretical dimensions thus are the basis for interregional trade flows, and the factors that influence location and size of processing plant facilities.

Interregional trade flows result from regional price differences that are more than the cost of shipping the product. This may be illustrated by the well-known back-to-back diagram, in which the equilibrium trade flow and regional prices may be determined if the relevant supply and demand functions and transfer costs are given. Figure 1 shows a two-region example. The supply and demand curves for region 2 (shown on the left half of the diagram) result in a pretrade price (OS) exceeding that in region 1 (PQ) by more than transfer costs (t_{12}). Region 1 will therefore ship goods to region 2, thus increasing the effective supply in the latter region and decreasing the price. The diversion of some of the supply in region 1 to region 2 will simultaneously result in a higher price in region 1. Trade will continue to occur so that in equilibrium the price in the importing region equals that in the exporting region plus transfer costs, with quantity *a* shipped from region 1 to region 2. These results may be generalized to the multimarket case (Samuelson, 1952). This formulation is that of the point-trading model in that all production and consumption occur at specified locations. The alternative continuous location model, although theoretically appealing, has not been used in this analysis due to computational restrictions. The theory will therefore relate to the point-trading model employed in the empirical analysis.

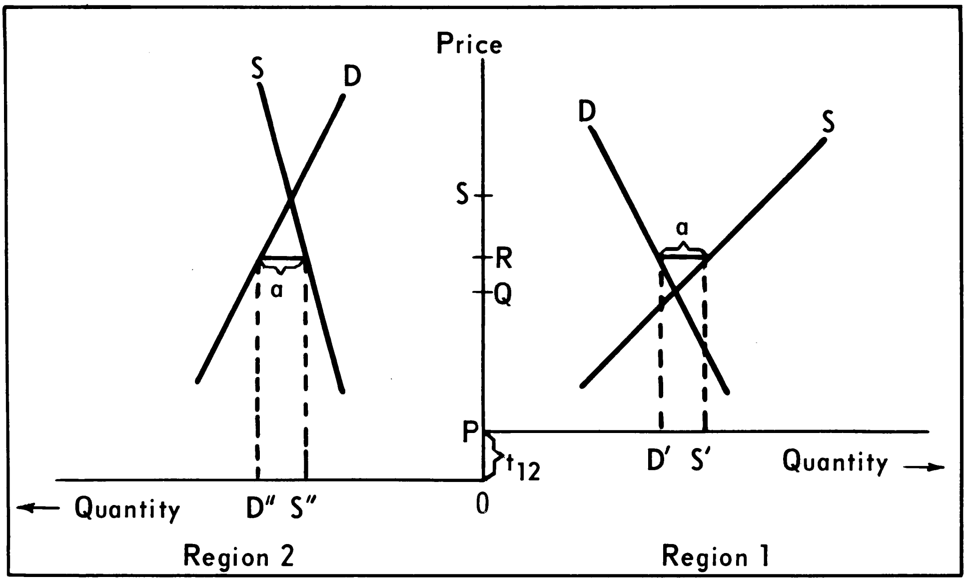

Fig. 1. Equilibrium market prices and shipment pattern with trade between two regions.

Minimizing Total Costs

The problem to be faced is: Given a level of supply of raw product and a level of demand for final product in each region, what conditions are necessary and sufficient for minimizing the total costs of processing and transportation under the equilibrium restraint that total supply equals total demand?

Consider the general case. Each region, i, has a given supply of raw product, Q_i. The processing cost in each region (PC_i) is a function of the level of processing, Q_i^*, and may be represented by $PC_i = f_i(Q_i^*)$. Conceptually, Q_i^* can vary from 0 to $\sum_{i=1}^{n} Q_i$. Raw product assembly cost (AC_i) for shipments from other regions is a function of the difference between quantity of raw product in region i and the level of processing in that region, or

$$AC_i = g_i\ (Q_i^* - Q_i).$$

Final product distribution costs from each region to other regions (DC_i) can be described in terms of the difference between the level of processing and the demand for the final product in region i, (D_i), or

$$DC_i = h_i\ (Q_i^* - D_i).$$

In the simplest case, AC_i = transportation cost per unit from region j to region i times the total shipment from j to i. For example, for two regions, $AC_1 = (c_{21})\ (Q_1^* - Q_1)$ with c_{21} equal to cost per unit moved and $Q_1^* - Q_1$ equal to total units moved. Here the c_{21} is a constant; in the more complicated case, c_{21} could be a function of $Q_1^* - Q_1$. The same situation holds for the distribution costs.

If we consider these functions for a simple two-region case, then the total costs of processing and transportation, given Q_1 and Q_2, would be

$$TC = PC_1 + PC_2 + AC_1 + AC_2 + DC_1 + DC_2 + \lambda[(Q_1 + Q_2) - (Q_1^* + Q_2^*)]\ ,$$

or

$$TC = f_1(Q_1^*) + f_2(Q_2^*) + g_{21}(Q_1^* - Q_1) + g_{12}(Q_2^* - Q_2) + h_{12}(Q_1^* - D_1) + h_{21}(Q_2^* - D_2) + \lambda[(Q_1 + Q_2) - (Q_1^* + Q_2^*)]$$

where $\lambda[(Q_1+Q_2)-(Q_1^*+Q_2^*)]$ is the restraint that total processing output must equal total supply of raw product (in equivalent units), or that final demand equals initial supply.

Assuming continuous functions with continuous first and second derivatives, the first order conditions for minimizing total cost with respect to processing levels in the two regions are the following:

$$\frac{\partial TC}{\partial Q_1^*} = f_1'(Q_1^*) + g_{21}'(Q_1, Q_1^*) + h_{12}'(Q_1^*, D_1) - \lambda = 0$$

$$\frac{\partial TC}{\partial Q_2^*} = f_2'(Q_2^*) + g_{12}'(Q_2, Q_2^*) + h_{21}'(Q_2^*, D_2) - \lambda = 0$$

$$\frac{\partial TC}{\partial \lambda} = (Q_1 + Q_2) - (Q_1^* + Q_2^*) = 0$$

or

$$f_1'(Q_1^*) + g_{21}'(Q_1, Q_1^*) + h_{12}'(Q_1^*, D_1) = f_2'(Q_2^*) + g_{12}'(Q_2, Q_2^*) + h_{21}'(Q_2^*, D_2) = \lambda .$$

Thus, to minimize total costs with respect to output in each region, it is necessary that the sums of the marginal costs of processing, assembly, and distribution in each region be equal. The second order conditions for a minimum stipulate that the second derivatives be positive, or

$$f_1''(Q_1^*) + g_{21}''(Q_1, Q_1^*) + h_{12}''(Q_1^*, D_1) > 0$$

$$f_2''(Q_2^*) + g_{12}''(Q_2, Q_2^*) + h_{21}''(Q_2^*, D_2) > 0.$$

In other words, the sums of the slopes of the marginal cost functions within a region must be greater than zero, or the marginal curve to the regional total cost curve must be upward sloping.[3]

The above development can be extended to n regions easily. In this case the total cost function is

$$TC = \sum_{i=1}^{n} f_i(Q_i^*) + \sum_{j=1}^{n}\sum_{i=1}^{n} g_{ij}(Q_i, Q_i^*) + \sum_{i=1}^{n}\sum_{j=1}^{n} h_{ij}(Q_i^*, D_i) + \lambda\left(\sum_{i=1}^{n} Q_i - \sum_{i=1}^{n} Q_i^*\right) .$$

The first order conditions are:

$$\frac{\partial TC}{\partial Q_1^*} = V_1 = f_1'(Q_1^*) + \sum_{j=1}^{n} g_{j1}'(Q_1^*, Q_1) + \sum_{j=1}^{n} h_{1j}'(Q_1^*, D_1) - \lambda = 0$$

$$\vdots$$

$$\frac{\partial TC}{\partial Q_n^*} = V_n = f_n'(Q_n^*) + \sum_{j=1}^{n} g_{jn}'(Q_n^*, Q_n) + \sum_{j=1}^{n} h_{nj}'(Q_n^*, D_n) - \lambda = 0 .$$

[3] A similar derivation, without consideration of assembly or distribution costs can be found in Patinkin (1947). See also a comment by Leontief (1947). Patinkin studies cost minimization for a multiple-plant firm and discusses conditions whereby equating marginal costs may not result in a minimum—that is, the second order conditions are not met. Specific examples of such conditions will be discussed later in this paper.

The second order conditions are that the bordered principal minors of the Hessian determinant of second partial derivatives all be negative for a minimum, or[4]

$$\begin{vmatrix} V_{11} & V_{12} & -1 \\ V_{21} & V_{22} & -1 \\ -1 & -1 & 0 \end{vmatrix} < 0 \cdots \begin{vmatrix} V_{11} & V_{12} \cdots & V_{1n} & -1 \\ V_{21} & & \cdot & \cdot \\ \cdot & & \cdot & \cdot \\ \cdot & & \cdot & \cdot \\ \cdot & & \cdot & \cdot \\ \cdot & & \cdot & \cdot \\ V_{n1} & \cdots & V_{nn} & -1 \\ -1 & \cdots & -1 & 0 \end{vmatrix} < 0 .$$

If the functions involved are not continuous functions with continuous first and second derivatives, the above approach must be reformulated. Frequently the cost functions or transportation rates for a given distance will be linear in nature, an intercept term may be involved, or the functions will be relevant only for certain ranges of quantities (for instance, assembly costs may not be relevant until the local supply of raw product is exhausted). In these cases, the summation of the various functions results in a kinked or, possibly, a step function rather than the smooth, continuous curves to which calculus can be applied. Indeed, minimization via the above procedures will not yield a unique point as will be discussed later.

Before considering the reformulation of conventional theory for minimizing costs of processing and transportation (and thus determining the size and location of plants), the nature of the demand, supply, and transfer cost functions applicable to the immediate analysis may be noted briefly.

In this situation, the demand function for a single homogeneous product requires no special comment, except to note its conventional nature—namely, that the quantity consumed is an inverse function of price, holding prices of competing goods, income, and other factors constant. The supply function (fig. 1) combines the raw product supply function with the processing supply function. We specify raw product assembly costs to be zero within the region, and similarly for final product delivery and associated distribution costs of wholesalers and retailers. Interregional transfer costs will be developed in more detail subsequently. The product supply function for raw product is considered to be an increasing function of price in each region. Theoretical constructs relating to this proposition are readily available, and attention is directed to the processing supply function.

The processing supply function conventionally is specified as an increasing function of price, which follows directly from assumed U-shaped average cost functions for the firm and an increas-

[4] For development of maxima and minima criteria, see Henderson and Quandt (1958), pp. 272–274.

ing-cost industry situation. Empirical estimation of processing firm economies of scale cost curves would indicate decreasing average costs over the entire relevant range of output for the single-plant firm, if plants are operated an 8-hour shift with no overtime payments. With plants operated at capacity (minimum average cost), replication of plants of this size would assure supply functions for the long-run situation that are relatively more elastic than implied with the usual U-shaped cost function, even though the nature of the long-run curve for larger single plants may be upward sloping. In fact, a perfectly elastic supply function over large ranges of output for processing services does not appear unreasonable for an industry of minor importance in the regional economy. The total supply function, however, would have a positive slope due to the response in the production of raw product.[5]

Figure 2, section A, presents a hypothetical economies of scale curve for a processing operation. The level and/or slope of the curve may vary among regions, due to differences in such costs as construction, labor, and utilities. This relationship also is shown as a total cost function for each region for convenience in later arguments. Section A of figure 2 shows functions for a situation in which the scale of plant can increase smoothly and continuously. When considering expansion of processing facilities the use of multiple plants may offer the economically feasible means. Section B, figure 2, shows relationships for long-run cost functions for multiple plants. The long-run total cost function will appear as a step function with an intercept value added with each additional plant. When one plant is fully utilized, expansion is achieved by addition of another plant.[6]

The interregional final product shipment costs shown in figure 3 are specified to be a constant average cost per quantity for a given distance of shipment. This is a simple supply function for transportation services in the case where product shipments are a minor portion of total shipments by the transportation firm. Similar transfer cost functions could be shown for shipment of raw product. For this theoretical development, we assume that in terms of final product equivalent the cost for raw material equals that for final product.

Turning now to the location of processing facilities, we may illustrate this problem in a simple context in which regional supplies of raw product and product demand are specified at a given level in each region. Product demand (figure 4, section A) equals OD' in region 1 and OD'' in region 2, giving a total of OT in the two regions. Product supply is OS' in region 1, and OS'' in region 2 with $OS' + OS'' = OD' + OD'' = OT$. The question is: Should processing be done in one region or in two regions, and—if in two regions—how much should be processed in each region? Factors to consider are the following: (1) regional differences in the processing cost function; (2) the shape of the processing cost function; (3) the level of regional demand in relation to raw product supply; and (4) transfer cost function characteristics for final product and for raw product.

Figure 4 illustrates a particular situation for these variables. Section A presents total costs of processing and shipment of final product and/or raw prod-

[5] Within region raw-product assembly costs are taken to equal zero in this development. However, as production in a region is increased, these assembly costs would increase. This continuous location model has been discussed by French (1960) and Henry and Seagraves (1960).

[6] Capacity may be considered either technically or economically. Technical capacity in this case refers to the maximum rate of output possible for the plant regardless of costs, and is bounded by the technical nature of the plant and equipment. The economic capacity indicates the least average cost point of operation. Capacity or size in the cost-volume relationships will be assumed to be one of economically efficient output for a plant operating one 8-hour shift per day as opposed to maximum technical output.

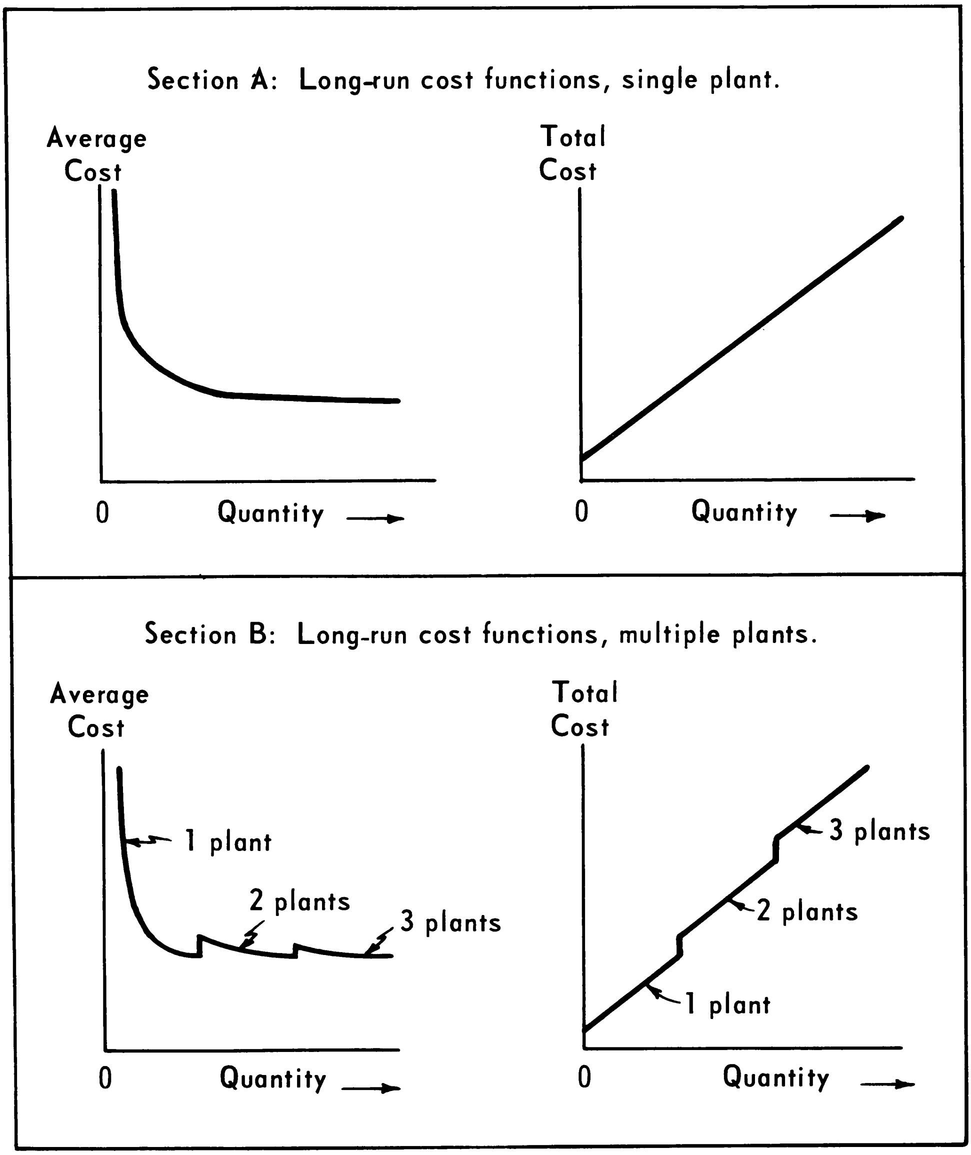

Fig. 2. Average and total long-run cost functions for single plants (section A) and for multiple plants (section B).

uct under alternative levels of processing in each region. To illustrate for region 1, if this region processes more than domestic demand (OD′), this will require product shipments to region 2. Thus, the product shipment transfer function is added to the processing cost function at this level of processing output. Similarly, if region 1 processes more than the domestic supply of raw product (OS′), then raw product must be shipped in from region 2. Thus, the raw product shipment cost is added to the function at output level OS′. A similar function is developed for region 2.

Determination of total costs of processing, if all processing is done in one region, requires only the comparison of total costs at output level OT. In

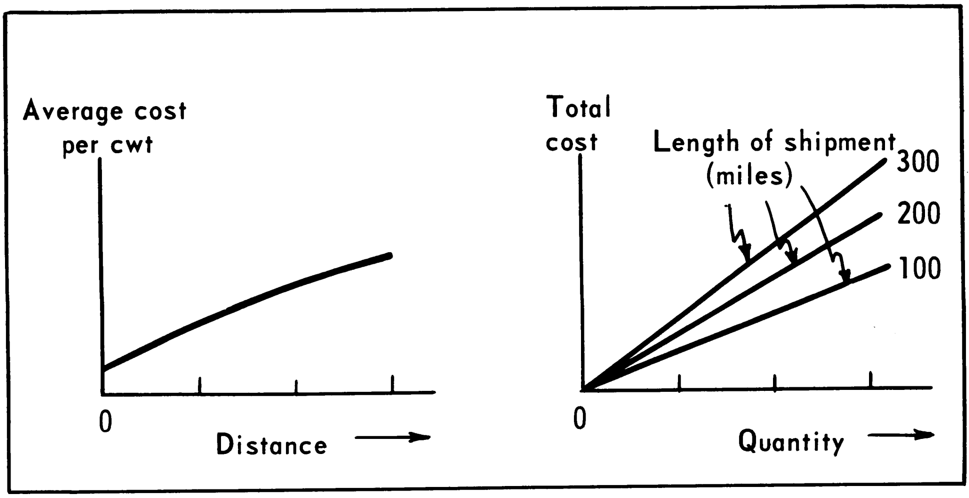

Fig. 3. Interregional final product shipment costs, average and total.

this case, costs would be lower at region 1. The more interesting case involves the determination of levels of cost and output of processing done in both regions. The pattern of processing and shipments which minimizes total costs in this case cannot be derived through use of calculus.

The first order conditions are that the sums of the slopes of the individual cost functions for each region must be equal. However, the second order conditions that the second derivatives be positive is not met since the second derivatives of the linear functions are equal to zero. Thus, we cannot say that equating the slopes will be a minimum. Also, since the first order conditions indicate equal slopes of the area total cost functions are necessary for a minimum, and since the slopes of linear functions are constant, it may be that there is no point at which the area slopes are equal, or there may be no unique point—that is, they may be equal for all quantities.

Since it may be less costly to produce in one plant, examination of total rather than marginal costs is required. In the illustrated case where the total cost curves for each region are straight lines, the marginal cost curves are discontinuous (fig. 4, section B.) Section C of figure 4 shows the total costs associated with varying levels of processing the quantity OT in region 1.

If no processing is done in region 1, total costs equal OW, with all processing done in region 2. If all processing is done in region 1, total costs equal TZ. If processing is done in both regions, the long-run fixed costs for two plants are required, and thus the upward shift in the cost function shown in section C for all outputs other than those mentioned above. The minimum cost situation of S′Y is associated with each region processing that volume equal to its raw product supply (OS′ and OS″).

Other specific cost situations may also require evaluation of total cost alternatives rather than the use of marginal concepts used in conventional theory. For example, if the processing cost function included a large enough intercept value, it can be shown that costs would be lowest by processing at only one location. If the raw product supply in the region is small, average processing costs are apt to be excessively high in relation to other regions with large supply sources. Similarly, if the processing costs vary between regions to an important extent (either because of different intercept values or slopes), this can influence location. In addition, the distance of source to processing point

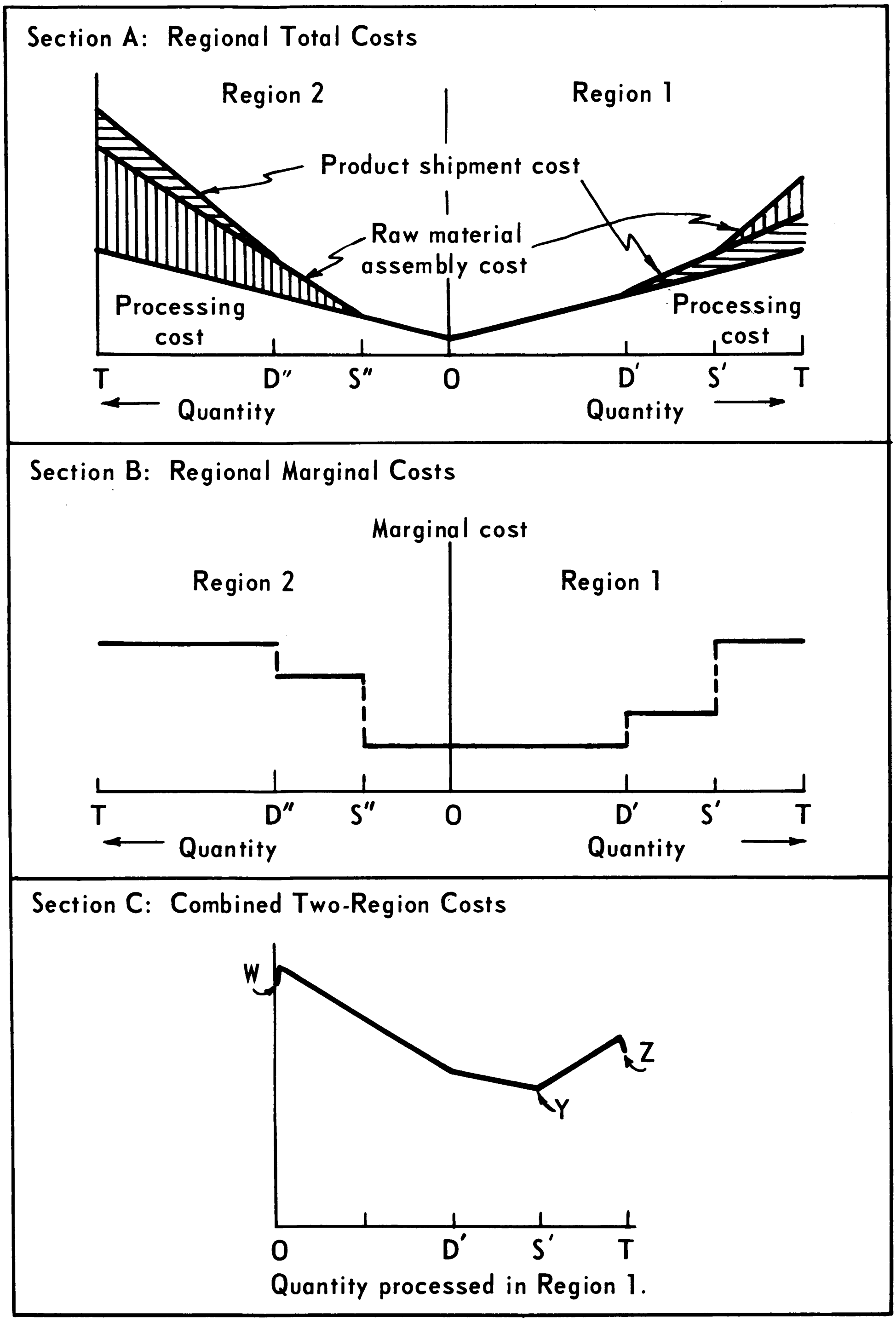

Fig. 4. Cost-minimizing plant location for two regions with given levels of raw product supply, product demand, processing costs, and transfer costs.

will influence the transfer cost function (fig. 3) and will affect location.

For a particular set of conditions, it is possible to specify the least-cost location for processing facilities. Results developed for the two-region case may be generalized to the multiregion case.

MODEL OF OPTIMUM SIZE AND LOCATION

The framework for this analysis is based upon location and trade theory relating to a single homogeneous product. The theoretical constructs used in this study draw upon previous theoretical and empirical analyses, as will be noted in the following sections. The empirical analysis is concerned with the following problem: Various regions in California have given supplies of live animals and/or given demand for meat. The transportation costs for both live animals and dressed beef are given and do not vary with quantity shipped.[7] Slaughtering costs for animals vary by region, and economies of scale exist in slaughtering facilities. The questions to be answered are: Where should processing plants be located? What should be the capacity of each plant? What is the optimum number of plants needed to move the animals through slaughter plants to consumers at least aggregate cost?

The model thus considers a system of plants and shipment patterns that minimize the cost of assembling, processing, and distributing the final product. The regional supply functions for the raw material (live animals) are considered as completely inelastic at given levels. The regional demand functions for the product (beef) are also considered inelastic at given levels. The framework for appraising location and size of plants under this model specification will be developed next, followed by the linear programming model used in the analysis.

When the alternative supply sources and demand areas are few in number or are treated as such, the determination of location and size of plant may be solved by budgeting methods as shown by Isard, Schooler, and Vietorisz (1959). Less aggregative analyses, involving spatially separated markets for raw product and final product, make budgeting procedures complex, especially when consideration is given to economies of scale in processing plant costs.

With the specification that the regional supply functions of the live animals and the demand functions for the carcass beef are completely inelastic (unresponsive to price changes), a modified form of the transhipment model of linear programming provides a convenient computational tool for deriving optimum plant location. An iterative procedure is required to obtain a final and approximate solution when economies of scale (or diseconomies) are present in long-run average costs.

Because of area aggregation and the use of central points representing these aggregated regions, the model is a point-trading variety rather than a continuous market supply-area model, and is similar to the transportation or spatial equilibrium models. This factor also imposes spatial monopoly aspects necessarily present within the regions (Bressler, 1958).

TWO ALTERNATIVE MODELS

The logic of the location problem is seen most readily if it is stated as a product-factor spatial equilibrium model. This model will be developed first, followed by a restatement of the problem as a modified transhipment model noting the computational advantage of such a formulation.

[7] Actually, transportation rates do show economies of scale as the quantity shipped increases. In this case, however, the shipments of raw product and final good were in sufficient quantity to qualify for the lowest rate, and thus, in effect, the transportation rate can be considered fixed.

Raw Product-Final Product Spatial Equilibrium Model[8]

For simplicity, assume initially that there are no economies of scale in slaughter operations but that costs vary by region. Supplies of slaughter animals and the quantity consumed by region are given. The problem is to minimize the combined cost of assembly of live animals, slaughter, and shipment of meat to consuming regions. The solution provides the optimum volume of slaughter at each location. With no economies of scale in processing, we may determine the number of plants of given capacity required to process this volume. We will relax the assumption as to economies of scale presently. This problem may be expressed in mathematical terms as follows:

Minimize:

$$\sum_i\sum_j T_{ij}X_{ij} + \sum_i H_i S^i + \sum_i\sum_j t_{ij}L_{ij} \qquad (1.1)$$

(total cost of meat shipment, slaughter, and animal shipment)

Subject to:

$$\sum_j X_{ij} = \alpha_i S^i \qquad (1.2)$$

(meat shipments equal meat equivalent of animals slaughtered)

$$S^i = S_i - \sum_j (L_{ij} - L_{ji}) \qquad (1.3)$$

(number slaughtered equals supply adjusted for shipments)

$$\sum_j X_{ji} = D_i \qquad (1.4)$$

(shipments to a region equal quantity consumed)

$$0 \leq X_{ij},\ L_{ij},\ S^i \qquad (1.5)$$

$$\sum_i D_i = \sum_i \alpha_i S^i = \sum_i\sum_j X_{ij} \qquad (1.6)$$

(quantity consumed equals total slaughter equals total meat shipment)

where

X_{ij} = meat shipment from region i to region j
L_{ij} = live animal shipment from region i to region j
S^i = slaughter of cattle in region i
T_{ij} = meat transfer cost from region i to region j
t_{ij} = animal transfer cost from region i to region j
H_i = slaughter cost per head in region i
α_i = dressing percentage in region i[9]
S_i = supply of slaughter cattle in region i
D_i = demand for meat in region i.

Table 1 gives the linear programming format for an illustrative two-region case. Such a factor-product model for, say, 30 regions would require some 90 equations and 1,800 activities (900 for meat shipment, 30 for slaughter, and 870 for live animal shipment since shipments within a region are not required). We must also consider adjustments

[8] The general nature of a factor-product model of spatial equilibrium may be seen in the study by Schrader and King (1962). The model presented here is based on an unpublished paper by Judge. (1962).

[9] In the following empirical analysis, an average value of α_i and an average live weight per head for the entire state have been used in estimating meat supplies. It is recognized, however, that the dressing percentage and live weight may vary somewhat between regions, particularly if the regions are heavily populated with dairy animals (or conversely with heavy-fed cattle). Because of the heterogeneous composition of cattle supplies in most of the regions, it was assumed that errors in estimation of meat supplies for the regions resulting from this specification would be negligible.

TABLE 1

A TWO-REGION EXAMPLE OF THE SLAUGHTER PLANT LOCATION USING A FACTOR-PRODUCT SPATIAL EQUILIBRIUM MODEL*

Equation	Activity								Total
	Meat shipment				Livestock slaughter		Live animal shipment		
	X_{11}	X_{12}	X_{21}	X_{22}	S^1	S^2	L_{12}	L_{21}	
0	T_{11}	T_{12}	T_{21}	T_{22}	H_1	H_2	t_{12}	t_{21}	.....
1	1	1	...	...	$-a$	...	...	...	$=0$
2	...	...	1	1	...	$-a$	...	...	$=0$
3	...	...	...	...	1	...	1	-1	$=S_1$
4	...	...	...	...	...	1	-1	1	$=S_2$
5	1	...	1	...	...	...	...	...	$=D_1$
6	...	1	...	1	...	...	...	...	$=D_2$

* Notation used is as follows (i and $j = 1$ and 2):
X_{ij} = meat shipment from region i to region j
L_{ij} = live animal shipment from region i to region j
S^i = slaughter of cattle in region i
T_{ij} = meat transfer cost from region i to region j
t_{ij} = animal transfer cost from region i to region j
H_i = slaughter cost per head in region j
a_i = dressing percentage in region i
S_i = supply of slaughter cattle in region i
D_i = demand for meat in region i

allowing for economies of scale in processing costs.

Consideration of Economies of Scale

Previous studies have included consideration of economies of scale in the location of processing plants, but these have been confined to assembly costs and processing costs.[10] In our problem, we must also consider product shipment costs. The general approach used in this study was to assign to each region a value of processing costs (H_i) associated with a large processing plant; this cost is the lowest possible for that region. The problem is run to determine the volume of processing under these conditions in each region. Second, the volume of processing at each location is then compared with the actual cost of processing that volume, based on an economies of scale curve for specialized beef slaughter plants. Third, processing costs are revised and the problem rerun. Costs for regions in which no processing took place under the most favorable cost situation are raised to that level associated with a small volume of slaughter, effectively eliminating them from consideration in the second approximation. Costs in other regions are adjusted to be in line with slaughter volume. Fourth, results from the second solution are inspected for possible adjustments and further adjustments made. Thus, an iterative approach is used to solve, by linear techniques, a nonlinear programming problem.[11]

Revising slaughtering costs to make them compatible with the volume of animals in a particular region may, in some cases, be misleading. For example, total assembly, processing, and distribution costs may be lowered for a group of small supply regions by combining their supplies of live animals at one central point, thus utilizing a larger plant than would be indicated by the volume of animals in any one of the regions. How-

[10] There are several studies in which this problem of plant location with economies of scale is considered in relation to assembly costs or distribution costs, namely Simmons (1959), Stollsteimer (1961), Mathia (1962), Olson (1959), Henry and Seagraves (1960), French (1960), Williamson (1962). King and Henry (1959) have written a useful article reviewing the use of the transportation model with modifications.

[11] For a similar procedure see Giaever and Seagraves (1960).

ever, if the costs of processing in the programming problem are those levels associated with the volume found in each region rather than the combined volume, then the establishment of a plant in that area of the state will likely be neglected. In these cases, a budgeting procedure may be used to estimate the feasibility of lowering the costs in a central region to allow for the possibility of a larger plant drawing on the combined supplies of surrounding regions.

Modified Transhipment Model

Orden (1956) has shown that the basic transportation model may be modified to allow shipments of a good to go by any sequence of points rather than just from m surplus regions to n deficit regions. Basically, the transportation model is modified by specifying each production and consumption area as a possible shipment or transhipment point. The possible use of this model became most apparent in an article by Kriebel (1961) dealing with warehousing with transhipment under seasonal demand. His problem deals with the shipment of a good from a producing center (or centers) to a consuming center (or centers) directly in a given time period or by shipment to a warehouse for transhipment immediately, or for storage for one or more periods. This is similar in some respects to our problem if we consider storage costs to be equivalent to slaughter costs. We ask: Should animals be slaughtered at the source and meat shipped, or should animals be shipped and slaughtered at one of several possible points and then the meat shipped to the demand areas? The slaughter costs will depend on the number of animals shipped to that slaughter point.

The nature of the solution is most readily apparent with a simple three-region example given in figure 5. In this case, each region has a supply of live animals and each region has a demand for the final product. No distinction is made as to whether the region is surplus or deficit. Therefore, whereas the usual transportation models allow for shipments from m surplus regions to n independent deficit regions, the example includes $m+n$ shipping regions and $m+n$ receiving areas.

Section A gives the matrix format which consists of four submatrices each of dimension N (where $N=m+n$).[12] Live animal supplies (k_i) are expressed in terms of meat equivalent. Costs are given in terms of units of meat equivalent also. Submatrix L gives the cost of live animal shipments. Thus, the shipment from region 1 to region 2 is $2.00 per unit. In this problem, an activity would be included in the final solution only if it were cheaper to ship from one source by transhipment through another source to a final destination, rather than directly from the origin to final destination.

Submatrix $L+S$ in section B gives the cost of live animal shipment, plus the cost of slaughter in region j; that is, slaughter cost is added to shipment cost to obtain the listed entries. In the example, the cost of slaughter is $5.00 in region 1, $7.00 in region 2, and $8.00 in region 3. These costs appear on the main diagonal, exhibiting zero shipment costs within a region.

Submatrix Y has no relevance to the problem and would enter only if cost of shipping meat from i to j differed from the cost of shipping meat from j to i. To avoid entries, high transfer costs are introduced in the cost matrix, as shown in section B.

Submatrix M provides for meat shipment from slaughter points to the consuming points. Both for live animal shipment and for meat, the within-

[12] In this example, each source region is also a demand region and vice versa, resulting in a square submatrices and a square over-all matrix. This is not essential. In fact, in the following analysis the submatrices are *not* square. If the latter is the case, this general three-region presentation can be modified to include nonsquare submatrices.

Section A: Matrix format

	1	2	3	1	2	3	
			L			L + S	
1							$k_1 + A$
2	Live animal shipment (in meat equivalent)			Live animal shipment, plus slaughter in region j (in meat equivalent)			$k_2 + A$
3							$k_3 + A$
			Y			M	
1							A
2				Meat shipment from region of slaughter to demand region			A
3							A
	A	A	A	$r_1 + A$	$r_2 + A$	$r_3 + A$	

Section B: Cost matrix

	1	2	3	1	2	3	k_i+.
			L			L + S	
1	0	2	3	5	9	11	45
2	2	0	4	7	7	12	38
3	3	4	0	8	11	8	35
			Y			M	
1	a	a	a	0	1	2	30
2	a	a	a	1	0	3	30
3	a	a	a	2	3	0	30
	30	30	30	37	44	37	
			$r_j + A$				

Section C: Minimum cost solution

						$k_i + A$
		L			L + S	
30	0	0	15	0	0	45
0	30	0	0	8	0	38
0	0	30	0	0	5	35
		Y			M	
0	0	0	22	6	2	30
0	0	0	0	30	0	30
0	0	0	0	0	30	30
30	30	30	37	44	37	
		$r_j + A$				

Section D: Final solution

						k_i
		L			L + S	
			15	0	0	15
			0	8	0	8
			0	0	5	5
		Y			M	
			-8	6	2	0
			0	0	0	0
			0	0	0	0
			7	14	7	
				r_j		

Fig. 5. A three-region example of the slaughter plant location model, using a modified transhipment formulation.

region transportation costs per 100 pounds are assumed to be equal for all regions, and thus set equal to zero.

The supplies of live animals in meat equivalent (k_i) for supply areas 1–3 are 15, 8, and 5, respectively. The meat requirements (r_j) for areas 1–3 are 7, 14, and 7, respectively. A key to the solution of this problem is the introduction of an artificial variable A which is taken to be equal or greater than the sum of the requirements r_j. In this problem, a value of 30 was used for illustration. As noted in figure 5, section A, this value is added to each row and column of the $2N$ matrix. The introduction of this variable allows transhipment of live animals through a slaughter point and on to a demand center, as will be illustrated for region 1 in the example. Use of a magnitude equal to total consumption in all regions allows processing the total quantity at one slaughter location.

The minimum cost solution of our sample problem is given in section C. The main diagonal consists of entries of the A value of 30 except where transhipment occurs. Entries in the $L + S$ matrix indicate levels of slaughter of 15 in region 1, 8 in region 2, and 5 in region 3. Entries in the M matrix indicate meat shipments from other slaughter regions to deficit regions. For example, region 1 ships 6 units to region 2 and 2 units to region 3, for a total of 8 units. Due to these transhipments the value in the main diagonal for region 1 differs from 30 by these eight units. The final solution to the problem (given in section D) subtracts the value of A of 30 for each row and column. In actual computations, the next step would be to correct the slaughter costs for volume slaughtered by the iterative technique suggested previously.

The computational advantage of the transhipment formulation is clear. For a 30-region case, a matrix of $2N$ is required, or 60 by 60. This compares with the alternative formulation requiring 90 equations and 1,800 activities. However, the latter method of solution is more flexible if it is desirable to relax the assumption of a completely inelastic demand function. The model to be described for location of California slaughter plants involved over 30 regions and was solved on an IBM 1620 (capacity = 60,000 digits) using the conventional transportation problem program.

The mathematical formulation of the model where each supply and/or demand region is a possible slaughter region may be stated as follows:

Minimize:

$$Z = \sum_{i=1}^{2N} \sum_{j=1}^{2N} c_{ij}x_{ij} \qquad (2.1)$$

(total cost of all shipments of meat, and shipment and slaughter of live animals in terms of meat equivalent)

Subject to:

$$\sum_i x_{ij} = r_j + A \quad \text{for } i,j \qquad (2.2)$$

$$= 1 \cdots N, N + 1 \cdots 2N$$

$$N = m + n$$

(total meat requirements at consuming area must equal total shipments to area, plus artificial value A)

$$-\sum_j x_{ij} = -k_i - A \qquad (2.3)$$

(total shipments from an area must equal total supply, plus artificial value A)

$x_{ij} \geq 0$ where x_{ij} are the meat equivalent of live animals for $i = 1 \cdots N$; $j = 1 \cdots N, N + 1 \cdots 2N$; and where x_{ij} are meat shipments for $i = N + 1 \cdots 2N; j = 1 \cdots N, N + 1 \cdots 2N$. (2.4)

$c_{ij} > 0$ for $i \neq j$ (2.5)

$= 0$ for $i = j$ and $i, j = 1 \cdots N, N + 1 \cdots 2N$.

(within region transporation cost is zero)

$= H_i$ for $i = j$ and $i = 1 \cdots N; j = N + 1 \cdots 2N$.

(diagonal of one submatrix contains slaughter costs)

$= \infty$ for $i = j$ and $i = N + 1 \cdots 2N; j = 1 \cdots N$.

(diagonal and entire cost matrix contains high cost to preclude entries in shipment pattern)

$$A \geq \sum_{j=N+1}^{2N} r_j \text{ where } r_j = 0 \text{ for } j = 1 \cdots N. \qquad (2.6)$$

(artificial value A is chosen to assure inclusion of only relevant x_{ij} in the optimum solution)

$$k_i = 0 \text{ for } i = N + 1 \cdots 2N. \qquad (2.7)$$

(supply of live animals in meat equivalent is limited to relevant matrix)

PRICE DIFFERENTIALS

Once the optimum pattern of shipments is determined a set of relative prices can be calculated for the shipping and receiving areas. Such calculation draws on the theoretical concept that prices between shipping and receiving areas will differ by exactly the cost of transportation in competitive equilibrium. Because of the dual nature of the transportation model, the prices which were derived from minimization of the transfer costs are the same as those which would exist if the firms were trying to sell their output at the maximum price under pure competition. Thus, had the problem been set up to maximize prices received by the slaughtering firms (and the producers of live animals) with the constraint that the prices could not exceed the value of the product at the plant plus transportation, the shipment pattern and the set of relative prices would be the same.[13]

SUPPLY, DEMAND, TRANSFER, AND PROCESSING COST FUNCTIONS

As outlined previously, the optimum size and location of plants depend basically on four criteria—the supply of raw materials, the demand for the final product, the transportation or transfer costs, and the nature of the processing cost function. These four functions then serve as the basic data to be used in deriving the location and scale of plants.

RAW PRODUCT SUPPLY

Animals for slaughter in California originate from several sources: feedlots, dairy herds, beef herds, grass-fed cattle, and inshipments of animals for immediate slaughter from neighboring states. While the number of cattle supplied by these sources is not available by county, information on a state-wide level is published from which county supplies can be estimated. Table 2 summarizes total annual slaughter, inshipments of stockers and feeders, inshipments of cattle and calves for immediate slaughter, and outshipments of cattle and calves, for 1960.

TABLE 2

CATTLE AVAILABLE FOR SLAUGHTER FROM VARIOUS SOURCES, 1960

Classification	Number of head
Dairy cows on farms	208,000
Beef cows on farms	315,000
Beef steers, bulls on farms	179,000
Inshipments of stockers, feeders	1,435,000
Inshipments for immediate slaughter	450,000
Calves	489,000
Outshipments	136,000
SUBTOTAL	2,940,000
Miscellaneous*	18,000
TOTAL	2,958,000

* Difference between total slaughter and number of animals available from above categories. Composed mainly of dairy bulls, steers on farms.

SOURCE: California Crop and Livestock Reporting Service, *California Annual Livestock Report, Summary for 1960.* Sacramento (1961).

[13] For proof of the duality of the transportation model, see Dorfman, Samuelson, and Solow (1958), pp. 122–129.

The total number of dairy cows on California farms in 1960 was estimated by adding the number of cows 2 years old or older on farms January 1, 1960—899,000 head—and the number of heifers 1 and 2 years old on farms January 1, 1960—250,000 head.[14] These heifers, it was assumed, would reach the category of "milk cows" sometime during 1960. A death loss of 3.7 per cent was then applied to these figures. From the total number of cows on farms was subtracted the death loss and the number of cows on the farms at the beginning of 1961—also 899,000 head. The resulting 208,000 head then became the number available for slaughter.

A similar procedure was followed to estimate the number of beef cows available for slaughter. At the beginning of 1960, there were 853,000 beef cows 2 years old or older and 358,000 heifers. Using the same death rate, the number available for slaughter was estimated at 315,000 head.

On January 1, 1960, there were 846,000 steers and bulls (beef type) 1 year old or older on California farms, and there were 630,000 calves. Half of these animals were assumed to be bull calves and to reach the year-old level in 1960, and the other half was assumed to be heifer calves. Again the 3.7 per cent death rate was used, resulting in a level of 179,000 head of beef steers and bulls available for slaughter. Of the calf crop the number raised, 1,449,000, minus the number at the end of the year, 960,000, left 489,000 head available for slaughter.

The total disappearance of cattle and calves during 1960 equalled 2,940,000 head (see table 2), but the total slaughter of cattle and calves for the year was 2,958,000 head. It was assumed that the additional 18,000 head were primarily dairy bulls and steers, a category not included in any of the above. (Some of the animals included in this group may also represent errors in the estimation of the other categories.)

There were 482,000 calves slaughtered in 1960. Since the disappearance was 489,000 calves, it was assumed that 7,000 head of calves were included in the outshipments. The state is self-sufficient with respect to demand for calves for slaughter; inshipments of animals for immediate slaughter were assumed to be cattle. Since the California calf crop exceeds the number slaughtered, this analysis will be concerned only with the slaughter and shipment of cattle.

Cattle available for slaughtering were divided into three classes: (1) marketings from feedlots, (2) dairy animals, and (3) cull beef and grass-fed cattle. There were 226,000 dairy animals available for slaughter; beef cattle total 1,800,000 head after subtracting outshipments. Of this last number, 1,595,000 head were marketed from feedlots, leaving 205,000 head as cull beef and grass-fed animals.

Dairy stock was allocated to the counties by computing the percentage of milk cows, 2 years old and older, found in each county in 1960 and then applying that figure to the total of 226,000 head. Data on marketings from feedlots by county for 1961 were obtained on a confidential basis from the California Crop and Livestock Reporting Service. Derivations of county marketings as a percentage of the state total were made and applied to the total marketings in 1960. The remaining classification, cull beef and grass-fed cattle, was separated into county supplies by use of data from U. S. Bureau of the Census (1961*a*). The number of milk cows by county for 1960 was subtracted from the total number of cows (beef and dairy) to estimate the quantity of beef cows by county. The percentage of the state total of beef cows in each county was assumed to be the same as the percentage of cull beef and grass-fed cattle available for slaughter in each county. Table 3 gives

[14] Unless otherwise specified, the figures on state supplies of animals were all derived or taken directly from California Crop and Livestock Reporting Service (1961), pp. 7–13.

the total supply of cattle for slaughter by county.

The supply of cattle for slaughter was converted to a dressed weight basis, using average 1960 weights of 1,026 pounds per head and a dressing percentage of 57.3 per cent given by the U. S. Department of Agriculture (1961). Average dressed weight was 587.9 pounds. In addition to the dressed carcass, however, the edible by-products—liver, heart, lungs, tongue, and cheek meat—must also be considered as part of the supply of beef available. These by-products equal approximately 3.7 per cent or 38 pounds of the live weight of the animal, according to Vaughn (1961), and increase the total weight of the edible meat from the average animal to 626 pounds.

Table 3 gives the production of live animals in terms of pounds of dressed beef (626 pounds times the supply of cattle).

Inshipments

Of the 450,000 head shipped into the state for immediate slaughter in 1960, Arizona supplied 253,000; Colorado, 12,000; Idaho, 57,000; Nevada, 21,000; Oregon, 17,000; Texas, 32,000; Utah, 36,000; and other areas, 22,000 head

TABLE 3

ESTIMATED PRODUCTION AND DERIVED CONSUMPTION OF BEEF BY COUNTY, 1960

County	Production of live animals*	Production of dressed beef†	Consumption of dressed beef‡	County	Production of live animals*	Production of dressed beef†	Consumption of dressed beef‡
	number	*1,000 pounds*			*number*	*1,000 pounds*	
Alameda	9,263	5,799	109,486	Sacramento	57,265	35,848	60,608
Alpine	226	141	48	San Benito	10,727	6,715	1,856
Amador	1,900	1,189	1,204	San Bernardino	16,558	10,365	60,706
Butte	8,517	5,331	9,888	San Diego	9,888	6,190	124,530
Calaveras	3,307	2,070	1,240	San Francisco	......	0	89,245
Colusa	2,818	1,764	1,456	San Joaquin	53,996	33,801	30,135
Contra Costa	17,502	10,956	49,307	San Luis Obispo	23,380	14,636	9,770
Del Norte	1,255	786	2,142	San Mateo	1,125	704	53,570
El Dorado	1,607	1,006	3,543	Santa Barbara	33,003	20,660	20,368
Fresno	178,819	111,941	44,114	Santa Clara	19,942	12,484	77,429
Glenn	19,662	12,308	2,079	Santa Cruz	2,270	1,421	10,152
Humboldt	9,690	6,066	12,644	Shasta	6,773	4,240	7,169
Imperial	384,790	240,879	8,692	Sierra	947	593	271
Inyo	3,254	2,037	1,408	Siskiyou	13,593	8,509	3,964
Kern	231,199	144,731	35,198	Solano	31,298	19,593	16,225
Kings	73,011	45,705	6,022	Sonoma	14,974	9,374	17,766
Lake	1,452	909	1,662	Stanislaus	43,178	27,029	18,961
Lassen	8,978	5,620	1,639	Sutter	2,582	1,616	4,024
Los Angeles	144,836	90,667	727,960	Tehama	14,362	8,991	3,050
Madera	51,894	32,486	4,878	Trinity	1,193	747	1,170
Marin	8,131	5,090	17,699	Tulare	126,268	79,044	20,300
Mariposa	1,993	1,248	610	Tuolumne	1,735	1,086	1,736
Mendocino	4,268	2,672	6,155	Ventura	51,404	32,179	24,005
Merced	63,542	39,777	10,903	Yolo	18,474	11,565	7,923
Modoc	12,790	8,007	1,002	Yuba	7,398	4,631	4,082
Mono	1,089	682	267				
Monterey	31,954	20,003	23,911	*Total state*	2,026,000	1,268,276	
Napa	18,160	11,368	7,943	*Inshipments*			
Nevada	1,807	1,131	2,521	cattle	450,000	281,700	
Orange	12,440	7,787	84,858				
Placer	6,173	3,864	6,871	beef	......	344,700	
Plumas	1,626	1,018	1,401				
Riverside	145,714	91,217	36,910	TOTAL	2,476,000	1,894,676	1,894,676

* Includes feedlot marketings, dairy animals, cull beef, and grass-fed animals.
† Number of head times 626 pounds (includes by-products).
‡ Total state supply divided by state population of 15,717,204, then multiplied by county population level for 1960.

(Calif. Crop and Lvstk. Rptg. Serv., 1961). Truck shipments of both live animals and meat entering the state must pass through one of 17 border inspection stations. Two of these stations were used to represent the northern and southern entry points—Truckee and Blythe, respectively—for both live animals and dressed beef. Two central sources for inshipments of live animals were selected to represent transportation distances from out of state. Twin Falls, Idaho, represented live animal sources for shipments entering northern California, while southern inshipments came from Phoenix, Arizona.

Similar information on inshipments of meat is not published regularly. For 1961, meat and product inshipments were estimated to compose 18 per cent of the total beef supply in California, while the state's own livestock plus inshipments of cattle for immediate slaughter equalled 76 per cent of the total supply of dressed beef (King, 1962). (Imports from foreign countries equalled the other 6 per cent.) The dressed carcass weight of California slaughter in 1960, using a dressing percentage of 57.3 per cent, was 1,455,600,000 pounds.[15] From this figure—equal to 76 per cent of the total supply—inshipments were estimated to be 344,700,000 pounds. Foreign exports and imports of meat were not considered because of lack of data.

The analysis of 1961 inshipments indicated that for truck inshipments of all meat some 45 per cent was directed to northern California and the remaining 55 per cent to southern California. Of the 892 million pounds of meat shipped into the state in 1961, therefore, 401.4 million pounds went to the Northern part and 490.6 million pounds were directed to the southern section. Some 38.9 per cent of the meat shipped into the northern section was beef; the southern proportion was 34.9 per cent (King, 1962). From these figures, estimations of the percentages of beef entering the state by regional destination were 47.7 per cent for the northern section and 52.3 per cent for southern California. These percentages were applied to 1960 inshipment estimates, with resulting supplies of 164,422,000 pounds for northern California and 180,278,000 pounds for southern California.

From a limited sample of data it seems that 66 per cent of the inshipments into the northern part of the state originate in Idaho, Utah, Nevada, and Montana, while 63 per cent of those entering southern California came from Colorado. In aggregating the inshipments' supply points, it was assumed that the northern supplies would come from Salt Lake City, Utah, while those for southern California would be shipped from Denver, Colorado.

The total poundage of beef slaughtered in 1960 (including edible by-products) plus inshipments of beef equalled 1,894,676,000 pounds.

CONSUMPTION OF DRESSED BEEF

To derive the consumption of beef and edible by-products by county, the production of beef in 1960 was set equal to the total consumption and divided by the state population to obtain a per capita level. The per capita consumption level of 120.457 pounds was then multiplied by the county population to estimate the total county consumption levels.[16]

Slaughtering Regions

County boundaries offer a fairly simple means whereby regions within the state can be designated; however, the area represented by any one county is frequently quite different from those represented by other counties. In an effort to obtain meaningful regional patterns, the counties were combined

[15] Derived by multiplying the product of the number of animals slaughtered in 1960 and 1,026 pounds by 57.3 per cent.

[16] State and county population figures taken from Bureau of the Census (1961*b*).

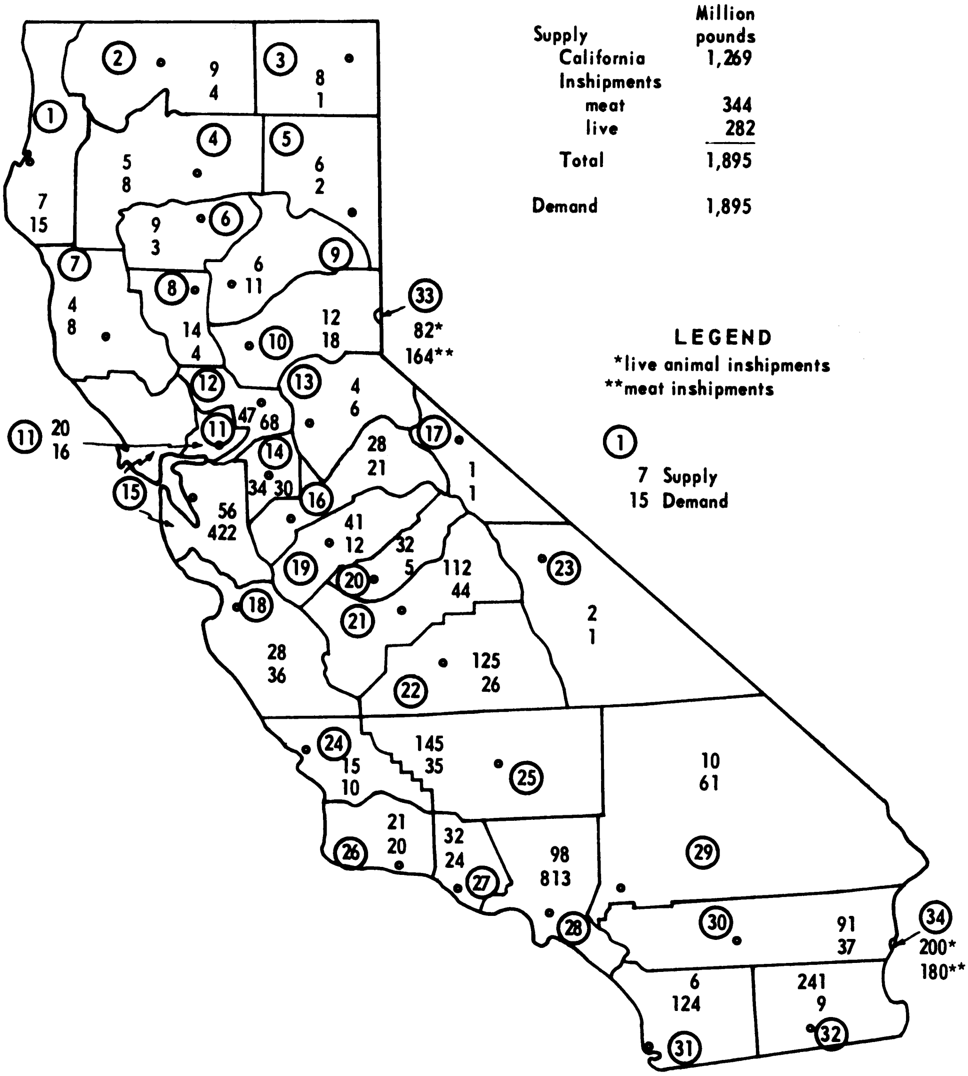

Fig. 6. Supply of live animals and demand for meat for 32 regions in California and 2 inshipment points (1961).

into thirty-two supply and demand regions.[17] The various regions and their supply of animals (in terms of dressed beef equivalent) are shown in figure 6.

TRANSFER COSTS

Estimating the actual costs incurred by transporting live animals or meat would have required a complete cost analysis in that area. Such an analysis would be a separate project in itself and is beyond the scope of this study. The State of California, through the Public Utilities Commission, sets minimum tariffs for hauling cattle and beef by truck within the state. According to the Commission, these rates are based on the cost of operation plus a return on investment for the hauling firms. While certain economies of vertical integration

[17] Although an attempt was made to combine counties into more uniform areas, such grouping is admittedly arbitrary.

of transportation—both assembling and distributing—might occur for slaughtering firms having their own transportation system, the rates set by the state appeared to offer the most reasonable cost estimates.

Both live animal and meat rates used were for 1960 and are given in terms of weight and constructive miles travelled. The constructive miles allow for topographical changes between points and for this reason should give a more accurate estimation of transportation costs than the use of road mileage. Rates for both cattle and beef vary with the minimum amount of weight to be hauled. In all cases, it was assumed that the shipments would qualify for the lowest rate, having minimum weights of 38,000 pounds for live animals and 20,000 pounds for the beef.

The transportation problem involves shipment of both meat and live animals, but to ease computational problems the live animal shipment costs and quantities shipped were expressed in dressed weight equivalent. Thus, the rate for shipping 38,000 pounds of live animals was adjusted by the ratio of live weight per head to dressed weight per head (1,026 pounds/626 pounds = 1.64). This cost was then applied to the dressed weight equivalents of the live animal shipments.

The rates were also applied to inshipments of dressed beef and live animals on the following basis. The distances from Salt Lake City to Truckee and from Denver to Blythe were 560 miles and 925 miles, respectively. The simplification of having only two entry points instead of seventeen would be expected to have a negligible effect on total costs of transportation, because of the long distances involved for all sources. The meat was then distributed from the two border stations using the Public Utilities Commission rates and mileage distances from those points to the consuming regions. A charge of 5 cents per 100 pounds per 50 miles travelled was placed on inshipments for the distance travelled outside the state to the two border stations.[18] This assessment resulted in increasing the transportation costs per 100 pounds from Truckee and Blythe to the consuming areas by 60 cents and 95 cents, respectively.

A further assumption was made that all incoming meat would be slaughtered in plants killing at least 120 head per hour. Because data on the costs of slaughtering in other states were not available, the Los Angeles processing rate was assigned to out-of-state meat.[19]

For live animals the out-of-state distances were 488 miles from Twin Falls, Idaho, to Truckee, and 170 miles from Phoenix, Arizona, to Blythe. In this case, a charge of 7 cents per 100 pounds (dressed weight equivalent) for every 25 miles travelled was added to the cost of shipping from the two entry points to consuming regions. This resulted in an addition of $1.33 for shipments from Twin Falls and 49 cents per 100 pounds for shipments from Phoenix.

Tables 4 and 5 give the transportation charges per 100 pounds, on a dressed weight basis, for live animals and carcass beef.

PROCESSING COSTS

The long-run costs of slaughtering cattle were taken from a previous study (Logan and King, 1962). Because a detailed explanation of the cost estimation procedure is available elsewhere, only a summary explanation will be given here.

Plants under consideration were

[18] Inspection of the rate table for meat issued by the Public Utilities Commission reveals that for distances over 800 miles the cost of transportation increases at the relatively constant rate of 5 cents per 100 pounds per 50 miles additional travel.

[19] Although the Los Angeles rate is the lowest processing rate in the state, its assignment to out-of-state meat may bias the costs of inshipments upward. Correspondence between R. L. Shutt, Assistant Research Director of the United Packinghouse Workers of America, A.F.L.–C.I.O., Chicago, and the authors indicate that labor costs in Los Angeles and San Francisco areas run somewhat higher than for the metropolitan areas elsewhere in the country.

TABLE

TRANSPORTATION RATES FOR

(Dressed Weight

Region and city	Eureka	Yreka	Alturas	Redding	Susanville	Red Bluff	Ukiah	Willows	Oroville	Marysville	Fairfield	Sacramento	Jackson	Stockton
	cents per													
1. Eureka	0													
2. Yreka	103	0												
3. Alturas	116	62	0											
4. Redding	71	46	59	0										
5. Susanville	116	90	43	59	0									
6. Red Bluff	79	52	71	18	48	0								
7. Ukiah	71	103	116	71	97	59	0							
8. Willows	90	71	79	31	62	23	46	0						
9. Oroville	97	71	85	38	52	28	52	21	0					
10. Marysville	103	79	90	43	62	34	48	26	16	0				
11. Fairfield	97	97	110	62	85	51	43	41	41	31	0			
12. Sacramento	103	90	103	56	74	48	52	34	31	23	21	0		
13. Jackson	123	110	116	74	90	66	71	51	48	41	38	28	0	
14. Stockton	116	103	153	71	90	62	59	48	46	38	26	23	26	0
15. Oakland	103	110	123	74	97	71	51	52	52	46	26	38	48	34
16. Modesto	123	110	123	79	97	71	71	56	52	46	34	31	34	16
17. Bridgeport	277	264	277	231	251	225	225	212	212	205	192	192	192	179
18. Salinas	130	138	153	103	123	97	79	79	79	74	52	62	66	48
19. Merced	130	123	138	90	103	79	79	71	66	56	46	43	46	28
20. Madera	146	130	146	97	116	90	85	74	74	66	56	51	52	41
21. Fresno	153	138	153	103	123	97	90	79	79	74	62	59	59	46
22. Visalia	159	153	166	116	130	110	103	97	90	85	74	71	74	56
23. Bishop	244	231	244	198	218	192	192	179	179	172	159	159	159	110
24. San Luis Obispo	172	172	192	138	166	130	116	116	123	110	90	97	103	85
25. Bakersfield	179	166	185	130	153	123	123	110	110	103	90	90	90	74
26. Santa Barbara	205	205	198	172	192	166	153	153	153	146	123	130	138	116
27. Ventura	212	205	198	172	192	166	159	153	153	138	130	123	130	116
28. Los Angeles	218	205	198	172	192	166	166	153	153	138	130	123	130	116
29. San Bernardino	225	218	231	185	205	179	172	166	159	153	146	138	138	123
30. Indio	251	238	251	205	225	198	198	185	185	172	166	159	166	153
31. San Diego	251	238	251	205	225	198	198	185	185	179	166	166	166	153
32. El Centro	271	264	277	225	244	218	218	205	205	198	185	185	185	172
33. North, out-of-state	271	249	207	212	181	207	218	199	189	181	192	181	192	195
34. South, out-of-state	326	313	326	280	300	274	274	261	261	247	241	234	241	228

SOURCE: Rates are based on Minimum Rate Tariff 3-A, effective October 28, 1960, section 2, Distance Commodity Rates, page 18 Distances to which the rates were applied in order to derive the above figures were taken from Distance Table 4 containing Regula

those slaughtering only cattle without horizontal operations such as rendering, boning, sausage-making, or hide curing. Costs of live animals were not considered. Two major technologies of cattle slaughtering were studied: (1) the conventional single rail or bed-type system, and (2) the on-the-rail dressing system. In the long run, the conventional plants alter scale by adding or eliminating the "beds" or work areas in which the carcass is skinned, eviscerated, and the hooves removed; that is, there are one-bed plants, two-bed plants, and so on. On-the-rail systems, however, change scale by lengthening or shortening the existing line and using more, or fewer, workers along the line.

For the most part, costs were estimated for various levels of output by synthesizing aggregate production and cost relationships. This method involves the derivation of elementary input-output relationships and then, through the use of these relationships as "building blocks," the construction of production and cost functions.[20] The input-output relationships can be obtained through

[20] For a detailed description of the method of synthesizing costs, see L. L. Sammet (1958).

4
SHIPPING LIVE ANIMALS
Equivalent)

Oakland	Modesto	Bridgeport	Salinas	Merced	Madera	Fresno	Visalia	Bishop	San Luis Obispo	Bakersfield	Santa Barbara	Ventura	Los Angeles	San Bernardino	Indio	San Diego	El Centro	North, out-of-state	South, out-of-state
100 pounds																			
0																			
38	0																		
192	172	0																	
41	43	172	0																
46	20	159	43	0															
56	31	153	46	18	0														
62	38	146	51	26	15	0													
74	48	130	62	38	28	21	0												
146	138	46	138	123	116	110	97	0											
79	79	159	51	71	62	56	56	123	0										
90	71	110	74	56	48	43	31	79	52	0									
110	110	138	79	103	97	85	79	103	43	59	0								
116	103	130	90	97	85	79	71	97	51	51	18	0							
130	103	123	110	97	85	79	71	90	74	51	41	31	0						
146	116	116	123	110	97	90	85	85	85	62	56	48	28	0					
166	138	138	146	130	116	116	103	103	110	85	79	71	48	34	0				
166	146	153	146	130	123	116	103	116	103	85	74	71	46	46	59	0			
185	166	166	172	153	146	138	130	130	130	110	103	90	74	56	34	51	0		
207	204	358	230	212	223	230	243	325	271	256	305	299	299	312	331	331	351	0	
241	215	215	221	208	202	195	179	179	187	159	152	146	123	111	90	134	108	274	0

tions, Mileage Distances Between Points within the State of California. Effective January 1, 1952, pages 1–160. Both data sources are issued by the Public Utilities Commission of California, San Francisco.

work sampling, time studies, interviews with management personnel, or through direct use of accounting data.

Basically, the analytical model was as follows:

I. Construction of eight hypothetical or model plants with specified designed capacities.[21]

A. Determination of the physical input requirements for labor and management and utilities, and the application of appropriate cost rates thereto.[22]

B. Determination of investment requirements, first in a physical sense and then in a cost sense, through application of manufacturers' prices.

[21] Designed capacity is defined as maximum number of cattle which can be slaughtered per hour by a given plant.

[22] In order to escape the problems of cost differentials among various areas of the state in the initial part of the analysis, the cost rates used were for the Los Angeles area, the principal slaughtering area of California. Plants were assumed to operate one 8-hour shift a day, 5 days a week, and 52 weeks a year with 8 paid holidays during this period.

TABLE

TRANSPORTATION RATES FOR

Region and city	Eureka	Yreka	Alturas	Redding	Susanville	Red Bluff	Ukiah	Willows	Oroville	Marysville	Fairfield	Sacramento
												cents per
1. Eureka	0											
2. Yreka	80	0										
3. Alturas	86	58	0									
4. Redding	62	46	57	0								
5. Susanville	86	73	44	57	0							
6. Red Bluff	66	53	62	24	48	0						
7. Ukiah	62	80	86	62	77	57	0					
8. Willows	73	62	66	35	58	28	46	0				
9. Oroville	77	62	69	40	53	33	53	26	0			
10. Marysville	80	66	73	44	58	37	48	30	22	0		
11. Fairfield	77	77	83	58	69	51	44	43	43	35	0	
12. Sacramento	80	73	80	55	64	48	53	37	35	28	26	0
13. Jackson	90	83	86	64	73	60	62	51	48	43	40	33
14. Stockton	86	80	104	62	73	58	57	48	46	40	30	28
15. Oakland	80	83	90	64	77	62	51	53	53	46	30	40
16. Modesto	90	83	90	66	77	62	62	55	53	46	37	35
17. Bridgeport	166	160	166	150	155	146	146	138	138	134	127	127
18. Salinas	93	97	104	80	90	77	66	66	66	64	53	58
19. Merced	93	90	97	73	80	66	66	62	60	55	46	44
20. Madera	100	93	100	77	86	73	69	64	64	60	55	51
21. Fresno	104	97	104	80	90	77	73	66	66	64	58	57
22. Visalia	107	104	111	86	93	83	80	77	73	69	64	62
23. Bishop	155	150	155	130	141	127	127	118	118	114	107	107
24. San Luis Obispo	114	114	127	97	111	93	86	86	90	83	73	77
25. Bakersfield	118	111	122	93	104	90	90	83	83	80	73	73
26. Santa Barbara	134	134	141	114	127	111	104	104	104	100	90	93
27. Ventura	138	134	141	114	127	111	107	104	104	97	93	90
28. Los Angeles	141	134	141	114	127	111	111	104	104	97	93	90
29. San Bernardino	146	141	150	122	134	118	114	111	107	104	100	97
30. Indio	155	150	155	134	146	130	130	122	122	114	111	107
31. San Diego	155	150	155	134	146	130	130	122	122	118	111	111
32. El Centro	166	160	166	146	155	141	141	134	134	130	122	122
33a. North, out-of-state	157	146	124	126	108	124	129	120	115	108	117	108
34a. South, out-of-state	261	255	261	245	250	241	241	233	233	225	222	217

SOURCE: Rates are based on Minimum Rate Tariff 2, effective September 23, 1960, section 2, page 41. Distances to which the rates were applied in order to derive the above figures were taken from Distance Table 4 containing Regulations, Mileage Distances Between

C. Determination of miscellaneous variable costs of operation.

D. Determination of the total costs for model plants.

II. Estimation of short-run cost functions for model plants by varying the rate of output.

III. Determination of the long-run cost function by fitting an envelope to short-run cost points derived for the model plants.

The eight model plants include three conventional plants with designed capacities of 17, 35, and 50 head per hour (equivalent to one bed, two beds, and three beds, respectively) and five on-the-rail plants capable of killing 20, 40, 60, 75, and 120 head per hour. The cattle had an average live weight of about 1,100 pounds and average dressed weight of between 600 and 700 pounds.

Labor

Labor input requirements were synthesized from time studies, accounting data, and interviews with management personnel obtained from actual plants in California, and from data provided by on-the-rail equipment-making con-

5

SHIPPING DRESSED BEEF

Jackson	Stockton	Oakland	Modesto	Bridgeport	Salinas	Merced	Madera	Fresno	Visalia	Bishop	San Luis Obispo	Bakersfield	Santa Barbara	Ventura	Los Angeles	San Bernardino	Indio	San Diego	El Centro
100 pounds																			
0																			
30	0																		
48	37	0																	
37	22	40	0																
127	118	127	114	0															
60	48	43	44	114	0														
46	33	46	25	107	44	0													
53	43	55	35	104	46	24	0												
57	46	58	40	100	51	30	21	0											
64	55	64	48	93	58	40	33	26	0										
107	86	100	97	46	97	90	86	83	77	0									
80	69	66	66	107	51	62	58	55	55	90	0								
73	64	73	62	83	64	55	48	44	35	66	53	0							
97	86	83	83	97	66	80	77	69	66	80	44	57	0						
93	86	86	80	93	73	77	69	66	62	77	51	51	24	0					
93	86	93	80	90	83	77	69	66	62	73	64	51	43	35	0				
97	90	100	86	86	90	83	77	73	69	69	69	58	55	48	33	0			
111	104	111	97	97	100	93	86	86	80	80	83	69	66	62	48	37	0		
111	104	111	100	104	100	93	90	86	80	86	80	69	64	62	46	46	57	0	
122	114	122	111	111	114	104	100	97	93	93	93	83	80	73	64	55	37	51	0
117	118	124	122	206	137	126	133	137	143	187	157	150	174	171	171	178	190	190	201
222	213	222	206	206	209	202	199	195	188	188	192	178	175	172	159	153	138	164	152

Points within the State of California. Effective January 1, 1952, pages 1–160. Both data sources are issued by the Public Utilities Commission of California, San Francisco.

cerns. Time studies of various kill floor operations were taken to estimate the capacity in head per hour for various sizes of crews. For all operations in a one-bed plant, and for all operations requiring just one worker in any scale of plant, the capacity was the time (in minutes) required to handle one carcass divided into 60 minutes per hour. For operations in multiple bed-plants using crews of workers (such as the flooring operation and the removal of hide from rump and back), the crews work over all beds simultaneously as output increases. Until all beds are operated at full capacity per bed, production is some percentage of the capacity observed by timing one animal.

In synthesizing the entire killing crew for a particular output, the number of workers and their particular jobs are specified in such a manner as to make their respective capacities harmonious with the other laborers' production levels in order to minimize excess capacity. Thus, in the smaller plants workers may perform a combination of tasks such as killing and skinning, removing, and washing the head.

The over-all plant capacity in conventional slaughtering plants is generally determined by the speed of the "rumping and backing" operation—removing the hide from the rump and the back of the animal (the evisceration is performed at the same time). Production per bed reaches a maximum (17.6 head per hour per bed) with two workers doing these skinning operations simultaneously on the same animal. Thus, the plant capacities for the conventional plants were set at 17, 35, and 50 head per hour for the one-, two-, and three-bed plants, respectively.

Standards for cooler, dock, and cleaning crew personnel were derived from time requirements estimated by Hammons and Miller (1961) in a study of Texas slaughter plants. With each plant assumed to load out one day's kill every day, cooler workers in small plants also perform the loading jobs. Such workers might also clean equipment, and wash and oil the beef trolleys.

Maintenance and yard crew requirements were based on a sample of 14 plants in California. Generally, there were definite groupings of plants with similar outputs and having the same number of yard and maintenance men. Modal values of these groupings were used to select the crew sizes.

The number of office, buying, and selling personnel specified for the model plants was based on observations of the eight plants studied in detail, plus interviews with management personnel in the industry. In the smaller plants owner-managers perform some of the bookkeeping tasks, while in larger plants the office assignments become more specialized. The synthesized office force was developed on the basis that as daily kill increased, the various accounting and bookkeeping operations would require more specialized attention.

Determining the management personnel for packing plants is a complex task since in many independent plants, and particularly in small plants, managers and owners are the same. Despite this complexity, interviews with slaughter-plant officials and observations of the division of management responsibilities in the actual plants studied exhibited a hierarchy of command calling for a general manager, senior buyer, and sales manager. These officials handle plant operations, buying, and selling, respectively.

When output reached 40 head hourly in the eight plants surveyed, a plant superintendent was added to manage the plant operations and serve as liaison between the production area and front office. At 60 head per hour, an assistant plant superintendent was added. Table 6 shows the number of employees in the various departments of the eight model slaughter plants.

TABLE 6

LABOR REQUIREMENTS FOR EIGHT MODEL PLANTS

Operation	Number of employees required for plants with hourly kill rates of:							
	17 head	20 head	35 head	40 head	50 head	60 head	75 head	120 head
Kill crew	13	17	25	32	37	44	53	83
Cooler, dock crew	4	5	8	9	10	12	12	17
Maintenance crew	1	2	3	5	5	6	7	10
Yard crew	1	1	1	2	2	2	2	3
Clean-up crew	1	1	2	2	3	3	4	5*
Office	2	3	4	5	6	7	7	13
Buyers	1	1	2	2	3	5	5	7
Sellers	2	2	3	3	4	5	6	9
Management	1	1	3	4	4	5	5	5
TOTAL	26	33	51	64	74	89	101	152

* Includes full-time man working in the basement at regular pay.

SOURCE: Logan, Samuel H., and Gordon A. King, *Economies of Scale in Beef Slaughter Plants*, Giannini Foundation Research Report 260, University of California, Berkeley (1962).

TABLE 7

COSTS OF OPERATION AT DESIGNED CAPACITIES FOR EIGHT MODEL PLANTS*

Operation	Costs for plants with hourly kill rates of:							
	Conventional dressing			On-the-rail dressing				
	17 head	35 head	50 head	20 head	40 head	60 head	75 head	120 head
	dollars							
Labor:								
Union	134,497	258,557	376,511	173,435	328,753	436,978	506,029	766,881
Salaried	61,800	124,340	179,640	71,840	145,140	229,040	239,440	346,780
Investment:								
Interest	8,049	11,574	15,749	9,671	14,809	22,355	26,062	38,985
Insurance	1,254	1,772	2,405	1,515	2,282	3,458	4,022	6,004
Taxes	3,801	5,532	7,494	4,736	7,183	10,930	12,715	18,958
Depreciation	13,192	19,548	26,239	16,066	24,524	37,162	43,185	63,108
Utilities:								
Electricity	10,232	16,852	22,399	11,362	18,725	26,074	31,576	48,147
Water	1,612	3,258	4,463	1,970	3,695	5,395	6,458	9,665
Gas	1,226	1,983	2,415	1,486	2,204	2,806	3,288	4,975
Miscellaneous:								
Repair, maintenance	10,849	22,382	32,035	21,814	25,628	38,443	48,010	76,885
Killing supplies	10,659	14,537	17,784	11,320	15,629	19,938	23,156	32,866
Office supplies	5,130	6,797	8,192	5,414	7,266	9,118	10,502	14,675
Taxes, licenses	11,654	21,826	30,340	13,387	24,689	35,991	44,430	69,898
Telephone	9,736	18,887	26,547	11,295	21,463	31,631	39,223	62,136
Delivery	14,818	22,030	28,067	16,046	24,060	32,074	38,057	56,114
Feed, corral	3,200	6,602	9,450	3,780	7,560	11,340	14,162	22,680
Buying	1,600	3,301	4,725	1,890	3,780	5,670	7,081	11,340
TOTAL COST	303,309	559,778	794,455	368,027	677,390	958,403	1,097,396	1,650,097
Cost per head	9.48	8.48	8.41	9.74	8.96	8.45	7.75	7.28

* The annual slaughter figures used to calculate the cost per head (preceded by the hourly kill rate in parentheses) are as follows: (17) 32,004; (35) 66,024; (50) 94,500; (20) 37,800; (40) 75,600; (60) 113,400; (75) 141,624; (120) 226,800.

SOURCE: Logan, Samuel H., and Gordon A. King, *Economies of Scale in Beef Slaughter Plants*, Giannini Foundation Research Report 260, University of California, Berkeley (1962).

In estimating the labor costs for the model plants, the wage scale for the conventional plants was based on the Los Angeles union contract between the independent meat packing companies and the butchers' union; for the on-the-rail plants, the wage brackets were taken from the contract between Swift and Company and the United Packinghouse Workers of America.[23] The total estimated cost for union or hourly workers is found in table 7.

The salary rates applied to office, buying, and selling employees were selected from pay scales reported by slaughtering plants in the Los Angeles area. Salaries for comparable office jobs in the plants studied were generally the same without regard to size of plant, so no adjustment was made for scale of plant.

In many cases, combined ownership-management distorts the salary paid executives, as the payment allocated to management may represent profits and salaries combined. The salary rates applied in this study were based on salary figures given by a packing industry analyst for executives in similar types of work and in some non-independent or chain meat packing plants.

[23] *Working Agreement and Wage Scale*, October 1, 1959, by and between the Butchers' Union, Local No. 563, A.F.L.–C.I.O., and Independent Meat Packers of Los Angeles County, California. Also, *Swift and Company Master Agreement with United Packinghouse Workers of America (AFL–CIO)*, covering period October 23, 1959 to September 1, 1961.

Investment

Varying ages of plants, inflationary and/or depressionary trends, plus diversity among firms in accounting policies, make the use of accounting data in determining the investment in buildings, land, and equipment unreliable. Therefore, the physical requirements of these items were synthesized and the appropriate costs were applied to the various inputs. From the investment figures, annual charges for depreciation, insurance, taxes, and interest were calculated as additional "building blocks" in the over-all cost structure.

Buildings and Improvements

Building costs were derived by use of architectural drawings of various sizes of killing floors and office space, manufacturers' specifications for boiler and refrigeration units, and, in the case of basement, storage, and employee dressing areas, extrapolation from a detailed drawing of a two-bed plant. Coolers were "constructed" by specifying 2 feet of rail space per head of cattle and then spacing rails 3 feet apart in the chill cooler and 2.5 feet apart in the storage cooler.

Construction cost rates were obtained from a meat industry report (Rothra, 1961) and were verified for the Los Angeles area by architects in that region. Table 8 shows the building investment costs.

Corrals

Corrals were specified to have capacities approximately 2.5 times the number of animals killed daily. Pens were concrete, 10 feet by 20 feet, designed to hold 11 head. Cost rates used in deriving corral construction costs were $2.75 per square foot for waterproof concrete, $2.25 per linear foot for 6-foot wood fences, and $45.00 for the 10-foot swinging gates.

Linear regression functions were derived relating the synthesized square footage of corral space and the footage of fencing required, respectively, to the total number of cattle in the pens. The equations were:

$$C = 758.873 + 22.702X_1$$
$$r^2 = 0.99$$

where C = total square footage of corrals
X_1 = total number of cattle in pens

and

$$F = 172.462 + 2.484X_1$$
$$r^2 = 0.99$$

where F = total footage of fencing
X_1 = previously defined.

TABLE 8
INVESTMENT REQUIREMENTS FOR EIGHT MODEL PLANTS

Operation	Investment requirements for plants with hourly kill rates of:							
	Conventional dressing			On-the-rail dressing				
	17 head	35 head	50 head	20 head	40 head	60 head	75 head	120 head
	dollars							
Building	149,845	185,944	258,327	152,214	225,214	325,020	375,486	563,594
Corrals	24,899	50,274	69,339	29,632	56,629	83,649	104,292	164,939
Land	8,660	15,690	21,950	9,712	18,590	26,804	32,202	49,382
Equipment*	69,078	110,405	143,066	113,244	163,219	264,597	303,634	443,074
TOTAL	252,482	362,313	492,682	304,802	463,652	700,070	815,614	1,220,989

* Includes installation charge, freight costs, and 4 per cent sales tax.
SOURCE: Logan, Samuel H., and Gordon A. King, *Economies of Scale in Beef Slaughter Plants*, Giannini Foundation Research Report 260, University of California, Berkeley (1962).

Land

No definite policy with regard to the area of land owned was found in the actual plants surveyed. The amount of land set aside for future expansion, of course, may depend on the development of the area immediately surrounding the plant. For this analysis, land needs were defined as only the area required for buildings and corrals. A cost rate of $0.50 per square foot of land, based on reports by the Los Angeles County tax office, was used to calculate land investment (table 8).

Equipment

The physical equipment requirements for conventional plants were based on observations and itemized equipment breakdowns from the seven plants studied in detail. For the on-the-rail plants, the equipment needs were taken from specifications of actual plants obtained from the Allbright-Nell Co., Chicago equipment manufacturer. Manufacturers' prices, freight charges, and a 4 per cent sales tax were used to estimate costs of equipment.

On-the-rail equipment was assumed to originate in Chicago and move to Los Angeles, and shipments for conventional plants were assumed to go from San Francisco to Los Angeles. Items identical to both systems were assumed to originate in San Francisco in order to take advantage of lower transportation costs.

Specifications and costs of pumps, boilers, and refrigeration equipment were obtained from California concerns manufacturing these items.

Annual Costs of Investment

Five major cost items arise from the investment of the firm: depreciation, insurance, property taxes, interest, and repair and maintenance. (The latter will be considered elsewhere.)

Following a procedure common to many California slaughter houses, a straight-line depreciation policy was followed using the total installed cost of goods (including sales cost, installation cost, freight cost, and sales tax) and then subtracting the salvage value of the item from the installed cost. Use-lives for specific items were taken from firm accounting records with modal values used where possible.

On a per-head basis, depreciation costs show economies of scale for the conventional and on-the-rail plants. Such costs decrease from 18 cents for the one-bed plant to 13 cents for the two- and three-bed plants. For on-the-rail plants, the depreciation costs drop from 22 cents per head for 20 head per hour to 15 cents for the 120 head per hour. Per head cost, however, jumps to 18 cents from 16 cents, as the kill rate goes from 40 to 60 head hourly. This apparent diseconomy is attributable to the change in equipment requirements. The larger plant uses a moving top viscera table and more conveyors which eliminate hauling the viscera in hand trucks. (Larger federally inspected on-the-rail plants are required by the government to utilize a moving top table to facilitate viscera inspection.)

The personal property tax rate for Los Angeles County for 1960–61 (8.0964) was applied to the synthesized plants. Application of the tax rate to the full assessed valuation would not allow for the decrease in actual market value because of depreciation. Therefore, a tax rate equal to one-half the regular rate was applied to the assessed value of the depreciable property to show the average charges paid for property taxes over the life of the equipment and buildings. The full tax rate was applied to land investment and to the salvage value of the equipment since these values do not depreciate.

A similar procedure was followed with insurance and interest on investment, but charges were applied to the full market value rather than to the assessed value. Base rates used were 1 per cent of market value for insurance and 6 per cent per year interest.

Utilities

Functions were derived regressing annual consumption of water and electricity in physical units on the number of animals killed. A least squares regression linear function relating electrical consumption of plants to the size of slaughter yielded the following coefficients:

$$E = 157{,}183.647 + 15.448X$$
$$r^2 = 0.8294$$

where E = yearly consumption of electricity in kilowatt hours and X = annual slaughter in number of head.

Usage of water under the specifications of operation for the model plants is mainly for cleaning or washing operations—that is, cleaning of the dressed carcass, washing the head, the tripe, scalding the tripe, and cleaning the floor and equipment. In many of the plants studied, additional operations such as rendering or sausage-making made the data regarding water usage unacceptable for statistical analysis since these operations require large amounts of water. Data from four plants were used to estimate a linear function passing through the mean and the origin.[24] The function was $W = 0.362X$, where W = annual water consumption in 100 cubic feet and X = yearly slaughter in number of head.

Since the major fuel item in slaughtering plants is for heating boilers, gas requirements were estimated from the amount of fuel needed to operate the boilers for 8 hours daily. The resulting figures were then adjusted to a monthly basis.

The cost rates applied to the three utility requirements were taken from rates charged by the various companies in the Los Angeles area.[25] Consumption was adjusted to a monthly basis for application of the cost schedules and was then readjusted to the annual cost basis.

Miscellaneous Costs

There are several other inputs used by slaughtering plants whose costs are relatively small individually; when considered collectively, however, they become important cost items. These catagories include nonlabor costs of repair and maintenance, killing supplies, office supplies, taxes and licenses, telephone calls, delivery and selling supplies, feed and corral items, and buying supplies—items having little basis on which they can be accurately synthesized. In these cases, accounting data obtained from the slaughtering plants surveyed were used to derive statistical cost functions. Where data did not lend themselves to regression analysis because of nonhomogeneous nature, use was made of a mean or modal figure.

In all cases, the cost variable was considered to be a function of annual slaughter in number of head; table 9 gives the resulting coefficients.

Total Costs

The costs for the various inputs were combined into total costs for the model plants (table 7). For the three conventional bed-type plants, output was varied for each plant in order to derive short-run cost functions. For the short run, it was assumed that only union labor and miscellaneous costs were variable with depreciation, insurance, taxes, interest, and costs of utilities remaining constant.[26] The indivisibility of labor

[24] Initially a function was estimated which had a negative intercept. Since this is unacceptable logically the above function was used.

[25] Electricial rates were taken from Schedule A-7 General Service of Southern California Edison Company, Los Angeles, effective January 15, 1958. Water rates were taken from *Ordinance Approving New Water Rates Fixed by the Department of Water and Power,* City of Los Angeles, effective on bills dated on and after November 1, 1959. Section 2 gas rates came from Schedule G-50 of the Southern California Gas Company, Los Angeles.

[26] While the quantity of labor in number of men is a variable input, such variation is made over time periods of greater than 1 week, as the union contract guarantees payment for a 40-hour week.

TABLE 9

ESTIMATED FUNCTIONAL COEFFICIENTS BETWEEN VARIOUS COSTS AND YEARLY OUTPUT

Dependent variable	Coefficient of determination, r^2	Constant term	Regression coefficients
		dollars	*dollars per head*
Killing costs	0.26	7,010.745	0.114 (0.087)†
Office costs	0.78	3,561.957	0.049 (0.013)
Taxes and licenses	0.98	2,084.840	0.299 (0.028)
Telephone	0.89	1,126.435	0.269 (0.048)
Delivery	0.61	8,032.860	0.212 (0.085)
Repair and maintenance	*	0	0.339
Feed and corral	*	0	0.100
Buying costs	*	0	0.050

* These items were not estimated.
† Standard errors of the coefficients are in parentheses.
SOURCE: Logan, Samuel H., and Gordon A. King, *Economies of Scale in Beef Slaughter Plants*, Giannini Foundation Research Report 260, University of California, Berkeley (1962).

inputs resulted in a cost function with a step nature, and average short-run cost functions which are discontinuous (fig. 7). The labor force is constant for small shifts in output, but it varies over the entire range of output for a particular plant. Therefore, within the various production steps for a given plant, the only variable cost becomes miscellaneous costs.

Since data for on-the-rail plants were not obtained for varying levels of output, short-run costs were not estimated. The points associated with average costs for the respective plants operated at capacity were specified to lie on the long-run cost function for their respective technologies.

Because of the indivisible nature of the killing floor over large ranges of output in conventional plants and of the labor crew for smaller production ranges, the long-run average cost function will be discontinuous. The envelope curve shown in figure 7 illustrates the nature of the actual cost curve but does not indicate actual discontinuities.

Cost Adjustments

Slaughtering costs derived for the Los Angeles area were adjusted to allow for regional differences in tax rates, utility schedules, and wage rates. Costs were adjusted for the on-the-rail plant killing 120 head hourly (142 million pounds dressed weight annually), and the regional cost differentials were specified to remain constant over all sizes of plants. (A similar adjustment for one-bed plants showed little variation from the differential calculated for the large on-the-rail plant.)

Tax rates vary considerably within a county from one district to another, depending on outstanding improvement bond charges, etc. Thus, any adjustment of the Los Angeles charge should be considered as, at best, an approximation. The base tax rate was obtained for each county in which a point of origin was located (Cranston, 1960). City tax rates where applicable, were added to the county rate (Cranston, 1961). The ratio of the combined county and city rates of other regions to that of Los Angeles then served as an index by which the tax charges in Los Angeles were adjusted to comply with the tax rates in the other slaughtering areas. Such a procedure assumes uniform assessment ratios over the state (table 10).

Utility rates for water, gas, and electricity by point of origin were obtained from the California Public Utilities Commission and from the individual companies. Rate differences for industrial usage of gas and electricity for the most part split geographically between northern and southern California. For electricity, the southern counties of Los Angeles, Orange, Imperial, San Diego, Riverside, San Bernardino, Santa Barbara, Ventura, Kings, and Tulare were specified to be serviced by Southern California Edison at the same cost as

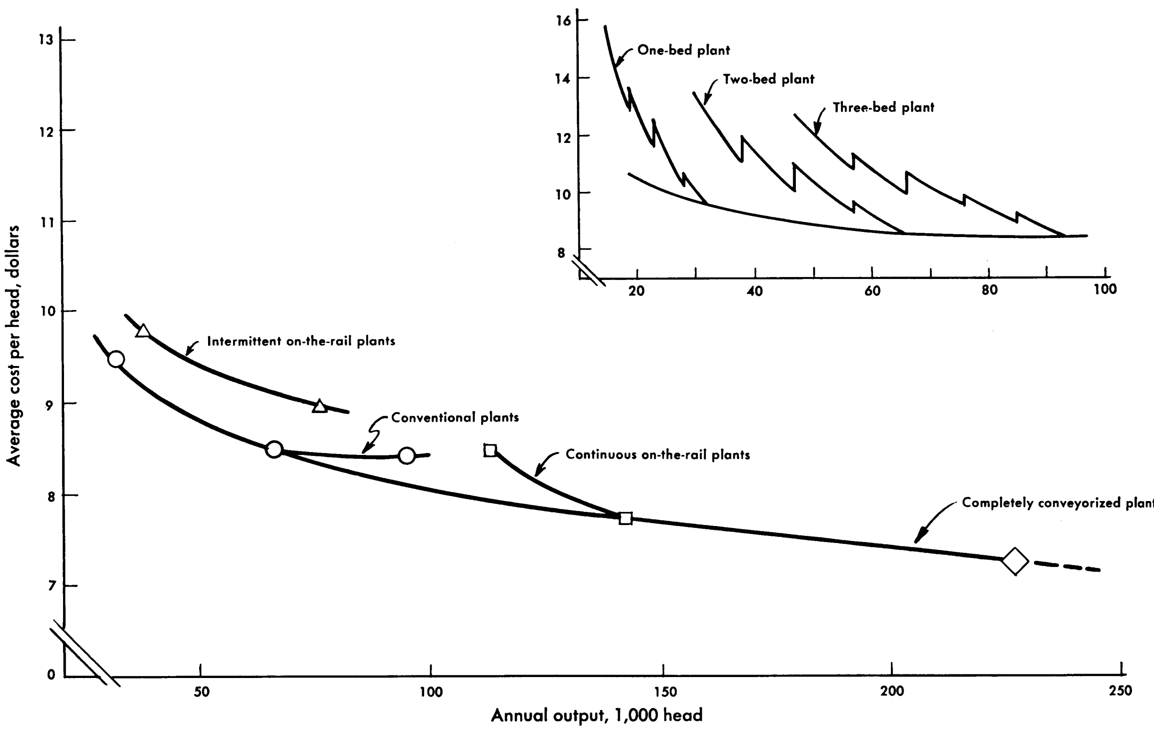

Fig. 7. Envelope curve to the long-run average cost points for the eight synthesized plants (inset in upper right shows envelope to the three short-run average cost functions for the conventional plants).

for Los Angeles County. Most of the remainder of the state was supplied by the Pacific Gas and Electric Company. The rates charged by these two concerns were assumed to be indicative of the cost of electricity in the few counties not included in their service areas.[27]

Natural gas service similarly divided into two major service areas with Pacific Gas and Electric again supplying the northern part of the state and Southern California Gas Company supplying the remainder at the same cost as for Los Angeles.[28] The same area boundary used for electricity was also applicable to the natural gas service.

Although electrical and gas service divide into two regions, the water rates from county to county show no such pattern. Much of the water service in the separate cities is supplied by municipal water districts or small individual companies. Therefore, individual water rates were obtained for the origin cities, and charges for this utility were adjusted accordingly.

In considering possible alterations in labor costs by area, union contracts for slaughterhouse workers were obtained from 17 local unions over the state. Many of the wage scales for neighboring regions were the same, or exhibited only minute differences. Five distinct differences in wage scales were evident, how-

[27] Electrical rates for northern California were taken from Pacific Gas and Electric Company Schedule P-3, General Power—Maximum Demand Basis—Alternating Current, effective November 15, 1957.

[28] Northern California gas rates were taken from Pacific Gas and Electric Company Schedule No. G-50, Interruptable Natural Gas Service, effective August 15, 1960. For Los Angeles gas and electric rates used in the study, see Logan and King (1962), pp. 85, 87.

TABLE 10

AN INDEX OF VARIOUS COST COMPONENTS OF SLAUGHTERING IN SUPPLY REGIONS AS A PER CENT OF LOS ANGELES COSTS

Central point	Water	Gas	Electricity	Taxes	Labor	Total costs
	per cent (Los Angeles = 100)					
Eureka	128	110	132	132	105	105
Yreka	127	110	132	96	105	105
Alturas	128	110	132	93	105	105
Redding	128	110	132	75	105	104
Susanville	43	110	132	89	105	104
Red Bluff	60	110	132	100	105	104
Ukiah	60	110	132	104	105	104
Willows	148	110	132	88	105	105
Oroville	105	110	132	106	105	105
Marysville	75	110	132	90	105	104
Fairfield	128	110	132	97	108	106
Sacramento	73	110	132	94	105	104
Jackson	112	110	132	60	105	104
Stockton	81	110	132	133	105	105
Oakland	98	110	132	130	108	107
Modesto	79	110	132	106	106	105
Bridgeport	82	110	132	32	106	104
Salinas	88	110	132	83	101	102
Merced	65	110	132	92	101	102
Madera	54	110	132	97	101	102
Fresno	85	110	132	114	101	102
Visalia	70	100	100	94	101	101
Bishop	87	110	132	59	101	101
San Luis Obispo	128	110	132	92	100	101
Bakersfield	69	110	132	98	100	101
Santa Barbara	138	100	100	75	100	100
Ventura	126	100	100	88	100	100
Los Angeles	100	100	100	100	100	100
San Bernardino	102	100	100	76	100	100
Indio	60	100	100	72	100	99
San Diego	193	100	100	98	100	100
El Centro	80	100	100	92	100	100

SOURCE: Based on utility and tax rates and union contracts prevailing in each area. Adjustment is for a plant killing 120 head hourly.

ever, so the state was divided into five regions (fig. 8) with the unions in a given region having the same wage scale. The wage scales for these five areas were then substituted for the Los Angeles wage rate in the killing crew cost analysis. An index was calculated with the total killing floor cost of each region expressed as a percentage of Los Angeles costs. This index was subsequently used to adjust the total union labor cost (including the nonkill floor personnel) in the other four regions. Salaries of nonunion personnel for the entire state were assumed to be the same as those used in the previous cost analysis.

Figure 9 shows the long-run average cost function—adjusted to millions of pounds of carcass beef per year, and figure 10 illustrates long-run total costs for processing cattle in terms of millions of pounds of carcass beef per year. Both functions are applicable to the Los Angeles region. The general nature of the cost function is shown by the line drawn through the points representing both on-the-rail and bed-type plants. This linear total cost function approximates the function envisaged in the theoretical model. Although use has been made (for purposes of illustration) of a continuous line, the discontinuous method of replicating kill floors for expansion under the bed system, will result in an actual function over the range for bed plants which is a step function. These

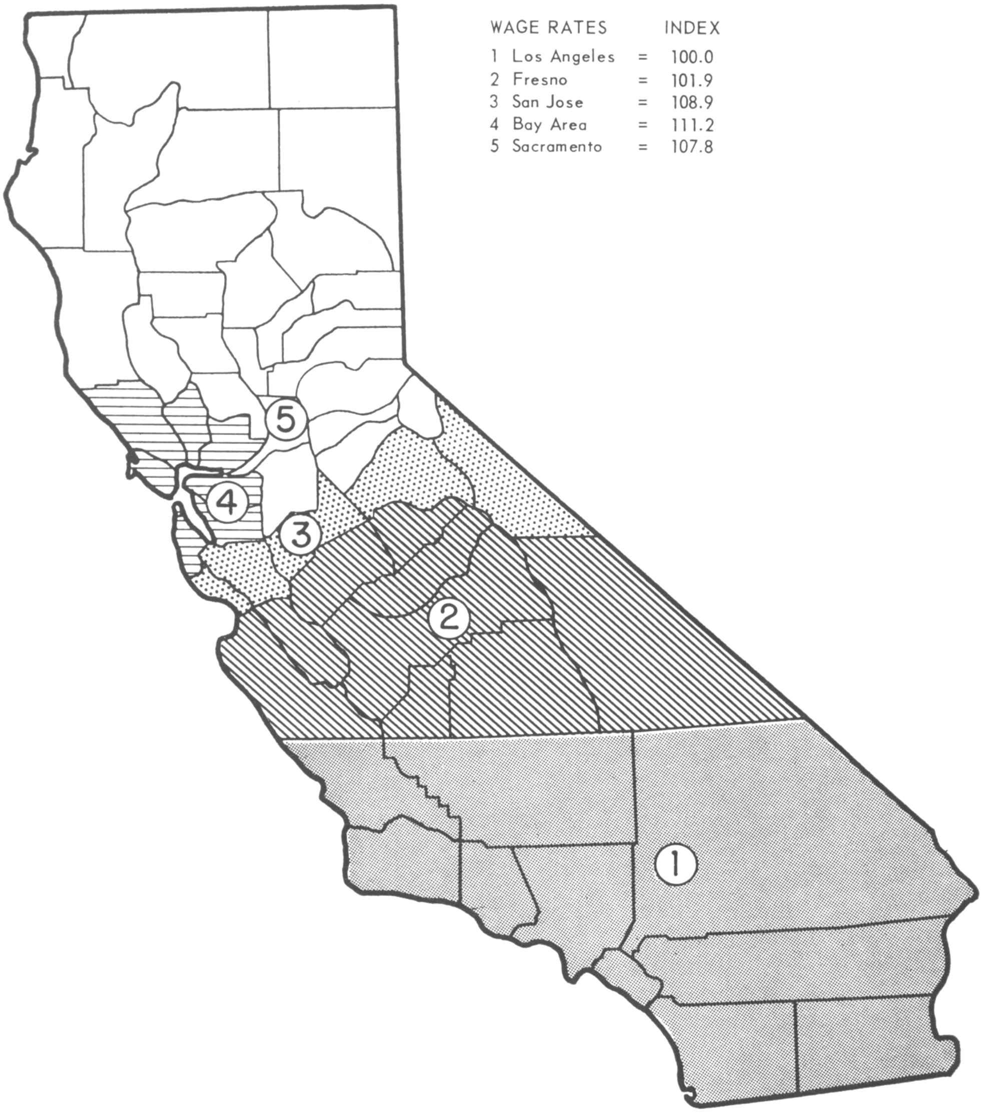

Fig. 8. Areas of the state having the same union wage scales.

departures from the smooth, continuous curves of conventional theory, therefore, require comparison of *total cost* alternatives under the spatial equilibrium model as described in the theoretical section, rather than equilibration of *marginal cost* functions. In addition, the function shown in figure 9 does not include assembly or distribution costs which will also vary for each region.

LOCATION AND SIZE OF PROCESSING PLANTS

MODEL RESULTS

The problem was set up in the transhipment framework described on pages 151 to 154. In this case, there were 34 points of origin for live animals (including the 32 in-state regions shown in

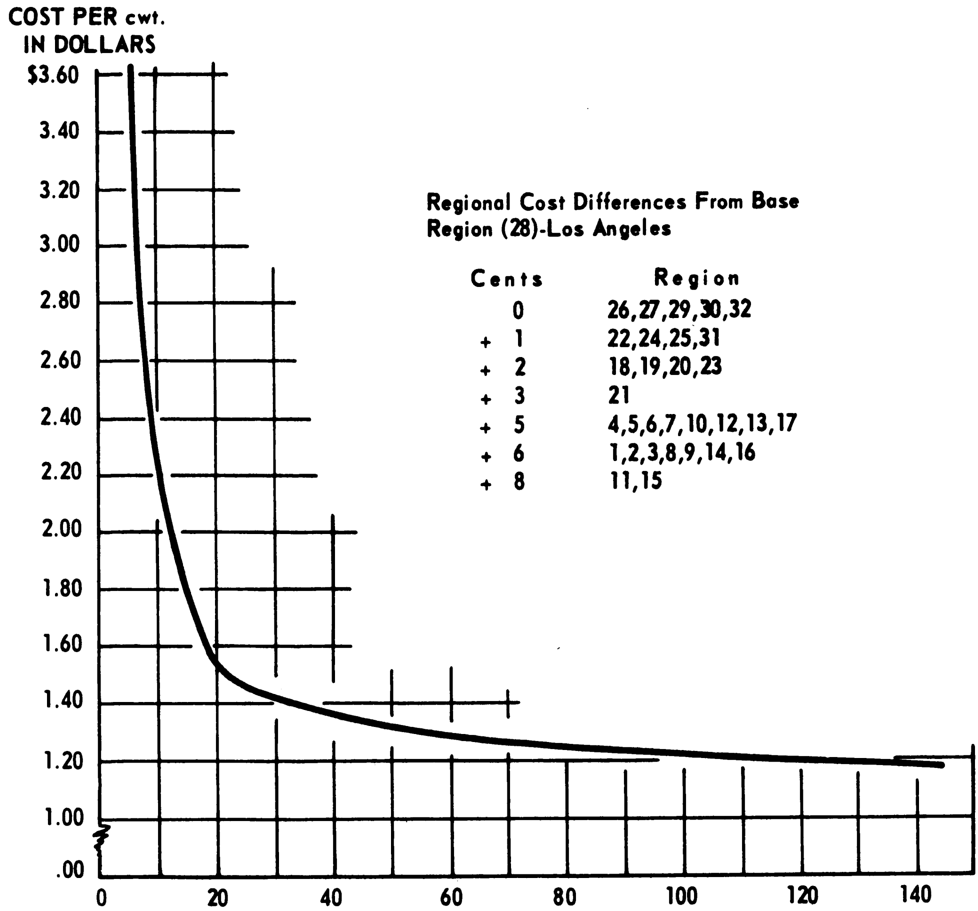

Fig. 9. Slaughter cost for beef cattle in Los Angeles, based on long-run average cost curve.

table 12, and 2 out-of-state locations) and 32 demand centers for the final product. In the transhipment model each demand center becomes a potential supplier of dressed beef by slaughtering more than its own demand; therefore, the supply centers for dressed beef were the same 32 in-state points and the 2 different out-of-state centers for final product shipment. Similarly, the supply sources of live animals also become demand centers for live animals in order to permit transhipment through intermediate points if such a procedure results in lower cost than direct point-to-point shipment.

Consequently, the transhipment problem utilized 68 sources with 66 destinations; or in terms of a cost matrix, the dimensions were 68 rows by 66 columns.

An artificial constant of 1,000 million pounds was added to each column and row. Computer restrictions prevented use of a larger constant, which would have permitted the slaughtering of the entire supply of animals at any one point; in view of the sizable transportation costs which would be incurred in such a case, however, the probability of altering the final solution by using 1,000 million pounds appeared to be negligible. Indeed, in the final solution no one point was in danger of passing the 1,000 million-pound slaughter mark.

In the initial solution of the transhipment problem, the slaughtering cost

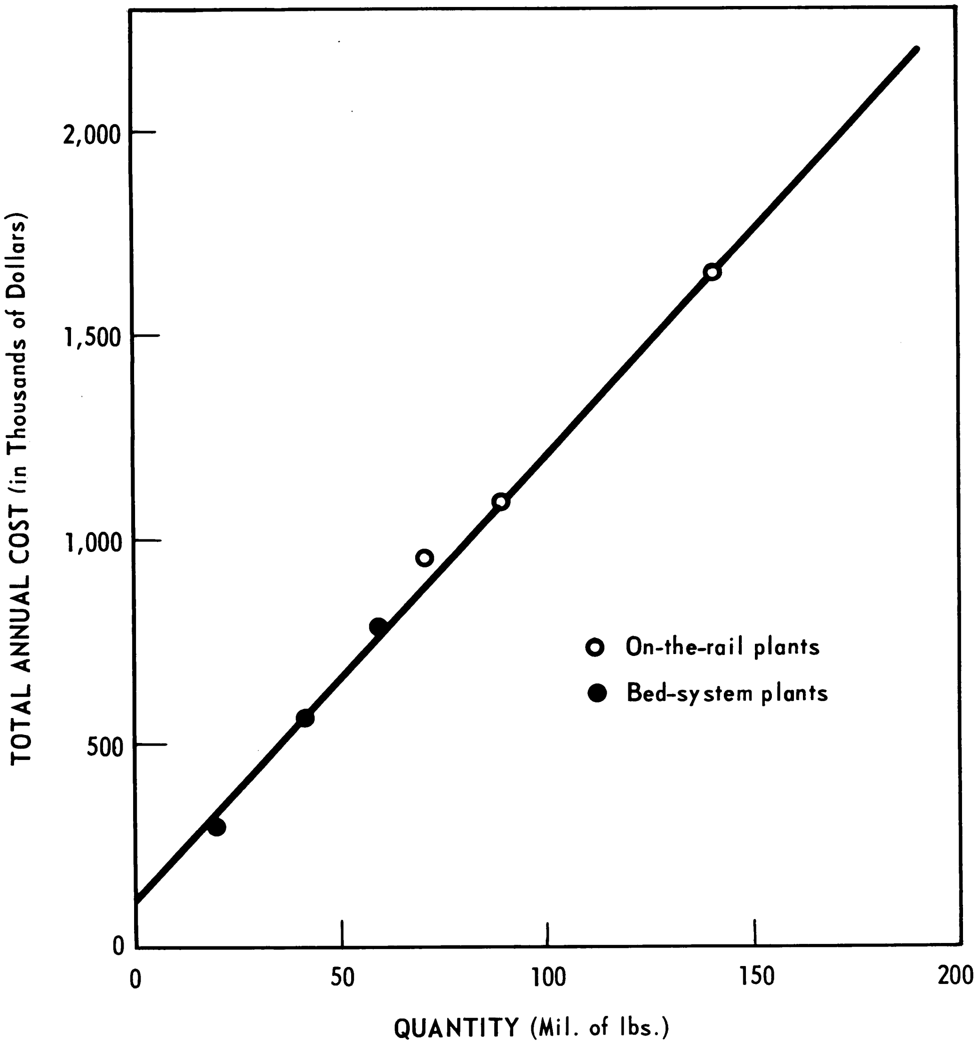

Fig. 10. Total annual cost of slaughtering cattle for Los Angeles area with plants operating at designed capacity, one shift per day.

for each region was set at the lowest point on the long-run average cost function—$1.16 per 100 pounds of dressed beef for Los Angeles. Regional differences in processing costs were included in the program.

This particular version of the problem, then, represents a situation in which processing costs per unit of output are constant regardless of size of plant. In this event, the solution to the transhipment problem is the optimum least-cost solution. The regional variations in processing costs were not of sufficient size to warrant combined slaughtering between any of the 32 regions. As a result, the solution indicated slaughtering in all regions with plants varying in size from one million pounds annual production (region 17) to multiple plant requirements with total output of 420 million pounds annually (region 28, Los Angeles).

Surplus production regions shipped their excess supplies to deficit regions either as live animals or dressed beef

TABLE 11

SLAUGHTERING AND SHIPMENT PATTERNS INDICATED BY FIRST SOLUTION

Region and city	Quantity available	Quantity of slaughter	Quantity shipped: Animals	Quantity shipped: Beef	Region and destination
	million pounds				
1. Eureka	7	7	0	7	1. Eureka
2. Yreka	9	9	0	4	2. Yreka
			0	1	1. Eureka
			0	4	15. Oakland
3. Alturas	8	8	0	1	3. Alturas
			0	7	1. Eureka
4. Redding	5	8	0	8	4. Redding
5. Susanville	6	6	0	2	5. Susanville
			0	4	15. Oakland
6. Red Bluff	9	3	0	3	6. Red Bluff
			3	0	4. Redding
			3	0	9. Oroville
7. Ukiah	4	8	0	8	7. Ukiah
8. Willows	14	4	0	4	8. Willows
			4	0	7. Ukiah
			2	0	9. Oroville
			4	0	15. Oakland
9. Oroville	6	11	0	11	9. Oroville
10. Marysville	12	18	0	18	10. Marysville
11. Fairfield	20	16	0	16	11. Fairfield
			4	0	15. Oakland
12. Sacramento	47	68	0	68	12. Sacramento
13. Jackson	4	6	0	6	13. Jackson
14. Stockton	34	30	0	30	14. Stockton
			4	0	15. Oakland
15. Oakland	56	128	0	128	15. Oakland
16. Modesto	28	21	0	21	16. Modesto
			7	0	15. Oakland
17. Bridgeport	1	1	0	1	17. Bridgeport
18. Salinas	28	31	0	31	18. Salinas
19. Merced	41	41	0	12	19. Merced
			0	29	15. Oakland
20. Madera	32	29	0	5	20. Madera
			0	24	15. Oakland
			3	0	18. Salinas
21. Fresno	112	112	0	44	21. Fresno
			0	68	15. Oakland
22. Visalia	125	125	0	26	22. Visalia
			0	1	15. Oakland
			0	98	28. Los Angeles
23. Bishop	2	2	0	1	23. Bishop
			0	1	28. Los Angeles
24. San Luis Obispo	15	15	0	10	24. San Luis Obispo
			0	5	18. Salinas
25. Bakersfield	145	35	0	35	25. Bakersfield
			110		28. Los Angeles
26. Santa Barbara	21	20	0	20	26. Santa Barbara
			1		28. Los Angeles
27. Ventura	32	24	0	24	27. Ventura
			8		28. Los Angeles
28. Los Angeles	98	420	0	420	28. Los Angeles
29. San Bernardino	10	61	0	61	29. San Bernardino
30. Indio	91	37	0	37	30. Indio
			51	0	29. San Bernardino
			3	0	28. Los Angeles
31. San Diego	6	6	0	6	31. San Diego
32. El Centro	241	241	0	9	32. El Centro
			0	114	28. Los Angeles
			0	118	31. San Diego
33. North, out-of-state (animals)	82	0	21	0	12. Sacramento
			2	0	13. Jackson
			53	0	15. Oakland
			6	0	10. Marysville
34. South, out-of-state (animals)	200	0	200	0	28. Los Angeles
33a. North, out-of-state (beef)	164	164		164	15. Oakland
34a. South, out-of-state (beef)	180	180		180	28. Los Angeles
TOTALS	1,895	1,895	489	1.895	

depending on the combined effect of regional cost differences and transportation differentials between live animals and dressed beef shipments (table 11).

When cost differences resulting from scale of plant are interjected into the model, however, the problem becomes more complex. In setting up the second iteration of the problem, the processing costs were changed to conform with either the supply of live animals within the region or the slaughter level indicated by the first solution, whichever resulted in lower cost. The effect of this change was to greatly increase slaughtering cost per 100 pounds in the regions where supplies were small (below 30 million pounds per year). Table 12 gives the average costs of slaughtering used in the transhipment problems.

TABLE 12

SLAUGHTERING COSTS PER 100 POUNDS OF CARCASS BEEF USED IN THE THREE TRANSHIPMENT PROBLEMS

Region and city	First solution	Second solution	Third solution
	cents		
1. Eureka	122	316	316
2. Yreka	122	251	365
3. Alturas	122	286	286
4. Redding	121	285	285
5. Susanville	121	364	364
6. Red Bluff	121	250	130
7. Ukiah	121	285	285
8. Willows	122	191	191
9. Oroville	122	226	226
10. Marysville	121	165	165
11. Fairfield	124	159	159
12. Sacramento	121	132	132
13. Jackson	121	364	364
14. Stockton	122	145	148
15. Oakland	124	126	124
16. Modesto	122	149	149
17. Bridgeport	121	364	364
18. Salinas	118	143	145
19. Merced	118	137	209
20. Madera	118	142	361
21. Fresno	119	124	121
22. Visalia	117	120	120
23. Bishop	118	361	361
24. San Luis Obispo	117	178	231
25. Bakersfield	117	117	117
26. Santa Barbara	116	150	151
27. Ventura	116	140	146
28. Los Angeles	116	116	116
29. San Bernardino	116	129	230
30. Indio	116	124	138
31. San Diego	117	360	360
32. El Centro	116	116	116

With the higher processing costs, it becomes feasible to ship animals from high slaughtering cost areas to regions with larger plants and lower costs. The solution to the second iteration indicated that slaughtering should be done in 17 regions rather than in all 32 areas. Production levels ranged from 4 million pounds to 485 million pounds. Most of the northern regions of the state shipped their animals to the Bay area, region 15, and received their dressed beef from out-of-state shipments of dressed beef.

At this point, the problem of coping with economies of scale in the transhipment (or any other linear programming type model) becomes evident. In the program solutions, shipments of live animals are made on a cost minimization basis for the costs entered in the program format. However, if live animal shipments are selected because of lower transportation cost to the destination and/or lower processing costs at the destination, the effect on slaughtering costs of reduced supply for slaughtering in the shipping region must be considered.

For example, in the second iteration, region 25 has a supply of 145 million pounds of dressed beef equivalent and a local demand of only 35 million pounds. The solution (table 13) indicates that region 25 sends 110 million pounds as live animals to region 28. The slaughtering cost in region 25 for 145 million pounds is \$1.17 per hundredweight; the cost in region 28 is \$1.16. The transportation costs for meat and live animals on a dressed weight equivalent are identical—51 cents per 100 pounds. As a result, it is cheaper by 1 cent per 100 pounds to ship live animals and slaughter them at the destination rather than ship meat. However, reduced supply in region 25 would raise average costs of processing to \$1.38. Thus, the savings, by shipping live animals, of \$11,000 is more than offset by the increased cost —\$73,500—of slaughtering the remaining 35 million pounds.

TABLE 13

SLAUGHTERING AND SHIPMENT PATTERNS INDICATED BY SECOND SOLUTION

Region and city	Quantity available	Quantity of slaughter	Quantity shipped: Animals	Quantity shipped: Beef	Region and destination
	million pounds				
1. Eureka	7	0	7	0	15. Oakland
2. Yreka	9	4	0	4	2. Yreka
			5	0	15. Oakland
3. Alturas	8	0	8	0	15. Oakland
4. Redding	5	0	5	0	15. Oakland
5. Susanville	6	0	6	0	15. Oakland
6. Red Bluff	9	0	9	0	15. Oakland
7. Ukiah	4	0	4	0	15. Oakland
8. Willows	14	0	14	0	15. Oakland
9. Oroville	6	0	6	0	15. Oakland
10. Marysville	12	0	12	0	15. Oakland
11. Fairfield	20	0	20	0	15. Oakland
12. Sacramento	47	68	0	68	12. Sacramento
13. Jackson	4	0	4	0	15. Oakland
14. Stockton	34	30	0	30	14. Stockton
			4	0	15. Oakland
15. Oakland	56	305	0	305	15. Oakland
16. Modesto	28	0	28	0	15. Oakland
17. Bridgeport	1	0	1	0	28. Los Angeles
18. Salinas	28	28	0	28	18. Salinas
19. Merced	41	12	0	12	19. Merced
			29	0	15. Oakland
20. Madera	32	5	0	5	20. Madera
			27	0	15. Oakland
21. Fresno	112	112	0	44	21. Fresno
			0	39	15. Oakland
			0	21	16. Modesto
			0	8	18. Salinas
22. Visalia	125	125	0	26	22. Visalia
			0	6	15. Oakland
			0	1	17. Bridgeport
			0	1	23. Bishop
			0	91	28. Los Angeles
23. Bishop	2	0	2		28. Los Angeles
24. San Luis Obispo	15	10	0	10	24. San Luis Obispo
			5	0	28. Los Angeles
25. Bakersfield	145	35	0	35	25. Bakersfield
			110	0	28. Los Angeles
26. Santa Barbara	21	20	0	20	26. Santa Barbara
			1	0	28. Los Angeles
27. Ventura	32	24	0	24	27. Ventura
			8	0	28. Los Angeles
28. Los Angeles	98	485	0	485	28. Los Angeles
29. San Bernardino	10	10	0	10	29. San Bernardino
30. Indio	91	37	0	37	30. Indio
			54	0	28. Los Angeles
31. San Diego	6	0	6	0	28. Los Angeles
32. El Centro	241	241	0	9	32. El Centro
			0	57	28. Los Angeles
			0	51	29. San Bernardino
			0	124	31. San Diego
33. North, out-of-state (animals)	82	0	21	0	12. Sacramento
			61	0	15. Oakland
34. South, out-of-state (animals)	200	0	200	0	28. Los Angeles
33a. North, out-of-state (beef)	164	164	0	15	1. Eureka
			0	1	3. Alturas
			0	8	4. Redding
			0	2	5. Susanville
			0	3	6. Red Bluff
			0	8	7. Ukiah
			0	4	8. Willows
			0	11	9. Oroville
			0	18	10. Marysville
			0	16	11. Fairfield
			0	6	13. Jackson
			0	72	15. Oakland
34a. South, out-of-state (beef)	180	180	0	180	28. Los Angeles
TOTALS	1,895	1,895	657	1,895	

In some cases, this problem can be solved by inserting the increased costs in the program and running a new iteration. If costs are greatly increased, the reduced slaughtering operation may be economically combined with that of another region at a new lower total cost. This was true, for instance, with regard to regions 19 and 20. The second solution indicated that these regions should ship live animals of 29 million and 27 million pounds dressed beef equivalent, respectively, to region 15 while slaughtering 12 million and 5 million pounds. As a result, processing costs in region 19 went from \$1.37 to \$2.09, while those of region 20 rose from \$1.42 to \$3.61. These higher costs were used in the third iteration of the problem. The new solution completely eliminated slaughtering in these two regions by having them ship all their animals to region 15 while being supplied from region 21.

Another problem in programs using linear cost functions is the possible combination of several high-cost plants into one large plant with lower costs. In the second iteration many of the northern regions shipped their live animals to the Bay area because their slaughtering costs were relatively too high. It is possible, however, that these regions could slaughter their combined live animal supply at a central point and in this manner reduce total costs of the program.

For the third iteration, therefore, costs were reduced for processing in one of the northern regions having available supplies in surrounding regions. The result was the establishment of a plant in that area in the third solution. The third iteration (table 14) indicated slaughtering plants in 12 of the 32 regions with annual production ranging from 2 million pounds to 542 million pounds. Because of the problems mentioned above, a budgeting procedure was performed on the regions whose shipments of live animals would result in substantially higher slaughter costs in those areas, and whose plants could not be economically combined with those of another region. As a result, region 25 was specified to ship meat rather than live animals to region 28, and region 14 was similarly specified to ship meat to the Bay area, thus raising its slaughter rate from 2 to 34 million pounds annually.

Of the twelve regions with slaughtering plants, six slaughtered less than or equal to the amount of their own demand. The remaining six areas received animals "from themselves," or from other areas, and transhipped the dressed beef to nonslaughtering or deficit-slaughtering regions.

While the adjusted third iteration is the least-cost solution, a circularity in the iterative procedure was found at this point. The processing cost of the Red Bluff plant used in the third iteration was \$1.30 per hundredweight. However, the supply of live animals received at that point in the solution was less than the quantity needed for a plant with costs of \$1.30. With a supply of about 37 million pounds (dressed weight equivalent), the processing cost would be \$1.42 per 100 pounds.

If a cost level of \$1.42 is utilized in the program, then Susanville (region 5) will send animals to the Bay area (region 15) and dressed beef for Oroville (region 9) and part of Eureka (region 1) will be supplied by out-of-state shipments. This again would cause processing costs to increase at Red Bluff because of the decrease in scale of operation. This pattern is followed until the plant at Red Bluff is eliminated; all supplying points send their live animals to the Bay area, and points formerly supplied with dressed beef from Red Bluff now receive shipments from out of state. However, this final solution results in a higher total cost (by about \$44,000) than the adjusted third iteration because of increased cost of shipping live animals. Therefore, the adjusted third iteration is selected as the approximate optimum location and shipment pattern because of the lower

Table 14

SLAUGHTERING AND SHIPMENT PATTERNS INDICATED BY THE THIRD SOLUTION*

Region and city	Quantity available	Quantity of slaughter	Quantity shipped		Region and destination
			Animals	Beef	
	million pounds				
1. Eureka	7	0	7	0	15. Oakland
2. Yreka	9	0	9	0	6. Red Bluff
3. Alturas	8	0	8	0	6. Red Bluff
4. Redding	5	0	5	0	6. Red Bluff
5. Susanville	6	0	6	0	6. Red Bluff
6. Red Bluff	9	37	0	3	6. Red Bluff
			0	15	1. Eureka
			0	4	2. Yreka
			0	8	4. Redding
			0	4	8. Willows
			0	3	9. Oroville
7. Ukiah	4	0	4	0	15. Oakland
8. Willows	14	0	14	0	15. Oakland
9. Oroville	6	0	6	0	15. Oakland
10. Marysville	12	0	12	0	15. Oakland
11. Fairfield	20	0	20	0	15. Oakland
12. Sacramento	47	68	0	68	12. Sacramento
13. Jackson	4	0	4	0	15. Oakland
14. Stockton	34	2	0	2	14. Stockton
			32	0	15. Oakland
15. Oakland	56	317	0	317	15. Oakland
16. Modesto	28	0	28	0	15. Oakland
17. Bridgeport	1	0	1	0	28. Los Angeles
18. Salinas	28	8	0	28	18. Salinas
19. Merced	41	0	41	0	15. Oakland
20. Madera	32	0	32	0	15. Oakland
21. Fresno	112	112	0	44	21. Fresno
			0	28	14. Stockton
			0	21	16. Modesto
			0	2	18. Salinas
			0	12	19. Merced
			0	5	20. Madera
22. Visalia	125	125	0	26	22. Visalia
			0	1	17. Bridgeport
			0	6	18. Salinas
			0	1	23. Bishop
			0	10	24. San Luis Obispo
			0	81	28. Los Angeles
23. Bishop	2	0	2	0	28. Los Angeles
24. San Luis Obispo	15	0	15	0	28. Los Angeles
25. Bakersfield	145	35	0	35	25. Bakersfield
			110	0	28. Los Angeles
26. Santa Barbara	21	20	0	20	26. Santa Barbara
			1	0	28. Los Angeles
27. Ventura	32	24	0	24	27. Ventura
			8	0	28. Los Angeles
28. Los Angeles	98	542	0	542	28. Los Angeles
29. San Bernardino	10	0	10	0	28. Los Angeles
30. Indio	91	0	91	0	28. Los Angeles
31. San Diego	6	0	6	0	28. Los Angeles
32. El Centro	241	241	0	9	32. El Centro
			0	10	28. Los Angeles
			0	61	29. San Bernardino
			0	37	30. Indio
			0	124	31. San Diego
33. North, out-of-state (animals)	82	0	21	0	12. Sacramento
			61	0	15. Oakland
34. South, out-of-state (animals)	200		200	0	28. Los Angeles
33a. North, out-of-state (beef)	164	164	0	1	3. Alturas
			0	2	5. Susanville
			0	8	7. Ukiah
			0	8	9. Oroville
			0	18	10. Marysville
			0	16	11. Fairfield
			0	6	13. Jackson
			0	105	15. Oakland
34a. South, out-of-state (beef)	180	180	0	180	28. Los Angeles
TOTALS	1,895	1,895	754	1,895	

* Costs are reduced by further adjustments: Stockton (region 14) sends dressed beef rather than animals to Bay area (region 15), while Bakersfield (region 25) sends meat rather than animals to Los Angeles (region 28). As a result, Stockton slaughters 34 million pounds, Bay area 285, Bakersfield 145, and Los Angeles 432.

cost. (This problem will also be discussed in respect to prices for live animals and dressed beef.)

The total program costs for each of the solutions, using costs associated with the indicated slaughter level in each program, were as follows:

First iteration (32 slaughtering points)	$33,602,000
Second iteration (17 slaughtering points)	32,756,000
Third iteration (12 slaughtering points)	32,374,000
Third iteration with budgeted adjustment	32,266,000
Final solution (11 slaughtering points and same budgeted adjustments as third iteration)	32,310,000

PRICE DIFFERENTIALS

The solution to the programming problem which minimizes total costs is also the dual solution which maximizes total revenue for producers, given the restraint that the revenue of the shipment cannot exceed the processing cost plus transportation charges. We have also pointed out that in a competitive framework the equilibrium prices among regions will differ only by the costs of transportation. Therefore it is possible, using the final solution to the transhipment problem and the transportation costs, to derive price differentials for dressed beef and then the imputed prices for the live cattle.

By setting the price in some base region, it is possible to calculate the prices in other regions. In this case, the base region was Los Angeles (region 28). The prices of dressed beef in regions which supply meat to Los Angeles would be the Los Angeles price minus the cost of transportation from the surplus region to Los Angeles. In algebraic terms:

$$P_{bi} = P_{b28} - t_{i28}$$

where P_{bi} = price of beef per 100 pounds in region i

P_{b28} = price of beef per 100 pounds in region 28

t_{i28} = cost per 100 pounds of shipping beef from region i to region 28.

If the price in the base region is set at zero, then the results from the above equation are the price differentials between other regions and that of the base region.

Through the various combinations of shipments of dressed beef, the price differentials for all but three regions can be calculated. These three regions (Sacramento, Santa Barbara, and Ventura) ship only live animals or receive only live animals without shipping either meat or animals. However, the prices of dressed beef can be derived by use of the imputed prices of the live cattle, as shown on page 182.

Table 15 gives the price differentials for dressed beef from the final adjusted solution; the equilibrium beef prices for various regions are also shown.

In a similar manner, the imputed prices for cattle can be calculated. In this case, the prices for cattle equal the price of dressed beef less the cost of slaughtering in the region where they are processed plus an adjustment for the transportation costs. In other words:

$$P_{cij} = P_{b28} + D_{j28} - c_j - t_{ij}$$

where P_{cij} = price of cattle per 100 pounds shipped from region i to region j (in dressed weight equivalent)

P_{b28} = price of dressed beef per 100 pounds in region 28

D_{j28} = differential in price in region j and price in region 28

c_j = cost per 100 pounds of slaughtering in region j

t_{ij} = cost per 100 pounds of transporting animals from region i to region j

TABLE 15
PRICE DIFFERENTIALS AMONG REGIONS FOR BEEF AND LIVE ANIMALS BASED ON THIRD ADJUSTED SOLUTION*

Region and central point	Beef differential (LA = 0)	Price of beef	Cattle differential (LA = 0)	Price of cattle (dressed weight)	Price of cattle (live weight)
1. Eureka	+0.27	40.27	−1.08	37.76	23.02
2. Yreka	+0.14	40.14	−1.17	37.67	22.97
3. Alturas	+0.03	40.03	−1.36	37.48	22.85
4. Redding	−0.15	39.85	−0.83	38.01	23.18
5. Susanville	−0.13	39.87	−1.13	37.71	22.99
6. Red Bluff	−0.39	39.61	−0.65	38.19	23.29
7. Ukiah	+0.08	40.08	−0.56	38.28	23.34
8. Willows	−0.11	39.89	−0.57	38.27	23.34
9. Oroville	−0.06	39.94	−0.57	38.27	23.34
10. Marysville	−0.13	39.87	−0.51	38.33	23.37
11. Fairfield	−0.04	39.96	−0.31	38.53	23.49
12. Sacramento	−0.15	39.85	−0.31	38.53	23.49
13. Jackson	−0.04	39.96	−0.53	38.31	23.36
14. Stockton	−0.34	39.66	−0.66	38.18	23.28
15. Oakland	+0.03	40.03	−0.05	38.79	23.65
16. Modesto	−0.15	39.85	−0.43	38.41	23.42
17. Bridgeport	+0.31	40.31	−1.23	37.61	22.93
18. Salinas	−0.04	39.96	−0.33	38.51	23.48
19. Merced	−0.25	39.75	−0.51	38.33	23.37
20. Madera	−0.34	39.66	−0.61	38.23	23.31
21. Fresno	−0.55	39.45	−0.60	38.24	23.32
22. Visalia	−0.62	39.38	−0.66	38.18	23.28
23. Bishop	+0.15	40.15	−0.90	37.94	23.13
24. San Luis Obispo	−0.07	39.93	−0.74	38.10	23.23
25. Bakersfield	−0.51	39.49	−0.52	38.32	23.37
26. Santa Barbara	−0.06	39.94	−0.41	38.43	23.43
27. Ventura	−0.01	39.99	−0.31	38.53	23.49
28. Los Angeles	0.00	40.00	0.00	38.84	23.68
29. San Bernardino	−0.09	39.92	−0.28	38.56	23.51
30. Indio	−0.27	39.73	−0.48	38.36	23.39
31. San Diego	−0.13	39.87	−0.46	38.38	23.40
32. El Centro	−0.64	39.36	−0.64	38.20	23.29
33. North, out-of-state	−1.21	38.79	−2.12	36.72	22.39
34. South, out-of-state	−1.59	38.41	−1.23	37.61	22.93

* Based on a price of dressed beef of $40.00 per 100 pounds in Los Angeles.
SOURCE: Differentials determined by setting the price in a base region and then (using transportation rates) calculating prices in remaining regions.

Differentials can also be calculated by setting the live animal price at zero in the base region and using the following formulation:

$$D_{cij28} = D_{bj28} + [c_{28} - c_j] - t_{ij}$$

where D_{cij28} = differential in price of live cattle (in dressed weight equivalent) in region i which are shipped to region j from the price in region 28

D_{bj28} = differential in price of beef in region j and price in region 28

c_{28} = cost per 100 pounds of slaughtering in region 28

c_j = cost per 100 pounds of slaughtering in region j

t_{ij} = cost of shipping animals from region i to region j.

The price differentials for live animals (in dressed weight equivalents) using region 28 as the base region are given in table 15 which also gives prices of cattle in dressed weight equivalent. The latter figures were derived on the basis of the carcass beef price of $40.00 per hundred pounds in region 28, or a live animal price of $38.84 ($40.00 less slaughtering costs of $1.16).[29]

[29] In the final solution the shipment pattern from Stockton to Oakland, and from Bakersfield to Los Angeles, was altered to dressed beef rather than live animals in order to retain lower

Prices of cattle on a live weight basis can be calculated by using the inverse of the figure used to adjust live cattle transportation charges to the dressed weight equivalent.

While the dual nature of the programming solution indicates prices which maximize total revenue and minimize cost for producers, the circularity of solutions explained above results in a set of live animal prices for the third adjusted solution which does *not* maximize returns to producers in four areas. These areas were the four regions (2, 3, 4, and 5) which ship their live animals to Red Bluff. Using a slaughtering cost of $1.42 per 100 pounds (rather than the $1.30 used in the problem itself) the derived prices indicate producers would be better off to ship to the Bay area. However, the total cost of the program increases if the latter procedure is followed, and this cost increase means that if producers ship animals to the Bay area the price of dressed beef in those regions formerly supplied by the Red Bluff plant would rise. Prices for beef would increase 9 cents per hundred pounds in region 1, 10 cents in region 8, 11 cents in region 2, 20 cents in region 4, and 42 cents in region 6.

At this point, one might conclude that it is a matter of the welfare of the producer versus that of the consumer. However, since the objective of this study is to derive the least-cost pattern of location and size of plant the third adjusted solution was the one used to calculate the price differentials.

Three regions did not have shipment patterns of dressed beef which allowed direct calculation of the price differentials between these areas and Los Angeles, but in these cases, shipment patterns permitted estimation of the price of live cattle in the regions. This price was simply adjusted upward by the cost of slaughter to derive the price of the finished product in the regions. A similar situation was found with respect to live animal prices for five regions which shipped only dressed beef. Here, the prices of dressed beef were adjusted downward by the cost of slaughtering to derive the prices of live animals.

The derived cattle and dressed beef prices do not show a great deal of variation over the state. The carcass beef prices range from $40.31 in Bridgeport to $39.36 in El Centro. (Out-of-state prices would be slightly lower.) Live animal prices (live weight basis) vary from $23.68 in Los Angeles to $22.93 in Alturas. On a per pound basis, the differentials would be even smaller—less than a cent a pound. It is interesting to note that the published data on slaughter cattle and dressed beef prices at a small number of points in California also indicate very little variation when considered on a per pound basis (Federal-State Mkt. News Serv., 1961).

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slaughtering costs in the surplus areas. As a result the prices shown for the live animals in Stockton are slightly lower than those that could be obtained by shipping to the Bay area; however, if the latter pattern were used the cost of slaughtering in Stockton would increase and the price of cattle sold there would be reduced. These increased costs would be more than the reduction in revenue resulting from selling all animals in Stockton and shipping meat to Oakland. For Bakersfield, transportation and slaughtering costs are such that the price to producers is the same (live weight basis) selling all animals in Bakersfield as it would be to sell them in Los Angeles. In addition, slaughtering costs in Bakersfield are lowered.

SUMMARY AND CONCLUSIONS

The objective of the above analysis was to estimate the optimum location and size of cattle slaughtering plants in California which would minimize the costs of shipping live animals to slaughtering points, processing them, and shipping the dressed beef to consumers. The method of analysis utilized the transhipment model of linear programming—a model which permitted simultaneous consideration of live animal shipments, processing, and distribution of final product.

California was divided into 32 producing and consuming regions, and two points each were designated to represent out-of-state inshipments of live animals and dressed beef, respectively. Production of feedlot cattle, dairy stock for slaughter, and culled beef herd animals was estimated by county and then combined into regional figures. A similar procedure was followed for consumption of carcass beef.

The costs of slaughtering were obtained from a previous study of economies of scale by the authors and were adjusted for regional cost differences in labor, utilities, and taxes. Transportation charges were taken from rate schedules published by the California Public Utilities Commission. (Live animal rates were adjusted to a dressed weight equivalent.)

Because of the linear nature of the programming method used, an iterative approach is required to consider economies of scale or a nonlinear average cost function. The problem was first considered with the lowest possible average cost of slaughtering for each region; then, cost rates consistent with the initial solution were substituted in the problem and another solution obtained. Three iterations were used, and the third solution was adjusted in order to take advantage of economies of scale of slaughtering in two surplus regions.

The least-cost solution with budgeted adjustments indicated 12 slaughtering regions in the state (not including the two out-of-state origin points for carcass beef). Six of the twelve slaughtering regions remained either deficit regions or slaughtered only enough for their own supply (two of these shipped surplus in the form of animals). The other areas received animals, processed them, and shipped dressed beef elsewhere.

The volume of slaughter indicated in table 14 (after adjustment) ranged from 20 million pounds at Santa Barbara (equivalent to a one-bed plant capacity) to 432 million pounds in Los Angeles (equivalent to about three of the large on-the-rail dressing plants considered in the cost study). Such a variety in the size of plants indicates the importance of assembly and distribution costs in determining the optimum size and location of plants.

Total cost of shipments and processing (not including cost of animals) decreased from $33.6 million in the initial iteration to $32.3 million in the third iteration after budgeted adjustments.

Use of the transhipment model also permitted computation of equilibrium prices for both carcass beef and live animals using the price in the Los Angeles region as a base figure. Under a competitive framework, the variation in prices over the state was $0.95 per 100 pounds for carcass beef and $0.75 for live animals (live weight basis).

MAJOR LIMITATIONS

One of the major limitations of most spatial equilibrium studies of this nature lies in the assumptions concerning the supply and demand functions involved. In this analysis the demand for final product within regions was specified as completely inelastic with respect to price—that is, it did not vary with price changes. Lack of data and the smallness of the regions prevented the estimation of demand functions by statistical methods. Should the assumption of price inelasticity be incorrect the final solution and shipment pattern could be changed, depending on the nature of the individual regional functions. Not only is there the problem of price elasticity, but other variables (such as income, sociological factors, and preferences for one type or grade of beef over another) may cause a variation in the level of demand among regions that is not reflected in the use of population factors only. The magnitude of error due to this oversimplification is impossible to determine with currently available data.

The same is true with respect to supply of live animals. The supply function within the region was again considered to be inelastic; when the over-all supply of animals facing the plant within any given region was considered, the supply function was upward sloping because of the transportation costs. No consideration has been made, however, of the production costs of the animals in feedlots or on farms. Here again if the supply function within a region is not inelastic, the equilibrium picture could easily be altered.

Any model which aggregrates areas into representative regions must also make some designation with respect to intra-regional assembly and distribution costs. For purposes of this study these costs were assumed to be equal for all regions, and therefore were not considered in the programming problems; they would have simply added a set increment to the costs used, and would not have altered the solution. But with varying density rates of both live animals and consumers, the assembly and distribution costs probably would vary among regions and thus modify the solution presented.

The use of representative origins and destinations also precludes the selection of other locations in a particular area which might be equally as appropriate as the one selected. To eliminate this limitation, however, would mean using a model with an extremely large number of possible sites and would require more data than is possible with the resources available.

Finally, the analysis presented here is of a static nature. Prices and costs are for 1960, but in industry conditions are subject to continual change, and as conditions change so may the equilibrium pattern indicated for one particular time period. Further, the above analysis deals with one year, whereas in actuality the nature of the slaughtering business is such that seasonal factors do not yield a continuous flow of live animals and dressed beef but, rather, show ups and downs within the year both in supply and demand.

IMPLICATIONS

The plants slaughtering more than 300,000 pounds live weight annually (both specialized and diversified plants) in 1960 were scattered over the state (U.S. Agr. Mktg. Serv., 1960). The large clusters of plants around the Los Angeles and Bay areas resulted in most of the processing being done at those two locations. In 1960, some 1,292,000 head were slaughtered in Los Angeles County, while 244,000 head were processed in the Bay area (Calif. Crop and Lvstk. Rptg. Serv., 1962).[30] These levels in dressed weight are equivalent to 808.8 million pounds and 152.7 million pounds, respectively.

The analysis presented above indicates that over-all costs of processing and shipping could be reduced by centralizing slaughter into 12 locations with approximately 16 plants (assumes multiples of largest plant when supply exceeds capacity of 1 plant). Regions with 1 plant include 6, 12, 14, 18, 21, 22, 25, 26, and 27. Region 15 and 32 have 2 plants each, while region 28 has 3 plants. While under the programming solution most of the state's slaughter

[30] Bay area includes Alameda, Contra Costra, Santa Clara, San Mateo, and San Francisco counties.

would be performed in the Los Angeles and Bay areas, some change is indicated from present patterns. The slaughter in Los Angeles County in 1960 was 187 per cent of that indicated by the programming solution, while the processing in the Bay area was approximately 46 per cent of the equilibrium solution. The Bay area in this case includes a smaller number than was included in the transhipment problem; therefore, the actual slaughter figures given here are likely too conservative.

In addition to a reduction in number of plants, the programming solution indicates a reduction in total costs by shifting more to the on-the-rail type of slaughtering. Out of the sixteen plants which could handle the state's slaughtering needs, only five would be of the bed-type category. These plants would be at Red Bluff, Stockton, Salinas, Ventura, and Santa Barbara (using points of origin as representative locations). The initial four would fall in the two-bed category (although not all would use the kill floor to full capacity) while Santa Barbara requirements could be met by a one-bed plant. Plant requirements in other regions would vary from one with a kill rate of slightly less than 60 head per hour (Sacramento), to multiple plant needs such as three plants in the Los Angeles region killing about 120 head per hour apiece.

The number of plants actually slaughtering cattle in California surpasses the number indicated by the programming solution, and most of them are smaller than those found in the final programming solution. A number of reasons exist for this situation. Many of the California plants are old plants. Buildings and equipment may be completely depreciated, resulting in lower total costs than the levels estimated for plants in this study. Business arrangements with feedlots or retail outlets may reduce buying and selling costs, thus enabling a plant to maintain operations which would be of higher cost otherwise. Additionally, diversified slaughtering in some areas faced with seasonal shifts in supply of animals may provide a uniform operation during the entire year even though the quantity of cattle, when considered by itself, may be relatively small. Despite the existence of many small plants in the state, the number of diversified plants appears to be declining.

Although published data concerning the size distribution of plants in California are limited, there has been evidence of a decrease in some particular categories of plants. The United States Department of Agriculture classifies plants as "medium" (annual output of 300,000 pounds to 2,000,000 pounds live weight) and "large" (annual output of more than 2,000,000 pounds live weight). The nonfederally inspected medium size plants (all species) declined by 50 per cent from 1955 to 1960 with 22 and 11 plants in those years, respectively. The large nonfederally inspected plants decreased from 53 to 48 in the same period. The number of federally inspected plants (which in general tend to fall in the "large" classification) increased from 56 to 59 (U.S. Agr. Mktg. Serv., 1960).

Considering the slaughtering regions indicated by the transhipment solution, it seems evident that slaughtering activity is tied closely to the feeding of cattle. Eight of the regions designated as slaughtering areas are among the top nine regions in the state with respect to the estimated number of cattle marketed from feedlots in 1960. Because of the uncertainty surrounding the supplies of live animals packers have engaged in custom feeding of cattle in feedlots, or have turned to the actual operation of integrated feedlots to assure themselves of a steady supply of slaughter animals. Therefore, it would seem that the future pattern of slaughtering location would be tied closely to feedlot activity.

With the apparent bond between cattle feeding and slaughtering, continued urban expansion may create a pressure to move feeding activity from heavily populated areas such as the Los Angeles and Bay areas. In this event, a decentralization of slaughtering might occur as a result of the importance of transportation costs of shipping live animals long distances.

ACKNOWLEDGMENTS

This analysis was made as a contributing study to Western Regional Research Project WM-37, "Economics of Transportation of Livestock and Meat in the Western Region," under the authority of the Agricultural Marketing Act of 1946. The authors are indebted to James N. Boles of the Giannini Foundation for initially suggesting the applicability of the transshipment model to this problem. Appreciation is also expressed to H. O. Carter, B. C. French, I. J. Hoch, G. M. Kuznets, all of the Giannini Foundation, and to G. G. Judge of the University of Illinois, for their constructive comments and criticisms in review of this manuscript.

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