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An economic analysis of alternative rail-based grain distribution systems

by

Dennis Ray Lifferth

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CHAPTER I. INTRODUCTION

Problem Statement

The physical distribution system for America's corn and soybeans has been criticized as being unresponsive to the needs of the grain industry, and slow to adjust to technological and economic change. In January of 1973 a grain elevator manager located in central Iowa stated:

For the past five years our cooperative has suffered because of a transportation crisis. At the present time we have been out of the corn market since December 15, 1972. We have the ownership and contracts of 1-1/2 million bushels of corn and 465,000 bushels of soybeans. To date we have our loan capital of $2 million borrowed to finance this grain. In the past four weeks we have moved by rail 32 cars, one half being open-top coal cars. At this rate it will take two years to move our inventory, not taking into consideration the grain inventory that is still on the farm. Iowa farmers are desperate to move their cash grain (48).

The "transportation crisis" faced by the grain distribution industry reflects significant innovations and changes in the grain industry. Corn and soybeans are becoming increasingly important products in domestic and international trade. From 1962-3 to 1972-3, U.S corn and soybean production increased from 4.3 billion bushels to 6.8 billion bushels. During this same time period, corn and soybean exports almost tripled, increasing from 538 million bushels to 1.5 billion bushels (53, 54).

This dramatic increase in grain production and
2

grain exports has contributed to storage and transportation problems. In the fall of 1969 and winter of 1970, the grain distribution system prevented many firms from fulfilling their contract commitments to both domestic and foreign buyers. A severe transportation crisis occurred again, in the fall of 1972 and winter of 1973 as reflected in the statement at the beginning of this section. And, according to an Iowa State News release in the spring of 1973, "transportation problems are expected to remain serious this summer [1973] as Iowa elevators try to move roughly 50 million more bushels than we have transportation capacity for" (44).

As grain production has been increasing, other changes have also affected the grain distribution system. Innovations in grain harvesting have caused huge quantities of corn and soybeans to move into storage or to market in short periods of time. In 1964, only ten percent of the corn crop in Iowa was shipped to elevators during the harvesting season. In 1972 thirty-two percent of the corn crop moved directly to elevators during harvest season (25). As a result of the increasing volume of grain being shipped to elevators from farms during times of peak harvest, coupled with a shortage of transportation services, elevator managers are often forced to store thousands of bushels of shelled corn in the open on roads or asphalt strips.
Railroads have introduced quantity discounts for shipping grain by multiple-car units. A single car export rate for shipping corn, for example, from a station near Fort Dodge, Iowa to Chicago is nineteen cents per bushel; a fifty car rate to the same location is only twelve cents per bushel.

In addition to multiple-car shipments, railroads are also encouraging the use of larger size rail cars for the transport of grain. The "Big John" hopper-car capable of hauling up to 3,200 bushels of grain is slowly replacing the 2,000 bushel-capacity box car. The number of 40 foot box cars in the United States has declined from 563,470 in 1960 to 212,000 cars in 1973. During the same period of time, covered hopper cars increased from 64,255 to 186,219 cars (8, 27).

Such innovations, however, as multiple-car shipping rates and the use of "Big John" covered hopper cars fail to relieve many grain elevators of their transportation problems. In fact, such innovations tend to complicate the problems of some elevator operators. Many of the rail lines in grain producing regions were located and designed to facilitate early 1900 technology. Some of the rail lines require upgrading and/or repair if they are to sustain the heavy hopper-cars and multiple-car trains. The decline in the number of 40 foot box cars and encouragement of multiple-car ship-
ments by rail carriers, place the elevators on a light branch rail line at a considerable disadvantage.

Railroad officials contend that the large number of rail lines in grain producing regions preclude an efficient rail system. As such, it has been proposed that a substantial portion of the rail services be eliminated by abandoning various rail lines. Larry S. Provo, president of the Chicago and North Western Railway Company stated:

We on the North Western want to concentrate on the services we can do best for you because from such concentration comes the efficiency that is in our mutual best interest.

This is easier for us to say than to perform for many reasons. One of these is that our physical plant—our network of railroad—is essentially unchanged from what it was at the turn of the century. In other words, we have too much railroad because we have too many branch lines with insufficient volume to justify their maintenance or their continued existence. While we are still agriculturally oriented, the very nature of our operation also makes us volume oriented. This is why we suffer severe losses in operating light density branch lines (39).

And, Jervis Langdon Jr., past president of the Rock Island Railroad stated that he

...believes that about half of Iowa's 8,500 miles of track should be abandoned, including at least a third of the Rock Island's 2,000 miles in the state. The North Western hopes to eliminate over 1,000 of its 2,800 miles in Iowa, as well as more than 400 of its 1,400 miles in South Dakota (17).

Although there seems to be a general agreement among railroads that too many branch lines are in existence, there is considerable uncertainty regarding how many lines should
be closed. Railroad companies compete with each other for a given supply of grain. If all grain transported from a given region is moved by rail then, clearly, the more grain moved by one company the less grain moved by the other carriers. In the event that several of the branch rail lines within the region are operating at a financial loss, the abandonment of one branch line may increase the demand for services of the remaining lines to a level great enough to allow the remaining lines to all operate above their break-even point. Since it is necessary in this case for one line to be abandoned to ensure the profitability of the remaining lines the question arises: Which rail company should abandon its line?

The various stages of production, processing, and transportation, that constitute the distribution channel of grain are also highly interdependent. The growth or adjustment of one stage should complement the other stages within the marketing channel. In the attempt to decide which lines should be abandoned, potential sites of processing plants should also be considered. And, likewise, processing plants must take into consideration the long-run adjustment plans of the railroads as expansion or relocation of processing facilities is scheduled.

Predicting the future actions of other market participants, however, is very difficult and probabilistic.
Integration either vertical or horizontal, or explicit collusion between various stages of the distribution channel are ways to circumvent such problems of uncertainty, but both methods are discouraged by the institutional constraints of public policy. The pricing system may provide information concerning equilibrium prices, production possibilities, and preferences, but often fails to provide adequate signals or information concerning the expansion plans of other members of the distribution channel. In this sense, the competitive pricing system fails to serve as an efficient guide for decision making.

A lack of information concerning the behavior or future plans of other marketing participants may delay or prolong the needed industry adjustments until additional information can be obtained. With insufficient information the marketing industry may attempt to adjust to a state of disequilibrium through a process of trial-and-error or tatonnement. This process often causes the adjustment path to be circuitous and indirect and, thus, less than optimal.

The extent to which industry resources are misallocated by delaying the adjustment process and/or following a circuitous adjustment path depends to a large degree on the size of the required capital investments or disinvestments. An industry in a state of disequilibrium following a structural change may adjust in various ways. The industry
may, for example, be able to simply change prices or output with very little change in plant equipment. In the search for the equilibrium configuration of prices and output there may be some misallocation of resources. In the event, however, that large changes in capital equipment are required, such as rail line abandonment or the construction of a large subterminal, the misallocation of resources resulting from a circuitous adjustment path is significant.

The public sector has also raised questions regarding the propriety of rail line abandonment: What impact would the closure of various rail lines have on the road system or community? Closing a rail line may impose certain costs on society that should be weighed against the benefits of the abandonment. One would expect a significant increase in the use of a road system if many rail lines were abandoned. An elevator, located on an abandoned rail line for example, and handling 1.6 million bushels of grain yearly would require an 800 bushel truck to make 2,000 trips to move the grain previously moved by rail.

The social costs resulting from rail abandonment could come from several sources: 1) The additional use of the road system by trucks adds to road congestion. Such congestion may not only slow the flow of traffic, but may also increase the hazards of road travel. 2) Additional public investment to upgrade and maintain the road network may be
required to handle the increased use of trucks. 3) Noise and smoke pollution around the road system may increase from the additional trucks being used. And, 4) increased truck usage, relative to rail, may result in additional energy requirements to transport grain.

Public regulation of rail abandonment began almost simultaneously with the birth of the railroad system. A brief historical sketch of rail abandonment regulation is presented in Appendix C. The effectiveness of such regulation, however, has been questioned.

To insure the viability of a national transportation system necessary to sustain interstate commerce, national regulation of rail abandonment was formalized in 1920 when congress passed the Transportation Act. The Act gave the Interstate Commerce Commission, I.C.C., the authority to regulate rail abandonment by providing that no rail company "...shall abandon all or any portion of a line of railroad, or the operation thereof, unless and until there shall first have been obtained from the Commission a certificate that the present or future public convenience and necessity permit of such abandonment" (51, p. 11870).

The disadvantages to the public brought about by rail line abandonment are typically weighed and balanced against the advantages that would accrue to the railroad seeking the abandonment. Relatively few efforts, however, have been
made to quantify the impact of rail abandonment on "public convenience and necessity".

In summary, recent innovations in grain harvesting and rail transportation, and changes in the supply of and demand for feed grains are some of the factors disrupting the grain distribution system. The production of corn and soybeans is increasing; larger volumes of grain are moving to more distant markets; new harvesting techniques are forcing huge quantities of corn and soybeans into elevator storage or market in short periods of time; railroad carriers are introducing multiple-car shipping rates, encouraging the use of "Big John" covered hopper cars, reducing the number of 40 foot box cars, and proposing the abandonment of a significant proportion of track milage; and, neither the pricing system nor regulatory policies are adequately designed to coordinate or facilitate the industry adjustments needed to insure an efficient physical distribution system and provide for the general transportation needs of the grain industry.

These innovations and changes in grain processing, transportation, and production are the source of many uncertainties and questions. How many new elevators should be built? Where should they be located? How large should they be? How many of the existing elevators should be expanded; and how large should they be? Which rail lines should be
Should existing rail lines be upgraded; or, should new lines be constructed? Those who attempt to determine which rail lines should be abandoned often find that the location of elevators must first be determined. Those who attempt to determine where elevators should be located discover that it depends on the future of the rail network. How much grain should each elevator receive from each origin? How long should each elevator store the grain; and, how much should each elevator ship to each destination? The overall purpose of this study was to account for some of these interdependencies of grain marketing and determine the economics of alternative rail-based grain distribution systems within a specific region.

Objectives

The idea of searching for a better system is at least as ancient as Plato's Republic, but it is only recently that tools have become available for a systematic, analytical approach to such search procedures. This new approach refuses to accept the institutional status quo of a particular time and place as the only legitimate object of interest and yet recognizes constraints that disqualify naive utopias (22, p. 1).

The general objective of this research was to determine and evaluate the advantages and investment requirements of alternative rail-based grain distribution systems by analysis of actual production, storage, and transportation elements within a given region. More specifically, the objectives of
this research were to determine 1) the number, size, and location of country elevators and grain subterminals; 2) the rail line network; and 3) the flow of grain from producers to terminal markets over time and space to maximize joint net revenue of the grain distribution industry within a specified region.

Method of Analysis

The nature and scope of the problem statement and objectives of this study suggest a method of analysis that lies within the purview of location-allocation models. Chapter II briefly reviews selected plant-location models and specifies a two stage multi-period plant-location model used to accomplish the objectives of this study.

In Chapter III data requirements for the model, including a description of the selected region, are presented. A description of the 1970 grain distribution facilities in the selected region was necessary in order to evaluate the additional investment requirements of alternative grain distribution systems. The planning horizon over which alternative distribution systems are evaluated extends to 1980. All costs, however, are expressed in terms of 1972.

In Chapter IV the results and conclusions of the study are presented. Alternative rail-based grain distribution systems are discussed in terms of costs, benefits and
investment requirements. The 1970-71 monthly flow of grain in the selected region is also presented as estimated 1) by data collected of actual grain flows, and 2) by the plant-location model, assuming all facilities in 1970 as given.
CHAPTER II. MODEL DEVELOPMENT AND SPECIFICATION

Review of Transhipment Plant-Location Models

Spatial models are designed to account for economic activities involving spatial transformations. Kuenne (30, p. 398) classifies spatial models into two types: inter-regional trade and locational models. Locational models may also be referred to as location-allocation models.

The first type, interregional trade models, specifies the locational points of supply, transhipment, and demand; and, for a given technology determines the commodity flows between such points. Interregional trade models, often referred to as spatial equilibrium models, may specify fixed supply and demand, fixed supply and variable demand, variable supply and fixed demand, or variable supply and demand. Such models have also been specified to allow for temporal and material transformations. The main distinction of this type of model is that the location of all regions or constellation of processing facilities, warehouses, origins, and destinations are exogenous to the model.

Location-allocation models, the second general type of spatial models, determine not only commodity flows over space but also the location of processing plants, and warehouses. That is, one objective of locational models is to endogenously determine the spatial structure of the economy.
Since it was the objective of this study to determine the number, size, and location of grain handling and distribution facilities within a specific region, the appropriate spatial model to use was a location-allocation model. More specifically, the type of model used for this study may be classified as a transhipment plant-location model.

Transhipment plant-location models are used to determine the spatial structure of a subsector of the economy when both the transportation costs from origin to plant, and from plant to destination are important. Various models have been proposed and used in an attempt to determine the optimal number, size, and locations of plants or warehouses. Many techniques of programming, including linear, separable, and concave have been used. In addition to these programming models, other techniques, building on procedures initially used by Stollsteimer (49), have been developed which employ combinatorial algorithms in the search for optimality. This section reviews programming and Stollsteimer-type transhipment plant-location models.

Programming models

The problem of plant location with transhipment may be expressed as a linear programming model. If we assume that the marginal costs of assembly, processing, and distribution are constant and assume inelastic supply and final demand, the
model may be expressed as follows:

Minimize

\[ z = \sum_i \sum_h C(h, i) X(h, i) + \sum_i P(i) X(i, i) \]
\[ + \sum_i \sum_j C(i, j) X(i, j) \]  \hspace{1cm} (2.1)

subject to the constraints

\[ \sum_i X(h, i) = X(h, \cdot) \] \hspace{1cm} (2.2)
\[ \sum_i X(\cdot, j) = X(\cdot, j) \] \hspace{1cm} (2.3)
\[ \sum_h X(h, \cdot) = \sum_j X(\cdot, j) \] \hspace{1cm} (2.4)
\[ X(h, i, j) \geq 0 \text{ for all } h, i, j \]
\[ h = 1, 2, ..., H \]
\[ i = 1, 2, ..., I \]
\[ j = 1, 2, ..., J \] \hspace{1cm} (2.5)

where \( H \) is the number of supply points, \( I \) is the number of processing plants, \( J \) is the number of demand points, \( X(h, \cdot) \) is the supply of a commodity at location \( h \), \( X(\cdot, j) \) is the demand for the commodity at location \( j \), \( C(h, i) \) is the marginal cost of shipping a unit of the commodity from origin \( h \) to plant \( i \), \( C(i, j) \) is the marginal cost of shipping a unit of the commodity from plant \( i \) to destination \( j \), \( P(i) \) is the marginal cost of processing at plant \( i \), \( X(h, i) \) and \( X(hij) \) are the number of units of commodity
shipped from origin h to plant i and from plant i to destination j in order to minimize total cost z.

Solving the above linear programming transhipment model by, for example, the simplex method will provide a least cost solution for a given constellation of plants. If the analysis were to end at this stage the model would be classified as a spatial equilibrium or interregional trade model. To determine the least cost number and location of plants, the model must be respecified with a different configuration of plants and the least cost outcome compared with the previous solution. This process must continue until all feasible combinations of plant number and locations are compared. From these comparisons the spatial structure providing the least cost solution could be chosen.

In the absence of economies of scale in processing, however, adding plants to the spatial structure will never increase processing or transportation costs and may lower the total costs of transportation. With supply being fixed, additional plants entering the solution will tend to lower the average volume processed for all plants. To avoid a solution suggesting the location of a plant at each possible plant site, a constraint could be added to the model specifying a minimum plant volume necessary for economic viability.

It is important to note that the solution to a linear programming model may not be unique. Several solutions may
exist which are equally optimal using least cost as a criteria. And as stated by Leath and Martin: "...the fact that multiple solutions do exist means that the minimum-cost shipment pattern for the industry will not, in general, yield a minimum cost shipment pattern for each individual segment of the industry under consideration. Thus, various segments of an industry may have very real preferences for a particular solution among the set of solutions which are optimal for the entire industry." (34, p. 906).

It is often desirable to consider the influence of economies of scale in either assembly, processing, or distribution on plant number, location, and size. Several methods exist to handle cases where marginal costs are dependent on the volume handled. King and Logan developed a model to determine the optimum number, size, and location of beef slaughter plants in a region in California (28). They assumed that the long-run average cost curves for slaughtering beef varied by region and sloped downward to the right.

To account for the economies of scale in slaughtering plants, King and Logan used the linear programming transshipment format and heuristically adjusted the processing cost coefficients to be consistent with the plant cost function. Adjusting the processing cost coefficients was accomplished by initially setting all processing cost coefficients equal
to the minimum average processing costs. The model was then solved for the optimal number, size, and location of plants. Plant volumes determined by the solution were then compared with the assigned marginal cost. If all cost coefficients of the initial run were consistent with the linear programming solution then further iterations were not necessary. If the coefficients were not consistent then the following two steps were taken: 1) all plants which failed to enter the previous solution were effectively removed from further solutions by assigning to them high marginal plant costs. And, 2) the remaining processing cost coefficient were adjusted to be consistent with the previously determined linear programming optimal size of plant. Following these two steps the linear programming model was rerun. In this manner King and Logan continued until a local optimum was reached wherein all cost coefficients were consistent with the least cost size of plant.

The solution may be neither global, unique nor optimal. King and Logan used a budgeting approach to supplement the linear programming solution in order to circumvent non-uniqueness.

Another method which may be used to solve plant location models with transhipment and economics of scale is separable programming. Separable programming provides a method of handling nonlinear objective functions. If there are
economies of scale in processing which may be approximated with linear segments, the plant location problem may again be expressed in a linear programming format. Unlike the heuristic approach of King and Logan requiring successive iterations, the initial solution of separable programming will provide an optimal solution.

Kloth and Blakley used separable programming to determine the number, size, and location of dairy processing plants to minimize the assembly, processing, and distribution costs of the dairy industry. In addition to assuming economies of scale in processing they also imposed market share restrictions on processing plants (29).

Another technique that may be used to solve the problem of plant location with transhipment and economies of scale in processing is concave programming. As with the King and Logan model, local optima may be neither unique nor global. Several methods to find the global are available. One procedure would be to examine all possible local optima from which the global would be chosen. This procedure is normally not feasible due to the expense of the exhaustive search.

An alternative method of solution for concave programming, which appears to be fairly operational, uses a cutting plane to insure examination of more than one local optima. Cnadler and Snyder used a cutting plane technique with concave programming to estimate rice mill location with falling
average cost (8). The following steps are a summary of their procedure: 1) set processing costs equal to zero and solve using linear programming techniques; 2) adjust processing costs for each plant to be consistent with the flows of step one and solve again using linear programming; 3) continue by following the iterative approach as suggested by King and Logan until a local optimum is obtained; 4) if several local optima exist insert a cutting plane, or constraint, which eliminates solutions of a greater value than the original optima. Thus, successive runs will provide solutions drawn from a feasible space smaller than the original. New solutions will either be comparable to the previous solution or preferable; and 5) continue step four until one local optimum can be found which will also be global.

Stollsteimer-type models

Stollsteimer developed a plant location model with economies of scale in processing to determine the least cost number, size, and location of pear packing facilities in the Lake County region of California (49). The model was designed to minimize the combined cost of assembling and packing pears, disregarding the influence of costs of distribution on plant numbers and locations. It is important to note that the algorithm developed by Stollsteimer is not an extension or application of linear programming. The model was
solved by using a systematic search of various feasible solutions and selecting that constellation of plants and commodity flows for which costs were minimized. It has been shown that Stollsteimer's combinatorial method of solution provides a unique, global optimum (32).

Various extensions and modification of the Stollsteimer model have been made. Shortly following the publication of the Stollsteimer model in 1964, Polopolus, in 1965, extended the single product model to encompass the multiple product case (38). Aggregate processing and assembly costs of products were determined by summing the costs of individual products and making the appropriate deductions for joint costs. Joint costs were involved whenever the same productive inputs were used for two or more products.

In 1970 three additional modifications of the Stollsteimer model were made. Ladd and Halvorson presented procedures to determine the sensitivity of the Stollsteimer model solution to changes in various parameters (31). Chern and Polopolous presented a technique to handle discontinuous plant cost functions (11). And, Warrack and Fletcher suggested various heuristic procedures to avoid the necessity of computing all combinations of plant numbers and locations (59). Several rules were suggested which may be used to circumvent the excessive computational costs when
large numbers of potential plants are considered.

In 1973, Professor George Ladd, in an article entitiled "Fifth Variation on a Theme by Stollsteimer", further extended the scope of the Stollsteimer model to include single-stage transhipment (33). Here, a procedure to determine the number, size, and location of processing plants to minimize the sum of the cost of assembly, processing, and distribution was presented.

In the event that supply is predetermined and no restrictions are placed on demand, the method of solution developed by Ladd may be outlined as follows: 1) Compute the transportation cost matrix for distribution from plant site i to destination j. Denote this matrix by $C(.ij)$. 2) For each plant, select that destination for which $C(.ij)$ is a minimum and denote by $C(.i \overline{j})$. And 3) add to the assembly cost matrix, $C(h i .)$, the minimum distribution cost for each plant i as determined in step 2. Denote this new augmented assembly matrix as $C(h i \overline{j})$. The augmented assembly cost matrix, therefore, reflects the transportation cost from origin h through plant i to that destination for which the distribution cost from plant i is minimized.

Once the augmented assembly cost matrix is computed the methodology and steps outlined by Stollsteimer may be used to determine the least cost number, size, and location of plants. Stollsteimer's assembly cost matrix is simply replaced with
the augmented matrix computed in step 3. A problem with
quantity restriction on demand, rather than on supply,
may be solved similarly.

Ladd also presented methods to handle per unit trans­
port costs that decline with increasing volume; and, market
prices which vary as a function of volume shipped. The
model used in this thesis to evaluate the economics of
alternative rail-based grain distribution systems was an
application and extension of the transhipment plant-location
model developed by Ladd.

Plant and Rail Line Location Model

The uses of the model are to determine: 1) the
number, size, and location of country elevators and grain
subterminals; 2) the rail line network; and, 3) the ship­
ments of grain from origins to final destinations over time
and space to maximize joint net revenue of producers. The
model is a two stage multi-period transhipment plant-location
model. The method of solution is based on a combinatorial
algorithm which systematically compares alternative rail-
based grain distribution systems and selects the optimal
configuration based upon the criteria of maximum joint net
revenue for producers. This section presents 1) the assump­
tions of the model and a restatement of the problem, a
definition of symbols and mathematical functions, 2) a
a mathematical statement of the problem, 3) a method of solution, and 4) an example.

Assumptions of analysis

The transhipment plant-location model and the method of solution are based on the following assumptions and problem statement: two grains, corn and soybeans, are shipped from origins located within a specified region. The supply of each grain at each origin is known for time t. Each grain producer located in the selected region has the option of shipping his monthly supply of each grain to either a country elevator or to a subterminal elevator. The elevator can store and ship grain to a subterminal or to a terminal market. A subterminal can store and ship to a destination. "Final destinations" and "terminal markets" are used synonymously and refer to either foreign export markets or domestic processing markets involving the physical transformation of grain.

A country elevator receives grain from producers. The grain is stored and then shipped by truck, truck-barge, or rail in single-car shipments to either a subterminal or to a final destination. A subterminal may receive grain from producers and country elevators. Grain received by a subterminal will be stored and then shipped by multiple-car rail shipments to final destinations. Country elevators are, by
definition, located such that they cannot take advantage of the lower rail costs (or rates) of jumbo hopper-cars or multiple-car rail shipments.

Grain received at an elevator during month \( t \) may be stored from \( t \) to \( t' \), \( t = 1,2,...,12; t' \geq t \). The length of time that grain is stored depends, in part, on monthly prices at terminal markets, seasonal transportation rates and elevator capacity. Monthly demand prices are known and vary by commodity and over time for each destination. Transportation rates are also known and vary over time and by commodity.

The costs of handling grain at elevators are separated into two components: 1) total annual cost of constructing or expanding an elevator; and 2) marginal operating and maintenance costs of receiving, storing, and loading out grain at elevators. Marginal elevator operating and maintenance costs are independent of the volume handled, but vary by commodity. The marginal operating cost of storing one bushel, however, depends upon the length of time the commodity is stored. Marginal operating costs of receiving include the operating cost of drying the grain and, thus, vary by time period. And, marginal operating costs of load out depend upon the mode of transportation used to ship grain to terminal markets.

Total annual costs of establishing or expanding an ele-
vator involve the costs of constructing or expanding receiving, drying, storage, and load out facilities. Elevators require a certain minimum capacity of facilities. Country elevators require a certain number of acres of land, a driveway, receiving pits, scales, driers, and other facilities all of which are necessary to perform the functions of a country elevator. Subterminals require greater receiving and drying capacity than country elevators because subterminals receive grain from both farmers and country elevators. Subterminals also require greater load out capacity than country elevators because subterminals load multiple car trains.

Total elevator expansion or construction costs of receiving, drying, and load out are independent of volume but vary by elevator type. Country elevators that expand to a subterminal status must upgrade receiving, drying, and load out facilities to meet the minimum capacity requirements of a subterminal. Total annual construction or expansion costs of storage consist of 1) a fixed cost that reflects the minimum annual cost of constructing storage facilities and 2) a marginal expansion cost that reflects the additional elevator costs of expansion to store one bushel of grain.

Some grain distribution facilities, including elevators and rail lines, exist at the beginning of the planning horizon, 1971. Some of the existing country elevators are to continue in use and some are to be expanded into subterminals.
Some new subterminals are, perhaps, to be constructed. And, some rail lines may need to be abandoned and other lines upgraded.

The constellation of elevators and rail lines that should exist at the end of the planning horizon, 1980, depends upon the number, size, and location of facilities existing in 1971. Facilities that exist at the beginning of the planning horizon affect the optimal path of industry adjustment due to the nature of their "sunk" costs. Total construction and/or expansion costs, therefore, vary by location and depend upon the size of the existing facility.

In addition to the physical facilities that exist at the beginning of the planning horizon, there are also established traditions and relationships between grain producers and local elevators. To account for some of the marketing and social rigidities resulting from producers preferring to patronize local elevators, a capacity expansion constraint is imposed. It is assumed that no elevator will expand storage capacity as long as there exists unused storage capacity at any other elevator.

Economies of scale in rail transportation result from both the fixed set up costs of rail line installation and maintenance, and the economies of transporting large volumes of grain. Total rail transportation costs, therefore, include:

1) a minimum cost of establishing and/or maintaining a branch
rail line; and 2) a marginal cost of shipping which depends upon the type of elevator and minimum rate available. The minimum rate available to a country elevator, for example, is a single car rail rate.

Producers in the area cooperate to maximize joint net revenue. Elevators in the area are members of co-operatives, organized by grain producers. The design of such organizations is to facilitate the marketing of grain to provide the greatest possible returns to the members of the co-operatives. Elevators, thus, pass on to producers all revenues minus elevator handling costs. Net revenue is the income received at terminal market minus all grain handling costs involving spatial and temporal transformations. For this problem net revenue maximization is appropriate rather than cost minimization because monthly prices at terminal markets vary by destination and are used to determine seasonal storage patterns.

**Definition of symbols and mathematical functions**

The definition of symbols and/or mathematical functions are presented in this section that relate to: 1) the spatial structure of the grain distribution system; 2) the spatial and temporal flow of grain; 3) total transportation costs; 4) total grain handling costs at country elevators; 5) total grain handling costs at subterminal elevators and; 6)
total revenue. All symbols defined in this section are needed in stating the objectives of the two stage multi-period transhipment plant-location model. Other symbols are defined as they are introduced.

The time horizon over which alternative rail-based grain distribution systems are evaluated extends from 1971 to 1980. Symbols, unless stated otherwise, represent the crop year 1980. Time, which varies from \( t = 1, 2, \ldots, 12 \), denotes months where the first month of the crop year is October.

Symbols are classified as exogenous, endogenous, or both exogenous and endogenous. The value of exogenous variables or parameters are determined outside of the model and taken as given. The value of endogenous variables are determined by the model. Variables are classified as both exogenous and endogenous if they are predetermined for one time period and then become endogenously determined thereafter.

Let:

\[ en = \text{the set of endogenous variables and} \]
\[ ex = \text{the set of exogenous parameters and variables.} \]

Symbols in this section are identified as exogenous, endogenous, or exogenous and endogenous by placing \( ex, en, \) or \( ex \) and \( en \) within parentheses at the end of each definition.
Spatial structure of the grain distribution system

The following symbols denote the predetermined location of final destinations and country elevators. Potential sites for subterminals and alternative rail line systems are also identified. Various combinations of rail line systems, and subterminal numbers and locations, form the spatial structure of alternative rail-based grain distribution systems. Let:

\[ e = \text{element of} \]
\[ L_j = \text{location of } j^{\text{th}} \text{ final destination}; \ j = 1,2,\ldots,J; \ (\text{ex}). \]
\[ L_{1h} = h^{\text{th}} \text{ plant site for a country elevator or elevator of type one}; \ h = 1,2,\ldots,H; \ (\text{ex}). \]
\[ L_{2i} = i^{\text{th}} \text{ plant site for subterminal or elevator of type two}; \ i = 1,2,\ldots,I; \ (\text{ex}). \]
\[ r = r^{\text{th}} \text{ rail line network}; \ r = 1,2,\ldots,R. \ A \text{ rail line network represents one feasible combination of rail lines in a region. The locational pattern of a rail line system may be altered by abandoning or upgrading rail lines existing at the beginning of the planning horizon, 1971; or by constructing new rail lines. Potential subterminal sites depend upon the rail line network since, by definition, a subterminal ships grain only by rail in multiple-car trains}; \ (\text{ex}). \]

\[ \lambda_{mnr} = \text{one alternative locational pattern for subterminals and rail line system, where } m \text{ denotes the } m^{\text{th}} \text{ locational pattern for } n \text{ plants of type two given the } r^{\text{th}} \text{ rail line network}; \ n \leq I; \ \text{and } m = 1,2,\ldots, [I!/n!(I-n)!]; \ (\text{ex}). \]

For example, if \( r \) denotes a rail line network that permits subterminals to be established at 30 subterminal sites; then, \( \lambda_{llr} \) denotes the location of one subterminal given \( r \).
The subterminal may be located at one of 30 possible sites; and \( m = 1 \) denotes the location, e.g. \( L2_4 \), for the one subterminal. One location pattern for 3 plants given \( r \) may be identified by \( \lambda_{1,3,r} \) and include subterminals located at sites \( L2_6, L2_8, \) and \( L2_9 \). \( \lambda_{2,3,r} \) identifies three plants with a different locational pattern than \( \lambda_{1,3,r} \).

Country elevators exist at the beginning of the planning horizon, 1971. Some country elevators may become subterminals, in which case the plant site of a country elevator is the same as the plant site for a subterminal, \( Ll_i = L2_i \). Whenever \( i \in \lambda_{mn} \) and \( Ll_i = L2_i \), the range of country elevators (\( h = 1,2,\ldots,H \)) excludes \( Ll_i \). Thus, \( h \in \lambda_{mn} \) and \( i \in \lambda_{mn} \) denote country elevators and subterminals included in the grain distribution system of \( \lambda_{mn} \). Note: \( \lambda \) is often used as a short-hand for \( \lambda_{mn} \).

**Spatial and temporal flow of grain** The following symbols denote the flow of grain from origins to final destinations over time and space. The monthly supply of grain from each farm is predetermined. The flows, or temporal and spatial routings, of grain from origins to final destination are determined endogenously by the model.

All symbols representing the flow of grain, marginal transportation costs, elevator capacity, and prices follow a general format. Variable or parameter indices are placed
within parentheses. The first index denotes commodity and is followed by a semicolon. The second index represents origin and has a time subscript to denote various months. The third index represents a country elevator and has two time subscripts to identify months of receiving and load out. The fourth index represents a subterminal and also has two time subscripts to identify months of receiving and load out. The difference between receiving and load out represents storage period. The last index represents final destination and has a time subscript to denote the month of receipt. Let:

\[ X(\pi; h_{ss}, i_{uu}, j_v) = \text{quantity of commodity } \pi \text{ shipped from origin } g \text{ time } t \text{ through } L1_h \text{ and/or } L2_i \text{ and received at destination } j \text{ in time } v. \text{ Quantity received at } L1_h \text{ in time } s \text{ is stored from } s \text{ to } s'. \text{ Quantity received at } L2_i \text{ in time } u \text{ is stored from } u \text{ to } u'. \text{ Either } v = u' \text{ or } v = s'. \text{ And, either } t = s \text{ or } t = u; \text{ (en).} \]

\[ X(\pi; g_t...) = \text{predetermined supply of commodity } \pi \text{ at origin } g \text{ in time } t; \text{ (ex).} \]

\[ g = 1, 2, ..., G \]
\[ t = 1, 2, ..., T \]
\[ \pi = 1, 2, ..., \pi. \]

\[ X(\pi; h_{t...}) = \text{quantity of commodity } \pi \text{ shipped from origin } g \text{ in time } t \text{ and received during time } t \text{ at plant type 1 located at } L1_h; \text{ (en).} \]

\[ X(\pi; i_{t...}) = \text{quantity of } \pi \text{ shipped from origin } g \text{ in time } t \text{ and received during time } t \text{ at plant type 2 located at } L2_i; \text{ (en).} \]
\[ X(z; h_t, \ldots) = \Sigma X(z; g_t h_t, \ldots); \text{quantity of } z \text{ shipped from } \text{origins in time } t \text{ to plant type } 1 \text{ located at } L_{1h}; \text{ (en)}. \]

\[ X(z; h_{s'}, \ldots) = \text{quantity of } z \text{ shipped from plant type } 1 \text{ located at } L_{1h} \text{ at time } s'; \text{ (en)}. \quad s' = t, t+1, \ldots, T. \]

\[ X(z; h_{s'i_{s'}}, \ldots) = \text{quantity of } z \text{ shipped from plant type } 1 \text{ located at } L_{1h} \text{ during time } s' \text{ to plant type } 2 \text{ located at } L_{2i}; \text{ (en)}. \]

\[ X(z; i_t, \ldots) = \Sigma X(z; g_t i_t, \ldots) + \Sigma X(z; h_t i_t, \ldots); \text{quantity of } z \text{ shipped from all origins in time } t \text{ and from all plants type } 1 \text{ in time } t \text{ to plant type } 2 \text{ located at } L_{2i}; \text{ (en)}. \]

\[ X(z; i_u, \ldots) = \text{quantity of } z \text{ shipped from plant type } 2 \text{ located at } L_{2i} \text{ at time } u'; \text{ (en)}. \quad u' = u, u+1, \ldots, T. \]

\[ X(z; h_{s'j_s}, \ldots) = \text{quantity of } z \text{ shipped from plant type } 1 \text{ located at } L_{1h} \text{ during time } s' \text{ to destination } j \text{ and received during time } s'; \text{ (en)}. \]

\[ X(z; i_u j_u, \ldots) = \text{quantity of } z \text{ shipped from plant type } 2 \text{ located at } L_{2i} \text{ during time } u' \text{ to destination } j \text{ and received during time } u'; \text{ (en)}. \]

\[ X(z; \ldots j_s, \ldots) = \Sigma X(z; h_{s'j_s}, \ldots) + \Sigma X(z; i_{s'j_s}, \ldots); \text{quantity of } z \text{ shipped from all plants of type } 1 \text{ in time } s' \text{ and from all plants of type } 2 \text{ in time } s' \text{ to destination } j \text{; (en)}. \]

\[ = \text{quantity received at destination } j \text{ time } s'. \]
\[ X(s; h_{ss}, ...) = \text{quantity of} \ z \ \text{received at} \ L_1 \ \text{during time} \ s \ \text{and stored until the end of time} \ s'. \ \text{When} \ s = s', \ \text{grain is received and loaded out immediately requiring no storage capacity at} \ L_{1h}; \ \text{(en)}. \]

\[ X(z; i_{uu'}, ...) = \text{quantity of} \ z \ \text{received at} \ L_2_i \ \text{during time} \ u \ \text{and stored until the end of time} \ u'. \ \text{When} \ u = u', \ \text{grain is received and loaded out immediately requiring no storage capacity at} \ L_{2i}; \ \text{(en)}. \]

**Total transportation costs**  

The total transportation cost function accounts for 1) the annual cost of constructing, maintaining, and upgrading rail lines; and 2) the marginal costs of shipping grain from origins to destinations. The marginal costs of transportation represent the least costly mode of transport for a given month, distance, and load out facility. Subterminals may ship by rail to final destinations in multiple-car trains. Country elevators may ship by single car rail, truck, or truck-barge depending on their location and time of year. Farms ship grain to elevators using tractor-wagon or truck depending, again, upon distance and month.

The minimum annual cost of establishing and maintaining a given rail line option is based on the additional costs of upgrading, maintaining, and/or abandoning branch rail lines existing at the beginning of the planning horizon (1971) within the study area. The costs of maintaining the road network are included in the marginal costs of transporting grain by truck.
The total transportation cost function is presented by Equation 2.6.

\[ TTC = \gamma_r \]

\[ + \sum_{t} \sum_{g} \sum_{h} C(z; g_t h_{t \cdot \cdot}) X(z; g_t h_{t \cdot \cdot}) \]

\[ + \sum_{i} \sum_{g} C(z; g_t i_{t \cdot \cdot}) X(z; g_t i_{t \cdot \cdot}) \]

\[ + \sum_{h} \sum_{i} C(z; h_t i_{t \cdot \cdot}) X(z; h_t i_{t \cdot \cdot}) \]

\[ + \sum_{h} \sum_{j} C(z; h_t j_{t \cdot \cdot}) X(z; h_t j_{t \cdot \cdot}) \]

\[ + \sum_{i} \sum_{j} C(z; i_t j_{t \cdot \cdot}) X(z; i_t j_{t \cdot \cdot}) \] for \( h, i \in \lambda \)  \hspace{1cm} (2.6)

where:

\[ \gamma_r \] = minimum annual cost of establishing and maintaining rail line option \( r \); (ex).

\[ C(z; g_t h_{t \cdot \cdot}) \] = marginal cost of shipping commodity \( z \) to \( L_{1h} \) from origin \( g \) in time \( t \); (ex).

\[ C(z; g_t i_{t \cdot \cdot}) \] = marginal cost of shipping commodity \( z \) to \( L_{2i} \) from origin \( g \) in time \( t \); (ex).

\[ C(z; h_t s_{t \cdot \cdot}) \] = marginal cost of shipping to \( L_{2i} \) from \( L_{1h} \) in time \( s' \) minus the marginal cost of drying commodity \( z \) at \( L_{2i} \) in time \( s' \); (ex).

Grain received at \( L_{1h} \) will be dried at \( L_{1h} \). The marginal cost of receiving commodity \( z \) at \( L_{2i} \) also includes the marginal cost of drying commodity \( z \). Thus, the marginal cost of drying commodity \( z \) at \( L_{2i} \) is subtracted from the marginal cost of shipping commodity \( z \) from \( L_{1h} \) to \( L_{2i} \) to avoid the
double counting of drying costs.

\[ C(z; h_s; j_s') = \text{marginal cost of shipping to final destination } j \text{ from } L1h \text{ in time } s'; (ex). \]

\[ C(z; i_u; j_u') = \text{marginal cost of shipping to destination } j \text{ from } L2i \text{ in time } u'; (ex). \]

Equation 2.6 contains six terms on the right hand side of the equality sign. The first term is defined above, the second and third term denote the variable costs of shipping grain from origins to country elevators and subterminals, the fourth and fifth terms denote the variable costs of shipping grain from country elevators to subterminals and final destinations, and the last term denotes the variable cost of shipping grain from subterminals to final destinations.

**Grain handling costs: country elevators**

The cost function for handling grain at country elevators accounts for the marginal operating and maintenance costs of receiving and drying, storing, and loading out grain using facilities existing in 1971. Marginal operating and maintenance costs include items such as labor, elevator repairs, fuel, power, office supplies, and insurance on grain.

At the beginning of the planning horizon, 1971, \( H = 87 \) country elevators were in existence. Receiving, drying, and load out capacities of country elevators are somewhat flexible and depend upon the number of hours per day the elevator wishes to handle grain. Storage capacity, however,
is different. To increase storage capacity, additional storage facilities need to be constructed. Thus, it is assumed that by the end of the planning horizon, 1980, country elevators may need to expand storage facilities to accommodate the projected increase in grain supply. By increasing the number of hours per day that country elevators receive, dry, and loadout grain, it is assumed that the receiving, drying, and load out facilities of country elevators existing in 1971 are adequate to handle the increase of grain to be received at country elevators in 1980. The additional receiving, drying, and load out costs of labor, maintenance, and fuel are accounted for by the marginal operating and maintenance costs of receiving, drying, and load out.

The cost function for handling grain at country elevators, therefore, accounts for not only marginal operating and maintenance costs of handling grain with facilities existing in 1971, but also the total costs of expanding storage capacity when necessary beyond 1971 capacity.

Total costs of expanding storage facilities of a country elevator include an annual average cost of adjustment; and a marginal cost of expanding storage capacity. The annual average costs of adjustment reflect the cost of various indivisible items that are required to expand storage facilities. Such items include the purchase of additional land, conveyor systems used to move grain from receiving pits to
storage bins, aeration and heat detection equipment, and the cost of redesigning elevator layout. Some costs of adjustment may also result from the disruptions of elevator operations as elevator facilities are altered to permit the expansion of storage capacity.

The marginal cost of expanding storage capacity reflects the costs of constructing additional silos or storage bins. Grain silos and storage bins may be constructed for different volumes of grain, and do not encounter the indivisibilities of construction inherent in the annual average costs of adjustment as described in the preceding paragraph.

Since marginal storage expansion costs are incurred only after 1971 storage capacity has been exceeded, the total handling cost function for country elevators requires a switching rule. Before storage capacity is exceeded, the marginal cost of storing grain includes only the marginal operating and maintenance costs of using storage existing in 1971. Once capacity has been reached, additional bushels stored incur a marginal storage cost which includes both a marginal operating and maintenance cost, and a marginal cost of expanding storage capacity.

The total handling cost function for country elevator \( \ell_{h} \) is presented by Equation 2.7.
\[ THC(h_0) = \alpha(h_0) + \sum_z \sum_s \beta_R(z; h_s) X(z; h_s) \]
\[ + \sum_z \sum_{s=1}^{s' = s} \alpha S(z; h_s') X(z; h_s') \]
\[ + \sum_z \sum_{s' = s} \beta L(z; h_s') X(z; h_s') \]  
\[(2.7)\]

where
\[ \alpha(h_0) = \begin{cases} \text{SI if } ESK(h_s') < 0 \\ \text{or} \\ 0 \text{ otherwise} \end{cases} \]
\[(2.8)\]

and
\[ \alpha S(z; h_s') = \begin{cases} \beta S(z; h_s') + S2 \text{ if } ESK(h_s') < 0 \\ \text{or} \\ \beta S(z; h_s') \text{ otherwise.} \end{cases} \]
\[(2.9)\]

The symbols used in Equations 2.7, 2.8, and 2.9 are defined as follows:

\[ \alpha(h_0) = \text{minimum annual average cost of adjustment required to expand storage capacity of an existing country elevator located at } LL_h; \text{ (ex.)}. \]

\[ S1 = \text{minimum annual average cost of adjustment required to expand storage capacity of an existing country elevator; (ex).} \]

\[ \beta R(z; h_s) = \text{marginal operating and maintenance cost of receiving and drying commodity } z \text{ at } LL_h \text{ in time } s; \text{ (ex).} \]
\( \alpha \beta S(z; h, s') \) = marginal cost of storing commodity \( z \) at \( Ll_h \) from time \( s \) to \( s' \); (ex).

\( \beta S(z; h, s') \) = marginal operating and maintenance costs of storing commodity \( z \) at \( Ll_h \) from time \( s \) to \( s' \); (ex); and

\( S_2 \) = marginal cost of expanding storage facilities at a country elevator; (ex).

\( \beta L(z; h, s') \) = marginal operating and maintenance cost of loading out commodity \( z \) at \( Ll_h \) in time \( s' \); (ex).

\[
X(\cdot ; h, s) = \sum_{z} \sum_{s=1}^{s'} X(z; h, s')
\]

= total volume of grain in storage at \( Ll_h \) at the end of time \( s' \); (en).

\( SK(h, s') \) = storage capacity at \( Ll_h \) at the beginning of month \( s' \); (ex and en).

Storage capacity is predetermined for \( s' = 1 \). Storage capacity beyond the first month may be expanded and, thus, becomes endogenous for \( s' = 2, 3, \ldots, T \). Storage capacity existing at the beginning of month \( s' \), for \( s' \) greater than 1, equals the storage capacity existing at the beginning of month \( s'-1 \) plus the storage capacity added to the elevator during month \( s'-1 \). Storage capacity is added to an elevator only when excess storage capacity is negative. Excess storage capacity, denoted as \( ESK(h, s') \), is defined as follows:
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\[ ESK(h_{s'}.) = SK(h_{s'}.) - X(h_{s'}.) \]

= excess storage capacity at L_{1h} at the end of s'; (en).

Thus, storage capacity at L_{1h} at the beginning of month s', when s' is greater than 1, becomes:

\[
SK(h_{s'}.) = \begin{cases} 
X(h_{ss'-1}.) & \text{if } ESK(h_{s'-1}.) < 0 \\
SK(h_{s'-1}.) & \text{otherwise}
\end{cases} 
\]  

(2.12)

**Grain handling costs: subterminal**

The total cost function for handling grain at a subterminal is similar to the total cost function for handling grain at a country elevator. The grain handling cost function of a subterminal accounts for the marginal operating and maintenance costs of receiving and drying, storing, and loading out grain.

Unlike country elevators, however, subterminals were not in existence at the beginning of the planning horizon, 1971. To establish a subterminal, therefore, either an existing country elevator has to expand facilities to meet the minimum capacity requirements of a subterminal or a completely new subterminal must be constructed.

The minimum capacity requirements for grain-handling facilities at a subterminal differ from the capacity requirements of existing country elevators. Subterminals must be designed to load out multiple-car trains. Subterminals re-
quire more rail siding and switches than country elevators. A trackmobile or vehicle to move the rail cars on the rail siding, and special load out legs, spouts, and conveyor belts designed to rapidly load out grain are also required at a subterminal.

Minimum receiving and drying capacity requirements at subterminals also differ from those at country elevators. Subterminals receive grain from not only farmers, but also from country elevators. Receiving dumps, scales, truck hoists, and conveyor systems at subterminals must, therefore, be designed to handle 810 bushel grain semi-trailer trucks from country elevators as well as the smaller tractor-wagon and 300 bushel grain trucks used by farmers.

Total expansion cost of storage facilities is treated the same for subterminals as for country elevators. No minimum storage capacity is required. Additional storage capacity may be constructed according to the total storage expansion cost function specified for country elevators. Total storage capacity of subterminals and country elevators required at the end of the planning horizon, 1980, is endogenously determined by the model.

Total costs of establishing minimum capacities for receiving, drying, and loading out grain at a subterminal depends upon the receiving, drying, and load out capacities existing at the site where the subterminal is to be estab-
lished. The total cost functions for establishing receiving, drying, and load out facilities for a subterminal are of the form:

\[ aR(.i) = R1 + R2 \{RRK-RK(.i_u.)\}; \text{ (ex).} \]

= minimum annual total cost of establishing receiving facilities at L2_i; if RRK > RK(.i_u.); or

= zero if RRK ≤ RK(.i_u.) \quad (2.13) \]

\[ aD(.i) = D1 + D2\{RDK-DK(.i_u.)\}; \text{ (ex).} \]

= minimum annual total cost of establishing drying facilities at L2_i; if RDK > DK(.i_u.); or

= zero if RDK ≤ DK (.i_u.) \quad (2.14) \]

\[ aL(.i) = L1 + L2\{RLK-LK(.i_u.)\}; \text{ (ex).} \]

= minimum annual total cost of establishing load out facilities at L2_i; if RLK > LK(.i_u.); or

= zero if RLK ≤ LK(.i_u.) \quad (2.15) \]

where \( R1, D1, \) and \( L1 \) denote the minimum annual average costs of adjustment required to establish receiving, drying, and load out facilities for a subterminal. \( R1, D1, \) and \( L1 \) are determined exogenously and reflect the indivisibilities of constructing, receiving, drying, and load out facilities, and account for various start-up costs such as designing elevator layout and training of new personnel.

\( R2, D2, \) and \( L2 \) denote the marginal costs of establishing
receiving, drying, and load out facilities for a subterminal. R2, D2, and L2 are determined exogenously and account for the items that are influenced by the difference between required and existing capacity.

Required and existing capacities for receiving, drying, and loading out grain are denoted by the following symbols:

- \( RRK \) = minimum receiving capacity required to receive grain from country elevators and farmers at each subterminal \( i \) located at \( L2_i \); (ex).
- \( RDK \) = minimum drying capacity required to dry corn received from country elevators and farmers at each subterminal \( i \) located at \( L2_i \); (ex).
- \( RLK \) = minimum load out capacity required to load out multiple car trains at each subterminal \( i \) located at \( L2_i \); (ex).
- \( RK(\cdot i_u) \) = receiving capacity at \( L2_i \) existing at the beginning of the planning horizon, 1971; (ex).
- \( DK(\cdot i_u) \) = drying capacity at \( L2_i \) existing at the beginning of the planning horizon, 1970; (ex).
- \( LK(\cdot i_u) \) = load out capacity at \( L2_i \) existing at the beginning of the planning horizon, 1971; (ex).

The total annual average cost of establishing a sub-terminal located at \( L2_i \) may be, therefore defined by Equation 2.16.

\[
\alpha(\cdot i) = \alpha R(\cdot i) + \alpha D(\cdot i) + \alpha L(\cdot i) + S1 \quad (2.16)
\]

\( S1 \) is defined for a country elevator and denotes the minimum annual average cost of adjustment required to es-
establish storage capacity at an elevator; (ex).

Equation 2.17 presents the total handling cost function for a subterminal located at \( L_{2i} \):

\[
\text{THC}(t) = \alpha(t)
\]

\[
+ \sum_{u} \sum_{u'} \beta R(z; i_{u'}) X(z; i_{u'})
\]

\[
+ \sum_{u=1}^{T} \sum_{u'=u}^{T} \alpha \beta S(z; i_{uu'}) X(z; i_{uu'}).
\]

\[
\sum_{u} \sum_{u'} \beta L(z; i_{u'}) X(z; i_{u'})
\]

\[
\text{(2.17)}
\]

where

\[
\beta R(z; i_{u'}) = \text{marginal operating and maintenance cost of receiving and drying commodity } z \text{ at } L_{2i} \text{ in time } u; \ (\text{ex});
\]

\[
\alpha \beta S(z; i_{uu'}) = \begin{cases} 
\beta S(z; i_{uu'}) + S2 \\
\text{if } ESK(i_{uu'}) < 0 \\
\beta S(z; i_{uu'}) \\
\text{if } ESK(i_{uu'}) \geq 0
\end{cases}
\]

\[
\text{(2.18)}
\]

= marginal cost of storing commodity \( z \) at \( L_{2i} \) from time \( u \) to \( u' \); (ex);

and

\[
\beta S(z; i_{uu'}) = \text{marginal operating and maintenance cost of storing commodity } z \text{ at } L_{2i} \text{ from time } u \text{ to } u'; \ (\text{ex}); \text{ and}
\]
S2 = marginal cost of expanding storage facilities at a subterminal; (ex).

\[ X(\ldots i_{uu}. \ldots) = \sum_{z} \sum_{u=1}^{\ldots} X(z; \ldots i_{uu}. \ldots) \]

= total volume of grain in storage at \( L2_i \) at the end of time \( u' \); (en).

\[ SK(i_u.) = \text{storage capacity at } L2_i \text{ at the beginning of month } u'; \text{ (ex and en).} \]

(2.19)

Storage capacity is predetermined for \( u' = 1 \). Storage capacity beyond the first month may be expanded and, thus, becomes endogenous for \( u' = 2, 3, \ldots, T \). Storage capacity existing at the beginning of month \( u' \), for \( u' \) greater than 1, equals the storage capacity existing at the beginning of month \( u'-1 \) plus the storage capacity added to the elevator during month \( u'-1 \). Storage capacity is added to an elevator only when excess storage capacity is negative. Excess storage capacity, denoted as \( ESK(i_{u.}) \), is defined as follows:

\[ ESK(i_{uu.}) = SK(i_{u.}) - X(\ldots i_{uu.} \ldots) \]

(2.20)

= excess storage capacity at \( L2_i \) at the end of \( u' \); (en).

Thus, storage capacity at \( L2_i \) at the beginning of month \( u' \), when \( u' \) is greater than 1, becomes:
The last term in the total handling cost function, Equation 2.17, represents the total operating and maintenance cost of loading commodity \( z \) at \( L_{2_i} \) in time \( u' \) where:

\[
\beta L(z; i, u') = \text{marginal operating and maintenance cost of loading out commodity } z \text{ at } L_{2_i} \text{ in time } u'; \text{ (ex).}
\]

**Total revenue** Grain is shipped from subterminals and country elevators to final markets. For each month and destination there exists a demand price for commodity \( z \). Revenue obtained from each market, for each month, is determined by multiplying the volume of grain received at each final market by the price existing at that destination. Total revenue is the sum of all revenues obtained over all months and destinations. Let:

\[
\text{TR} = \sum_{s} \sum_{i} \sum_{n} \pi(z;...j,v)[\sum_{h} X(z;\cdot h,v,j,v) + \sum_{i} X(z;\cdot i,v,j,v)] \tag{2.22}
\]

where

\[
\pi(z;...j,v) = \text{price of commodity } z \text{ at final destination } j \text{ in time } v; \text{ (ex).}
\]
Mathematical statement

The uses of the model are to determine 1) \( n \), the number of subterminals; 2) \( h \lambda_{mn} \), the number of country elevators; 3) \( SK(h_{ST}) \) and \( SK(i_{UT}) \), the storage capacity of country elevators and subterminals; 4) \( \lambda_{mn} \), the rail line system and locational pattern for subterminals; and, 5) \( X(g_{ts}, i_{uv}, j_v) \), the flow of grain from origins \( g \) to final destinations, \( L_j \), over time and space to maximize \( \Pi \), the joint net revenue of producers where:

\[
\Pi = \left( \sum_{z} \sum_{j} \sum_{v} \pi(z; \ldots, j_v) \left[ \sum_{h} X(z; h, v, j_v) + \sum_{i} X(z; i, v, j_v) \right] \right) \\
- \left( \sum_{z} \sum_{g} \sum_{t} \sum_{h} \left[ \sum_{g} X(z; g, t, h) + \sum_{i} X(z; g, t, i) \right] \right) \\
+ \sum_{z} \sum_{g} \sum_{t} \sum_{i} \left[ \sum_{h} X(z; h, s, i) + \sum_{i} X(z; h, s, i) \right] \\
+ \sum_{z} \sum_{h} \sum_{s} \sum_{j} \left[ \sum_{h} X(z; h, s, j) + \sum_{j} X(z; h, s, j) \right] \\
+ \sum_{z} \sum_{i} \sum_{j} \left[ \sum_{i} X(z; i, u, j) + \sum_{j} X(z; i, u, j) \right] \\
- \sum_{h} \left( \sum_{z} \alpha(h) + \sum_{s} BR(z; h, s) X(z; h, s) \right)
\]
\[
\sum_{s=1}^{T} \sum_{s'=s}^{T} \alpha g_{s}(z; h_{s}, h_{s'}) X(z; h_{s}, h_{s'}) + \sum_{s'} \beta L(z; h_{s}, h_{s'}) X(z; h_{s}, h_{s'}) \]

\[
+ \sum_{i} \left( \sum_{u} \left[ \alpha(i) + \sum_{u} \beta R(z; i_{u}, i_{u}) X(z; i_{u}, i_{u}) \right] \right) ; \ h, i \in \lambda_{mnr} \quad (2.23)
\]

Simplifying, Equation 2.23 may be stated:

\[
\Pi = TR - TTC - \sum_{h \in \lambda} THC(h) - \sum_{i \in \lambda} THC(i) \quad (2.24)
\]

Symbols enclosed by the first set of \(\langle\rangle\) on the right hand side of the equality sign in Equation 2.23 and TR in Equation 2.24 represent total revenue as specified by Equation 2.22. Terms within the second set of \(\langle\rangle\) in Equation 2.23 and TTC in Equation 2.24 represent total transportation costs as specified by Equation 2.6. Terms within the third and fourth sets of \(\langle\rangle\) in Equation 2.23 and THC(h.) and THC(.i) in Equation 2.24 represent the cost of handling grain at country elevator h located at L1h and subterminal i located at L2i as specified by Equations 2.7 and 2.17.
The objective function defines joint net revenue as the income received at final destinations minus grain transportation costs and grain handling costs at elevators. Total transportation costs include the minimum annual cost of upgrading and maintaining alternative rail line network options; and the variable transportation costs from farm to elevator, country elevator to subterminal and to terminal market, and subterminal to terminal market.

All costs of upgrading and maintaining the rth branch rail line network option are to be borne by the grain industry in the selected region. Maintenance and upgrading costs of major trunk rail lines are to be borne by the railroad industry. Road upgrading and maintenance costs per bushel per mile are included in the marginal cost of shipping grain by truck.

Total handling costs at country elevators and subterminals include the marginal operating costs of receiving and drying, storing, and loading out grain. Total handling costs also include the annual costs of establishing and/or expanding elevator facilities.

The joint net revenue of producers as given by Equations 2.23 or 2.24 is maximized subject to the following material balance equations and prerequisite conditions for elevator capacity expansion:
Equation 2.25 states: The total supply of commodity $z$ received at all country elevators and subterminals directly from origin $g$ in time $t$ equals the predetermined supply from origin $g$ in period $t$.

\[ \sum_{h} X(z; g_t h_t \ldots) + \sum_{i} X(z; g_t i_t \ldots) = X(z; g_t \ldots) \]  

Equation 2.26 states: The total supply of commodity $z$ received at $L_1$ in time $t$ equals the supply of commodity $z$ shipped to $L_1$ from all origins in time $t$.

\[ \sum_{g} X(z; h_t z_t \ldots) = X(z; h_t \ldots) \]  

Equation 2.27 states: The supply of commodity $z$ received at subterminals and terminal markets from $L_1$ in time $s'$ equals the supply of commodity $z$ shipped from $L_1$ in time $s'$.

\[ \sum_{i} X(z; h_s i_s \ldots) + \sum_{j} X(z; h_s j_s \ldots) = X(z; h_s \ldots) \]  

Equation 2.28 states: The total supply of commodity $z$ received at $L_2$ in time $t$ equals the supply of commodity $z$ shipped to $L_2$ from all origins and all country elevators in time $t$.

\[ \sum_{g} X(z; g_t i_t \ldots) + \sum_{h} X(z; h_t i_t \ldots) = X(z; \ldots i_t \ldots) \]
Equation 2.29 states: The supply of commodity \( z \) received at all terminal markets from \( L^2_i \) in time \( u' \) equals the supply of commodity \( z \) from \( L^2_i \) in time \( u' \).

\[
\sum_j X(z; i, u', j_u') = X(z; i, u')
\]  

Equation 2.30 states: The supply of commodity \( z \) received at terminal market \( L_j \) in time \( s' \) equals the supply of commodity \( z \) shipped from country elevators and subterminals to \( L_j \) in time \( s' \).

\[
\sum_i \sum_h \sum s X(z; h, s, j_s') + \sum_i \sum_s X(z; i, s, j_s') = X(z; i, s, j_s')
\]  

Equation 2.31 states: Amount stored of commodity \( z \) at \( L^1_{h_s} \) at the end of month \( s' \) equals cumulative receipts minus cumulative shipments of commodity \( z \) to the end of time \( s' \).

\[
\sum_{s, s'} \sum_t X(z; h, s, t) - \sum_{s'} \sum_{s, s'} X(z; h, s, t) = X(z; h, s, s')
\]  

Equation 2.32 states: Total receipts of commodity \( z \) at \( L^1_{h_s} \) equals total out shipments of commodity \( z \).

\[
\sum_{u, u'} X(z; i, u, u') - \sum_{t, t'} X(z; i, t, t') = X(z; i, u, u')
\]
Equation 2.33 states: Amount of commodity \( z \) stored at \( L_{2i} \) at the end of month \( u' \) equals cumulative receipts minus cumulative shipments of commodity \( z \) to the end of time \( u' \).

\[
\sum_{u=1}^{T} X(z;..i_{u..}) = \sum_{u'>u}^{T} X(z;..i_{u'..})
\]  

(2.34)

Equation 2.34 states: Total receipts of commodity \( z \) at \( L_{2i} \) equals total outshipments of commodity \( z \)

\[
\sum_{t} \sum_{g} X(z;g_{t..}) = \sum_{v} \sum_{j} X(z;...j_{v})
\]  

(2.35)

Equation 2.35 states: Total supply of commodity \( z \) equals total receipts of commodity \( z \) at terminal markets.

Equations 2.36 to 2.43 present conditions necessary to permit expansion of elevator capacity; i.e., excess capacity in one elevator precludes another elevator from expanding. Equations 2.36, 2.37, 2.38, and 2.39 are operative if no elevator has unused storage capacity in time \( s' \).

\[
\alpha(h_{.}) = S1;
\]  

(2.36)

\[
\alpha(.i) = S1 + \alpha R(.i) + \alpha D(.i) + \alpha L(.i);
\]  

(2.37)

and

\[
\alpha S(z;h_{ss..}) = \beta S(z;h_{ss..}) + S2;
\]  

(2.38)

\[
\alpha S(z;..i_{uu..}) = \beta S(z;..i_{uu..}) + S2;
\]  

(2.39)

if
Equations 2.40, 2.41, 2.42 and 2.43 are operative if any elevator has unused storage capacity in time \( s' \).

Equation 2.44 states: All commodity flows over time and space and nonnegative.

Depending on the locational pattern of subterminals and rail lines, some country elevators may be the sites of subterminals. Thus, \( L_{1h} \not\in \{1,2,\ldots,H\} \) when \( L_{1h} = L_{2i}; h, i \in \lambda_{mnr} \).
Method of solution

As previously discussed, Stollsteimer developed a method of solution for plant location models with no transhipment, and Ladd extended the initial model to include a single stage of transhipment. The following method incorporates procedures developed by Stollsteimer and Ladd and expands the model to cover multiple transhipment over time and space, facilities existing at the beginning of the planning horizon, a capacity expansion constraint, and economies of scale in rail transportation resulting from the fixed costs of rail line installation and maintenance.

The method of solution outlined below is divided into two parts. Part I determines the spatial and temporal flow of grain from origins to final destinations that provides the maximum revenue net of variable transportation and grain handling costs for a given locational pattern of subterminals, country elevators, and rail lines. Two computing routines—ORA(1,t) and ORA(2,t)—are used in Part I to determine the optimal physical distribution of grain for each constellation of rail lines and grain handling facilities.

Part II determines the configuration of rail lines, country elevators, and subterminals for which joint revenue net of variable and fixed costs of grain transportation and handling is maximized. The optimal number, size, and location of rail lines and grain handling facilities are determined by
systematically comparing joint net revenue for each combination of $\lambda_{mnr}$ and selecting that constellation of rail lines and grain handling facilities for which joint net revenue is maximum.

The two routing algorithms—ORA(1,t) and ORA(2,t)—used in Part I to determine the optimal flow of grain for each locational pattern of rail lines and grain handling facilities are presented before Part I and Part II. The first routing algorithm assumes that the marginal cost of storage at country elevators and subterminals is independent of volume handled. The solution of the first routing algorithm is optimal if the data (marginal cost of storing grain) is consistent with the solution (the volume stored). However, since some elevators exist at the beginning of the planning horizon, 1971, marginal storage costs depend upon the amount of grain stored as defined by the switching rules of equations 2.9 and 2.18. If the use of switching rules as specified by Equations 2.9 and 2.18 are required to provide a solution that is consistent with the data then the second routing algorithm, ORA(2,t) is used.

The second routing algorithm assumes that marginal storage costs are dependent on the volume of grain stored. It also takes into account the expansion constraint that no elevator can expand storage capacity as long as there exists unused storage capacity at any other elevator.
Optimal routing algorithm: $\text{ORA}(l,t)$

The first routing algorithm is used to determine the optimal flow of grain shipped from origins in month $t$ for a given locational pattern of rail lines and elevators. The first optimal routing algorithm for month $t$ given $\lambda_{mnr}$ (denoted by $\text{ORA}(l,t)|\lambda$) assumes constant marginal costs of handling and transporting grain; and, total quantity shipped to each final market, country elevator, and subterminal is variable.

The marginal cost of storing grain is set equal to either 1) the marginal operating and maintenance costs of storage; or 2) the marginal operating and maintenance costs of storage plus the marginal costs of expanding storage facilities. The level at which the marginal costs of storage are set depends on the excess capacity of elevator storage existing at the beginning of month $t$. Switching rules for changing the level of the marginal costs of storage are presented by Equations 2.9 and 2.18.

The flow of commodities over time and space is governed by the price at each final destination net of marginal elevator handling and transportation costs. Each origin selects the route over space and time offering the highest net price. That is, the optimal route for shipping commodity $e$ from origin $g$ in time $t$ given $\lambda_{mnr}$ to some final destination is defined as that route over time and space which provides a net price at origin $g$ at least as high as any other route.
For each locational network of elevators and rail lines, \( \lambda_{mnr} \), there are many different possible shipping or marketing patterns over space and time for each origin. During one year with \( T \) marketing periods there are

\[
\sum_{t=1}^{T} \left[ t(H+n) + \left( t^2 - \sum_{t'=1}^{T} (t'-1) \right)Hn \right]
\]

(2.45)

different marketing options for each origin shipping commodity \( z \). A locational pattern with thirteen destinations, seven subterminals, eighty-seven country elevators, one commodity, and twelve time periods offers 2,977,104 marketing options for origin \( g \). Equation 2.45 only holds if all of commodity \( z \) in time \( t \) shipped from origin \( g \) follows the same routing. If parts of commodity \( z \) in time \( t \) shipped from origin \( g \) can follow different routes, the number of marketing options is much greater.

One method to find the optimal route for each origin in month \( t \), for each locational configuration of elevators and rail lines, would be to compute and compare all possible marketing combinations for each origin and select the route offering the highest price. If there were 416 origins, with each origin selecting from 2,977,104 marketing options, the number of marketing combinations given \( \lambda_{mnr} \) exceeds one billion.

Another procedure, and the one used in this study, to find the optimal routings, given \( \lambda_{mnr} \), for each origin in time
t, decomposes the marketing system into parts and solves the parts sequentially. This method reduces the number of marketing options requiring comparison for origin g, for example, from 2,977,104 to 143,962 when J = 13, I = 7, H = 87, \( z = 1 \), and T = 12. The number of comparisons required to select the optimal routing for origin g is further reduced if information that was obtained when evaluating other locational patterns is also used.

The best marketing alternative for a country elevator (or subterminal) in period t, for any given locational pattern of elevators and rail lines, is independent of the quantity of commodity \( z \) received at that county elevator (or subterminal) in period t. Thus, there is only one marketing alternative over time and space that provides a country elevator (or subterminal) a net price at least as high as any other marketing option. If the best outlet for grain \( z \) shipped from \( L_{2i} \) is destination \( j \), then we know that all of grain \( z \) shipped -- from some \( L_{1i} \) or from some origin--to \( L_{2i} \), will be shipped to destination \( j \).

Suppose that commodity \( z \) may be shipped 1) from \( L_{1h} \) directly to a final destination; or, 2) from \( L_{1h} \) through \( L_{2i} \) to a final destination. If the best outlet for grain \( z \) shipped directly from \( L_{1h} \) to a final destination is market \( k \) and the best outlet for \( L_{2i} \) is destination \( j \), then to determine the best market for grain \( z \) shipped from \( L_{1h} \) we
need only compare 1) the option of shipping grain z from L1_h directly to destination k with 2) the option of z transshipping grain z from L1_h through L2_i to destination j. To determine the best route, therefore, for commodity z shipped from L1_h in time t given λ_mnr, it is not necessary to compare all possible transhipment alternatives through subterminal L2_i.

The best route for shipping commodity z from origin g in time t given λ_mnr can be determined by considering 1) the marginal transportation costs of shipping commodity z from origin g in time t to each country elevator and each subterminal; and 2) the highest net price for commodity z received in time t at each country elevator and each subterminal. The highest net price for commodity z received at country elevator L1_hελ in time t is based on the marginal costs of handling commodity z at L1_hελ, the marginal costs of transporting commodity z from L1_hελ, the highest net prices at subterminals, and prices at final destinations.

Marginal costs of handling grain include the marginal costs of receiving, storing, and loading out grain. The highest net price for commodity z received in time t at subterminal L2_iελ is based on the marginal costs of handling commodity z at L2_iελ, the marginal costs of transporting commodity z from L2_iελ, and the prices of commodity z at final destinations.

The optimal marketing pattern for all grain shipped from
origin \( g \) in time \( t \) may be selected sequentially by the following steps of \( \text{ORA}(1,t)|\lambda_{\text{mnr}} \):

1. For each time period that \( L_{2i} \) receives commodity \( z \), select the combination of storage, transportation, and destination \( L_j \) for which the net price of grain \( z \) will be at least as high as any other combination. All of commodity \( z \) received during time \( t \) will be stored for the number of periods and shipped to that destination selected.

2. Specify for all origins and country elevators a set of destinations which include a) \( L_j \) where \( j = 1,2,..., J \); and b) all plants of type 2. Each \( L_j \) and \( L_{2i} \) offer a unique price at time \( t \). The price at \( j \) time \( t \) is predetermined. The price at \( L_{2i} \) time \( t \) is net of storage, handling, and transportation cost.

3. For each time period that \( L_{1h} \) receives commodity \( z \), determine the combination of storage, transportation, and destination which provides a net price for grain \( z \) at least as high as any other combination. Grain received during time \( 1 \) will be channeled through one of \( T(I+J) \) marketing option.

4. Specify for all origins a set of destinations which include plants of type 2 and plants of type 1. Each \( L_{2i} \) and \( L_{1h} \) offer a unique price at time \( t \) for commodity \( z \).
5. For each origin that ships commodity \( z \) in time \( t \), select the combination of storage, transportation, and destinations which provides a net price at least as high as any other combination. Commodity \( z \) shipped during time \( t \) will be channelled through one of \( (H + I) \) marketing options. Net price at origin \( g \) in time \( t \) when shipping, for example, grain \( z \) from origin \( g \) to a country elevator located at \( L_{j}^{h} \) is equal to the maximum net price at \( L_{j}^{h} \) in time \( t \) minus the marginal transportation cost from \( g \) to \( L_{j}^{h} \).

6. For each origin \( g \) in month \( t \) determine the maximum revenue net of marginal elevator handling and transportation costs for grain \( z \). The sum of the maximum net price at origin \( g \) in month \( t \) for grain \( z \) multiplied by the volume of grain \( z \) shipped from origin \( g \) in month \( t \) equals the maximum revenue net of variable costs from shipping grain \( z \) from origin \( g \) in month \( t \).

7. Repeat Step 1 through Step 6 of ORA(1,t)\( |_{\lambda_{mn}} \) for each commodity \( z \). Let \( \text{TRNVC}(1,t)\mid_{\lambda_{mn}} \) denote the total revenue net or variable costs in time \( t \) of all producers as determined by ORA(1,t), given \( \lambda_{mn} \). The value of \( \text{TRNVC}(1,t)\mid_{\lambda_{mn}} \) is computed by adding together the maximum revenue net of variable costs
for shipping all grain from all origins in month \( t \).

The algorithm used to estimate \( \text{TRNVC}(l,t) \) may be alternatively expressed as follows: Let \( \pi(z;...j,v) \) denote the predetermined price of commodity \( z \) at destination \( L_j \) in time \( v; \ j = 1,2,\ldots,J \). The net price at subterminal \( L_{2_i} \), for commodity \( z \) received in time \( u \) when stored to time \( v \) and shipped to destination \( L_j \) in time \( v \), can be computed as:

\[
\pi(z;...i_{uv}j_v) = \pi(z;...j_v) - \beta R(z;...i_u) - \\
\alpha S(z;...i_{uv}) - \beta L(z;...i_v) - c(z;...i_vj_v)
\] (2.46)

The maximum net price of commodity \( z \) at \( L_{2_i} \) in time \( u \) can be determined by selecting the storage and destination combination which provides a net price at least as high as any other combination. This may be expressed as:

\[
\pi(z;...i_{uvj_v}^{-}) = \max \max \pi(z;...i_{uv}j_v)
\] (2.47)

Define a set of destinations, \( j_l \), for shipments from country elevators, which include original destinations \( L_j; \ j = 1,2,\ldots,J; \) and plants type 2, \( L_{2_i} \). Thus, \( j_l = 1,2,\ldots,J, J+1, J+2,\ldots,J+I \) where \( j_l = 1,2,\ldots,J \) denote terminal markets, \( L_j \); and \( j_l = J+1, J+2,\ldots,J+I \) denote subterminals, \( L_{2_i} \).

Let \( \pi(z;...j_lv) \) denote the maximum price of commodity \( z \) offered at destination \( j_l \) time \( v \). The maximum net
prices for \( j_1 = J+1, J+2, \ldots, J+1 \) equal \( \pi(z; \cdots _{u=i_{u-1}^J v}) ; u=v \).

The net price, therefore, at plant \( L_1^h \), when commodity \( z \) received in time \( s \) is stored to time \( v \) and shipped to destination \( j_1 \) in time \( v \), may be computed:

\[
\pi(z; h_{sv} j_1 v) = \pi(z; \cdots j_1 v) - \beta R(z; h_s)
- \alpha \beta S(z; h_{sv}) - \beta L(z; h_v) - C(z; h_v j_v)
\]  \hspace{0.5cm} (2.48)

when \( j_1 = 1, 2, \ldots, J \); and

\[
\pi(z; h_{sv} j_1 v) = \pi(z; \cdots j_1 v) - \beta R(z; h_s)
- \alpha \beta S(z; h_{sv}) - \beta L(z; h_v) - C(z; h_v j_v)
\]  \hspace{0.5cm} (2.49)

when

\( j_1 = J+1, J+2, \ldots, J+I \).

The maximum net price of commodity \( z \) at \( L_1^h \) in time \( s \) is the storage and destination combination which provides a net price at least as high as any other combination; it may be expressed as:

\[
\pi(z; h_{sv} j_1 v) = \max \max \pi(z; h_{sv} j_1 v)
\]  \hspace{0.5cm} (2.50)

Define a set of destinations, \( j_2 \), for shipments from origins which include: 1) country elevators \( L_1^{h \in \Lambda} \), \( h = 1, 2, \ldots, H \); and 2) subterminals \( L_2^{i \in \Lambda} \), \( i = 1, 2, \ldots, I \). Thus, \( j_2 = 1, 2, \ldots, H, H+1, H+2, \ldots, H+I \) where \( j_2 = 1, 2, \ldots, H \) denote
all country elevators; and \( j_2 = H+1, \ldots, H+I \) denote all subterminals in locational option \( \lambda_{mnr} \).

Let \( \pi(z; \ldots j_2^v) \) denote the maximum price of commodity \( z \) offered at destination \( j_2 \) time \( v \). The maximum net prices for \( j_2 = 1, 2, \ldots, H \) equal \( \pi(z; h_{sv} j_2^v) \) when \( h = 1, 2, \ldots, H \); and \( j_2 = H+1, H+2, \ldots, H+I \) equal \( \pi(z; i_{uv} j_2^v) \) when \( i = 1, 2, \ldots, I \).

The net price at origin \( g \) when shipping commodity \( z \) in time \( v \) directly to destination \( j_2 \), may now be computed as:

\[
\pi(z; g_v \ldots j_2^v) = \pi(z; \ldots j_2^v) - C(z; g_v h_v \ldots) \quad (2.51)
\]

when

\( j_2 = 1, 2, \ldots, H \); and

\[
\pi(z; g_v \ldots j_2^v) = \pi(z; \ldots j_2^v) - C(z; g_v i_v \ldots) \quad (2.52)
\]

when

\( j_2 = H+1, H+2, \ldots, H+I \).

The maximum net price for commodity \( z \) at origin \( g \) time \( v \), when selecting that marketing option over time and space which offers a net price at least as high as any other combination, may be expressed as:

\[
\pi(z; g_v \ldots j_2^v) = \max_{j_2} \pi(z; g_v \ldots j_2^v) \quad (2.53)
\]

Once the optimal marketing pattern has been determined over time and space for each grain \( z \) and for each origin \( g \) in time \( t \), the total revenue and variable costs forthcoming from each shipping pattern can be computed for time \( t \). The
The final step of ORA(1,t) is to compute the total revenue of all producers in time \( t \) net of variable costs, \( \text{TRNVC}(1,t) \). The total revenue net of variable costs determined by ORA(1,t) is computed as follows:

\[
\text{TRNVC}(1,t) = \sum_{z,g} X(z;g_1 \ldots) \tau(z;g_1 \ldots j_{2_t})
\]

**Optimal routing algorithm: ORA(2,t)**

The first routing algorithm, ORA(1,t), takes the marginal costs of storage at country elevators and subterminals as given and independent of volume handled. In the event that the volume of grain to be stored in, for example, \( L_2 \) as determined by the solution of ORA(1,t) exceeds the storage capacity of \( L_2 \), and the marginal cost of storing grain at \( L_2 \) was set equal to only the operating and maintenance costs of storing grain, then, the data of the algorithm are inconsistent with the results. When the data of ORA(1,t) are inconsistent with the solution, a second routing algorithm—ORA(2,t)—is used to determine the optimal flow of grain from origins in month \( t \) for a given locational pattern of subterminals and rail lines.

The second routing algorithm assumes constant marginal costs of receiving, loading out, and transporting grain; total quantity shipped to each country elevator, subterminal, and final destination is variable; and marginal storage costs are dependent on volume stored. The second routing
algorithm, ORA(2,t), also takes into account the capacity expansion constraint that unused storage capacity in any country elevator or subterminal precludes the expansion of storage capacity at any other country elevator or subterminal.

Imposing the capacity expansion constraint on the plant-location model is similar to a problem, as specified by Ladd (33), containing "two-sided quantity restrictions". A "two-sided quantity restriction" problem assumes that the quantity available at each origin and maximum quantity required at each destination are known constants. The general method of solution for problems containing "two-sided quantity restrictions" as outlined by Ladd may be used to solve ORA(2,t).

The second routing algorithm uses ORA(1,t) as a first approximation of shipments from origins to country elevators and subterminals where the marginal cost of storage does not include the marginal costs of expanding storage facilities. The solution of ORA(1,t) determines the spatial and temporal routing of grain from origins for month t given $\lambda_{mnr}$. If the volume stored at an elevator during period t, as determined by ORA(1,t), is greater than the storage capacity of the elevator during period t then three options are available: 1) grain may be re-routed from storage in that elevator spatially and/or temporally; 2) the storage capacity at that
elevator may be expanded; or 3) a combination of re-routing and storage capacity expansion is possible.

As long as at least one country elevator or subterminal has unused storage capacity, however, grain must be re-routed. For example, assume that country elevator \( L_{le} \) has unused storage capacity in period \( t \); and, country elevator \( L_{lk} \) has, according to the solution of \( ORA(l,t) \), more grain in storage during period \( t \) than it's capacity allows it to store. Commodity \( z \) may be re-routed 1) spatially from \( L_{lk} \) to \( L_{le} \); 2) temporally by transhipping commodity \( z \) received at \( L_{lk} \) during time \( t \) to a destination during the same month that commodity \( z \) is received; or 3) a combination of 1 and 2.

With more than two elevators, off-setting re-routings are also possible. Grain may be re-routed from \( L_{lk} \) to either \( L_{l1} \) or \( L_{l2} \). Or, grain may be re-routed from \( L_{lk} \) to \( L_{l1} \), and to prevent the rerouting of grain from exceeding storage capacity at \( L_{l1} \), grain may be re-routed from \( L_{l1} \) to \( L_{l2} \).

Once the capacity expansion restriction has been met and no country elevator or subterminal has unused storage capacity, the loss in net revenue resulting from the re-routing of commodity \( z \) must be compared with the additional costs of expanding storage capacity at \( L_{lk} \). The cost of expanding storage capacity may be less than the revenue foregone from temporal
re-routings or the additional transport costs from spatial re-routings.

It is important to note that the decision to expand storage capacity or re-route commodity z in period t cannot be made by only comparing the resulting changes in joint revenue net of variable costs in period t. Joint net revenue is maximized over a finite time horizon of 12 time periods. Expanding storage capacity in period t may influence the spatial and temporal routing of grain in period t+1, t+2, ..., 12. If grain has to be re-routed from L1_k to avoid exceeding storage capacity constraints at L1_k in not only period t but also in some future periods, then the additional cost of expanding storage capacity at L1_k during period t must be compared with the total loss over all time periods in net revenue resulting from the re-routing of grain.

The many possible offsetting re-routing combinations, and combinations of re-routing over time and space suggests the need for a set of simplified heuristic re-routing rules. The following five steps of ORA(2,t)|λ_mnr were used in this thesis to determine the maximum total revenue of all producers in time t net of variable costs given λ_mnr. Step one uses ORA(1,t) as a first approximation of shipments from origins to final destinations. Step two determines the re-routing of grain as long as at least one country elevator or subterminal has unused storage capacity. Step three deter-
mines the amount of storage capacity that should be added and the amount of grain that should be re-routed given that the capacity expansion constraint is not a binding restriction. Step four determines the change in total revenue net of variable costs in time t from re-routing grain and/or expanding storage capacity as determined by step two and step three of ORA(2,t). And, step five determines the maximum total revenue of all producers in time t net of variable costs, given $\lambda_{mnr}$.

Steps one through five are repeated for each locational configuration of elevators and rail lines. The symbol $\lambda_{mnr}$ has been deleted from most equations in Steps one through four to simplify the presentation.

Step 1: Let ORA(1,t) be used as a first approximation of the optimal routings of grain from origins to country elevators, subterminals, and destinations in time t.

Step 2: From the solution of ORA(1,t) the excess storage capacity of each country elevator and each subterminal can be determined. Excess storage capacity for country elevator $L_l$ was defined by Equation 2.11: and, excess storage capacity for subterminal $L_2$ was defined by Equation 2.20. For each country elevator or subterminal with negative excess storage capacity, grain may be re-routed and/or additional storage capacity may be constructed. The decision to re-route and/or expand storage capacity depends upon the alternative that
minimizes the loss in revenue net of variable costs subject to the constraint that no elevator can expand storage capacity as long as there is unused storage capacity at any other elevator. The purpose of Step 2 is to determine the re-routing of grain when at least one country elevator or sub-terminal has unused storage capacity.

Assume that the solution of ORA(1,t) shows that country elevators $L_{1_1}^1, L_{1_2}^2,..., L_{1_h}^h$, and subterminals $L_{2_1}^1, L_{2_2}^2,..., L_{2_i}^i$, have negative excess storage capacity; and, that country elevators $L_{1_{h'+1}}^1, L_{1_{h'+2}}^1,..., L_{1_h}^h$, and subterminals $L_{2_{i'+1}}^1, L_{2_{i'+2}}^1,..., L_{2_i}^i$, have unused storage capacity. Denote the set of country elevators and subterminals that have negative excess storage capacity as $\{ESK < 0\}$. Let $\{ESK > 0\}$ denote the set of country elevators and subterminals that have unused storage capacity.

Some of the grain stored at country elevators and subterminals that have negative excess storage capacity needs to be re-routed temporally and/or spatially. Grain may be re-routed spatially by reducing the shipments of grain to each elevator with negative excess capacity and increasing the shipments of grain to some of the elevators with unused storage capacity. Grain may be re-routed temporally at elevators with negative excess storage capacity by changing the length of time that grain is stored. Because of the capacity expansion constraint, storage capacity cannot be expanded as long
as there exists unused storage capacity at any other elevator.

Assume that country elevator \( L_1 \) and subterminal \( L_2 \) have unused storage capacity; and, country elevator \( L_1 \) has, according to the solution of ORA(1,t), more grain in storage during period \( t \) than it's capacity allows it to store. And, suppose that \( X(z;g,\ldots) \) is shipped to \( L_1 \) by origin \( g \) in period \( t \) for all \( g \) shipping commodity \( z \) to \( L_1 \); and all of commodity \( z \) received at \( L_1 \) in time \( t \) is stored at \( L_1 \) until the end of period \( s \).

Many temporal and spatial re-routing alternatives are available to reduce the amount of grain in storage at \( L_1 \) where \( k \in \{\text{ESK} < 0\} \). Equations 2.59 through 2.66 present the change in price net of variable costs resulting from various re-routing alternatives that may be used to reduce the amount of commodity \( z \) in storage during time \( t \) at \( L_1 \). Equations 2.59 through 2.66 are repeated for each \( L_1 \) \( k \in \{\text{ESK} < 0\} \) where \( k = 1,2,\ldots,h' \).

Define \( \pi(z; t, s, i, u) \) as the net price at \( L_1 \) for commodity \( z \) received in time \( t \) where commodity \( z \) is stored to time \( s \), shipped to \( L_2 \) in time \( s \), stored at \( L_2 \) to time \( u \), and shipped from \( L_2 \) to \( L_j \) in time \( u \). Compute \( \pi(z; t, s, i, u) \) as follows:
\[ \pi(z; h_{ts} s u J_u) = \pi(z; i_{su} j_u) - \beta R(z; h_t) \]

- \[ a \beta S(z; h_{ts} j_s) - \beta L(z; h_s) \]

- \[ C(z; h_{.s} .j_s) \quad (2.55) \]

Define \[ \pi(z; h_{ts} j_s) \] as the net price at \[ Ll_h \] for commodity \[ z \] received in time \[ t \] where commodity \[ z \] is stored at \[ Ll_h \] to time \[ s \], and shipped from \[ Ll_h \] to \[ L_j \] in time \[ s \]. Compute \[ \pi(z; h_{ts} j_s) \] as follows:

\[ \pi(z; h_{ts} j_s) = \pi(z; i_{j_s}) - \beta R(z; h_t) \]

- \[ a \beta S(z; h_{ts} j_s) - \beta L(z; h_s) \]

- \[ C(z; h_{.s} .j_s) \] \quad (2.56)

Define \[ \pi(z; g_t h_{ts} s u j_u) \] as the net price at origin \[ g \] for commodity \[ z \] shipped to \[ Ll_h \] in time \[ t \] where commodity \[ z \] is stored to time \[ s \] at \[ Ll_h \], shipped to \[ L2_i \] in time \[ s \] from \[ Ll_h \], stored to time \[ u \] at \[ L2_i \], and shipped from \[ L2_i \] to \[ L_j \] in time \[ u \]. Compute \[ \pi(z; g_t h_{ts} s u j_u) \] as follows:

\[ \pi(z; g_t h_{ts} s u j_u) = \pi(z; h_{ts} i_{su} j_u) - C(z; g_t h_t) \]

(2.57)

Define \[ \pi(z; g_t h_{ts} \{I_j\} \_{s}) \] as the maximum net price for commodity \[ z \] at origin \[ g \] time \[ t \] when commodity \[ z \] is shipped to destination \[ \{I_j\} \] through \[ Ll_h \]. Compute \[ \pi(z; g_t h_{ts} \{I_j\} \_{s}) \] as
The change in net price resulting from re-routing grain may now be computed. Terms beyond the "max" notation on the right hand side of the equalities of Equations 2.59 through 2.66 are defined in the previous section "Optimal routing algorithm: ORA(1,t)", or they are defined by Equations 2.55 through 2.58. Let:

\[
\Delta \pi(z; g_t e_t v, j_v) : L_k = \max_v \max_j \pi(z; g_t e_t v, j_v) - \pi(z; g_t k_t, j_s) \leq 0 
\]  

Equation 2.59 computes the minimum loss in net price resulting from origin g re-routing one bushel of commodity z during time t from L_k to country elevator L_e, and commodity z is shipped from L_e to destination L_j. Country elevator L_k has negative excess storage capacity; country elevator L_e has unused storage capacity; and, t \neq v. The first term on the right hand side of the equality (i.e., max max \pi(z; g_t e_t v, j_v)) is the maximum net price of commodity z at origin g in time t when commodity z is shipped from origin g to L_e in time t and commodity z is stored at L_e and shipped to that final destination which provides a net price at least as high as any other final destination. The
second term on the right hand side of the equality denotes the maximum net price of commodity $z$ at origin $g$ in time $t$ as determined by the solution of $ORA(1,t)$. Since $\pi(z; g, k, t, s, j, l, m)$ is the max net price of commodity at origin $g$ in time $t$, where $j$ includes all final destinations as well as all subterminals, the value of Equation 2.59 will always be less than or equal to zero.

The alternative of re-routing commodity $z$ to $L_{1e}$ in time $t$ and shipping commodity $z$ from $L_{1e}$ in time $t$ is considered below in Equations 2.62, 2.64, and 2.66. Equation 2.59 is repeated for each country elevator $L_{1e} \in \{ESK > 0\}$ where $e = 1, 2, \ldots, (H' - h')$; for each commodity $z$ shipped to $L_{1k}$; and for each origin $g$ that supplies commodity $z$ to $L_{1k}$.

$$\Delta \pi(z; g, t, f, v, l, v; L_{1k}) = \max_{v, j} \pi(z; g, t, f, v, j, v)$$

$$- \pi(z; g, k, t, s, j, l, m) \leq 0 \quad (2.60)$$

Equation 2.60 computes the minimum loss in net price resulting from re-routing one bushel of commodity $z$ during time $t$ from $L_{1k}$ to subterminal $L_{2f}$, and commodity $z$ is shipped from $L_{2f}$ to $L_{j}$ where $L_{1k} \in \{ESK < 0\}; L_{2f} \in \{ESK > 0\}$; and $t \neq v$. Equation 2.60 is repeated for each subterminal $L_{2f}$ where $f = 1, 2, \ldots, (I' - i')$; for each commodity $z$ shipped to $L_{1k}$; and for each origin $g$ supplying commodity $z$ to $L_{1k}$. 
\[ \Delta \pi(z; \gamma_{k}^{f} u_{j} v_{l}) : L_{l} = \max \max_{v} \pi(z; \gamma_{k}^{f} u_{j} v_{l}) - \pi(z; \gamma_{k}^{f} u_{j} v_{l}) \leq 0 \]  

(2.61)

Equation 2.61 computes the minimum loss in net price resulting from origin \( g \) re-routing one bushel of commodity \( z \) during time \( t \) from \( L_{l}^{e} \) to \( L_{l}^{e} \), and commodity \( z \) is shipped from \( L_{l}^{e} \) to \( L_{l}^{j} \) through \( L_{l}^{f} \) where \( L_{l}^{k} \in \{ \text{ESK} < 0 \}; L_{l}^{e} \in \{ \text{ESK} > 0 \} \); \( L_{l}^{f} \in \{ \text{ESK} > 0 \} \); \( z \neq v \); and \( t \neq u \). Equation 2.61 is repeated for each \( L_{l}^{e} \) where \( e = 1, 2, \ldots, (H' - h') \); for each \( L_{l}^{f} \) where \( f = 1, 2, \ldots, (I' - i') \); for each time \( u \) where \( u = t, t + 1, \ldots, T \); for each commodity \( z \) shipped to \( L_{l}^{k} \); and for each origin \( g \) shipping commodity \( z \) to \( L_{l}^{k} \).

\[ \Delta \pi(z; \gamma_{h}^{f} t_{t} t^{v} u_{j} v_{l}) : L_{l} = \max \max_{v} \pi(z; \gamma_{h}^{f} t_{t} t^{v} u_{j} v_{l}) - \pi(z; \gamma_{h}^{f} t_{t} t^{v} u_{j} v_{l}) \leq 0 \]  

(2.62)

Equation 2.62 computes the minimum loss in net price resulting from origin \( g \) re-routing one bushel of commodity \( z \) during time \( t \) from \( L_{l}^{k} \) to \( L_{l}^{h} \), and commodity \( z \) is shipped from \( L_{l}^{h} \) to \( L_{l}^{j} \) through \( L_{l}^{f} \) where \( L_{l}^{k} \in \{ \text{ESK} < 0 \}; L_{l}^{e} \in \{ \text{ESK} > 0 \}; \) \( L_{l}^{f} \in \{ \text{ESK} > 0 \} \); and \( t \neq v \). Equation 2.62 is repeated for each \( L_{l}^{h} \) where \( h = 1, 2, \ldots, H \) because Equation 2.62 does not consider any storage options at country elevators. Grain that is received at a country elevator for the options
described by Equation 2.62 is shipped out in the same month that it is received. Country elevator \( L_l k \in \{ \text{ESK} < 0 \} \) can receive grain in time \( t \) and ship it out in the same month without adding to the amount of grain in storage. Thus, the range of country elevators by Equation 2.62 extends from \( L_l 1 \) through \( L_l H \). Equation 2.62 is also repeated for each \( L_2 f \) where \( f = 1, 2, \ldots, (I' - i') \); for each commodity \( z \) shipped to \( L_l k \); and for each origin \( g \) shipping commodity \( z \) to \( L_l k \).

\[
\Delta \pi(z; t; k, t; g, v, j, v) : L_l k = \max_{v} \max_{j} \max_{i} \pi(z; t; g, t; v, j, v)
\]

\[
- \pi(z; t; k, t; g, v, j, v) \leq 0 \quad (2.63)
\]

Equation 2.63 computes the minimum loss in net price resulting from origin \( g \) re-routing one bushel of commodity \( z \) during time \( t \) from \( L_l k \) to \( L_l e \), and commodity \( z \) is shipped from \( L_l e \) in time \( v \) to \( L_l j \) through \( L_2 i \) where \( L_l k \in \{ \text{ESK} < 0 \} \); \( L_l e \in \{ \text{ESK} > 0 \} \); and \( t \neq v \). Grain received at \( L_2 i \) in time \( v \) from \( L_l e \) is not stored. Thus, in Equation 2.63 it is possible to maximize over \( L_2 i \) where \( i = 1, 2, \ldots, I \) because the selection of the best subterminal given \( \lambda_{mn} \) does not influence the amount of grain in storage at any other country elevator or subterminal. Equation 2.63 is repeated for each \( L_l e \in \{ \text{ESK} < 0 \} \) where \( e = 1, 2, \ldots, (H' - h') \); for each commodity \( z \) shipped to \( L_l k \); and for each origin \( g \) shipping commodity \( z \) to \( L_l k \).
\[
\Delta \pi(z; g_t h_{tt \cdot j_t}) : L_l_k = \max \max \pi(z; g_t h_{tt \cdot j_t}) \\
- \pi(z; g_t k_{ts \cdot j_{l_s}}) \leq 0
\] (2.64)

Equation 2.64 computes the minimum loss in net price resulting from origin g re-routing one bushel of commodity \( z \) during time \( t \) from \( L_l_k \) to \( L_l_h \), and commodity \( z \) is shipped from \( L_l_h \) to \( L_{j \cdot t} \) (in time \( t \), where \( L_l_k \in \{ ESK < 0 \} \); and \( h = 1, 2, \ldots, H \). Grain received at \( L_l_h \) from origin \( g \) in time \( t \) is shipped immediately to destination \( j \). Equation 2.64 is repeated for each commodity \( z \) shipped to \( L_l_k \); and for each origin \( g \) shipping commodity \( z \) to \( L_l_k \).

\[
\Delta \pi(z; g_t \tilde{h}_{tt \cdot \tilde{j}_t}) : L_l_k = \max \max \pi(z; g_t \tilde{i}_{tt \cdot \tilde{j}_t}) \\
- \pi(z; g_t k_{ts \cdot \tilde{j}_{l_s}}) \leq 0
\] (2.65)

Equation 2.65 computes the minimum loss in net price resulting from origin \( g \) re-routing one bushel of commodity \( z \) during time \( t \) from \( L_l_k \) to \( L_j \) in time \( t \) through \( L_{2 \cdot i} \) where \( L_l_k \in \{ ESK < 0 \} \); and \( i = 1, 2, \ldots, I \). Equation 2.65 is repeated for each commodity \( z \) shipped to \( L_l_k \); and for each origin \( g \) shipping commodity \( z \) to \( L_l_k \).

\[
\Delta \pi(z; g_t \tilde{h}_{tt \cdot \tilde{i}_{tt \cdot \tilde{j}_t}}) : L_l_k = \max \max \max \pi(z; g_t h_{tt \cdot i_{tt \cdot j_t}}) \\
- \pi(z; g_t k_{ts \cdot j_{l_s}}) \leq 0
\] (2.66)
Equation 2.66 computes the minimum loss in net price resulting from origin g re-routing commodity z during time t from $L_{l_k}$ to $L_{j}$ through $L_{l_h}$ and $L_{2_i}$ where $L_{l_k}E{SK < 0}; h = 1,2,\ldots,H; \text{ and } i = 1,2,\ldots,I$. Equation 2.66 is repeated for each commodity $z$ shipped to $L_{l_k}'$ and for each origin $g$ shipping commodity $z$ to $L_{l_k}$.

The re-routing alternatives defined by Equations 2.59 through 2.66 may be summarized as follows: In Equation 2.59, grain is re-routed from an elevator with negative excess storage capacity to a country elevator ($L_{l_e}$) with unused storage capacity. In this alternative grain is then shipped from country elevator $L_{l_e}$ to a final market without transhipping the grain through a subterminal.

In Equation 2.60, grain is re-routed from an elevator with negative excess storage capacity to a subterminal that has unused storage capacity.

In Equation 2.61, grain is re-routed from an elevator with negative excess storage capacity to a country elevator ($L_{l_e}$) with unused storage capacity. Here, grain is then shipped from country elevator $L_{l_e}$ to the best final market by transhipping the grain through a subterminal elevator with unused storage capacity.

In Equation 2.62, grain is re-routed from an elevator with negative excess storage capacity to a country elevator ($L_{l_h}$) that has no unused storage capacity. Grain received at
country elevator L1h is transhipped directly to a subterminal elevator with unused storage capacity.

In Equation 2.63, grain is re-routed from an elevator with negative excess storage capacity to a country elevator (Lle) with unused storage capacity. Grain is then transhipped through a subterminal elevator that has no unused storage capacity to a final destination.

In Equation 2.64, grain is re-routed from an elevator with negative excess storage capacity to a country elevator (L1h) that has no unused storage capacity. Grain received at country elevator L1h is shipped directly to a final destination.

In Equation 2.65, grain is re-routed from an elevator with negative excess storage capacity to a subterminal elevator (L2i) that has no unused storage capacity. Grain that is re-routed to subterminal L2i is transhipped immediately to a final destination.

In Equation 2.66, grain is re-routed from an elevator with negative excess storage capacity to a country elevator (L1h) that has no unused storage capacity. Grain that is re-routed to country elevator L1h is transhipped to a final market through a subterminal that has no unused storage.
capacity.

Many temporal and spatial re-routing alternatives are also available to reduce the amount of grain in storage at $L_{2_k'} \in \{ESK < 0\}$. Equations 2.67 through 2.74 present the change in net price resulting from various re-routing alternatives that may be used to reduce the amount of commodity $z$ in storage during time $t$ at $L_{2_k'}$, given $\lambda_{mnr}$. Equations 2.67 through 2.74 are defined the same as Equations 2.59 through 2.66 respectively if each $L_{1_k}$ in Equations 2.67 through 2.66 is replaced by $L_{2_k'}$. Equations 2.67 through 2.74 are repeated for each $L_{2_k'} \in \{ESK < 0\}$ where $k' = 1, 2, \ldots, i'$.

$$\Delta \pi(z; g_t e_{tv} J_v): L_{2_k'} = \max_{v} \max_{j} \pi(z; g_t e_{tv} J_v)$$
- $\pi(z; g_t \cdot k' s_{ts} s) \leq 0$ (2.67)

$$\Delta \pi(z; g_t f_{tv} J_v): L_{2_k'} = \max_{v} \max_{j} \pi(z; g_t f_{tv} J_v)$$
- $\pi(z; g_t \cdot k' s_{ts} s) \leq 0$ (2.68)
\[
\Delta \pi(z; g_t e_t u_{v j_v}^T) : L_{2k}, = \max_{v} \max_{j} \pi(z; g_t e_t u_{v j_v}^T)
\]
- \( \pi(z; g_t e_t u_{v j_v}^T) \) \( \leq 0 \) \( (2.69) \)

\[
\Delta \pi(z; g_t h_t t_{v j_v}^T) : L_{2k}, = \max_{v} \max_{j} \pi(z; g_t h_t t_{v j_v}^T)
\]
- \( \pi(z; g_t h_t t_{v j_v}^T) \) \( \leq 0 \) \( (2.70) \)

\[
\Delta \pi(z; g_t e_t u_{v j_v}^T) : L_{2k}, = \max_{v} \max_{j} \pi(z; g_t e_t u_{v j_v}^T)
\]
- \( \pi(z; g_t e_t u_{v j_v}^T) \) \( \leq 0 \) \( (2.71) \)

\[
\Delta \pi(z; g_t h_t t_{v j_v}^T) : L_{2k}, = \max_{v} \max_{j} \pi(z; g_t h_t t_{v j_v}^T)
\]
- \( \pi(z; g_t h_t t_{v j_v}^T) \) \( \leq 0 \) \( (2.72) \)

\[
\Delta \pi(z; g_t h_t t_{v j_v}^T) : L_{2k}, = \max_{v} \max_{j} \pi(z; g_t h_t t_{v j_v}^T)
\]
- \( \pi(z; g_t h_t t_{v j_v}^T) \) \( \leq 0 \) \( (2.73) \)

\[
\Delta \pi(z; g_t h_t t_{v j_v}^T) : L_{2k}, = \max_{v} \max_{j} \pi(z; g_t h_t t_{v j_v}^T)
\]
- \( \pi(z; g_t h_t t_{v j_v}^T) \) \( \leq 0 \) \( (2.74) \)

For each origin \( g \) required to re-route commodity \( z \) in time \( t \) from \( L_{1k} \in \{ESK < 0\} \) there are \( [(H'-h')+(I'-i')+
(H'-h')(I'-i')(T-t)+H(I-i')+(H'-h')+3] \) re-routing alternatives as defined by Equations 2.59 through 2.66. And for
each origin \( g \) required to re-route commodity \( z \) in time \( t \) from storage in \( L^2_{k'} \{ \text{ESK} < 0 \} \) there are \([2(H'-h')+(H+1)(I'-i')(T-t)+3]\) alternatives as defined by Equations 2.67 through 2.74.

Now define a change in net price matrix that may be used to determine the best pattern of re-routing grain in storage from country elevators and subterminals with negative excess capacity. Let \( L^3_{1}, L^3_{2}, \ldots, L^3_{h'}, L^3_{h'+1}, L^3_{h'+2}, \ldots, L^3_{h'+i'} \) denote the set of country elevators and subterminals with negative excess storage capacity as determined by the solution of ORA(1, t) where \( L^3_{1} = L_{11}, L^3_{2} = L_{12}, \ldots, L^3_{h'} = L_{h'}, L^3_{h'+1} = L_{21}, L^3_{h'+2} = L_{22}, \ldots, L^3_{h'+i'} = L_{i1} \). Define a set of re-routing alternatives, \( j_3 \), for origin \( g \) when commodity \( z \) in time \( t \) is re-routed from \( L^3_{k} \{ \text{ESK} < 0 \} \) where \( j_3 \) includes all possible alternatives as defined by Equations 2.59 through 2.74. Thus, \( \Delta \pi(z; g_t, j_3_t) : L^3_{k} \) denotes the loss in net price resulting from origin \( g \) re-routing one bushel of commodity \( z \) in time \( t \) from elevator \( L^3_{k} \) to destination \( j_3 \) where \( k = 1, 2, \ldots, h'+i' \); and \( j_3 = 1, 2, \ldots, [2(H'-h') + (H+1)(I'-i') + (H'-h')(I'-i')(T-t)+3] \). By repeating Equations 2.59 through 2.74 for each commodity \( z \) \((z = 1, 2, \ldots, z')\) shipped by each origin \( g \) \((g = 1, 2, \ldots, G')\) to an elevator with negative excess storage capacity, we end up with a \( G' \sum_{g_t} z' \) by \([2(H'-h') + (H+1)(I'-i') + (H'-h')(I'-i')(T-t)+3]\) \( [h'+i'] \) matrix. \( z'_{g_t} \) denotes the total number of grains.
shipped from origin g in time t to an elevator t with negative excess storage capacity as determined by ORA(l,t).

The change in net price matrix \([\Delta \pi(\varepsilon; g_t \ldots j3_t):L3_k]\) may now be used to determine the best pattern of re-routing grain in storage from elevators with negative excess storage capacity. Scan the change in net price matrix to find the largest element. Since the change in net price is negative, the largest negative net price will minimize the loss in total revenue net variable costs. Assume that \(\Delta \pi(a; b_t \ldots c_t):L3_d = \max \max \max \max \Delta \pi(\varepsilon; g_t \ldots j3_t):L3_k\) where \(j3 = c\) and \(L3_k = L3_d\) denote the option of origin b re-routing commodity a in time t from \(L1_{h'}\in\{ESK < 0\}\) to \(L2_{f}\in\{ESK > 0\}\); and commodity a received at \(L2_f\) in time t is stored until time v and then shipped to final destination \(L_j\). The value of the largest element, thus, is \(\Delta \pi(a; b_t f_t \ldots j3_t):L1_{h'}\). If

\[
\sum_{z} X(z; \cdot h'v \ldots) - X(a; b_t \ldots) \geq SK(h'_t .)
\]

(2.75)

and

\[
\sum_{z} X(z; \cdot f_v \ldots) + X(a; b_t \ldots) \leq SK(f_t .)
\]

(2.76)

re-route \(X(a; b_t \ldots)\); and, delete the row vector for origin b and commodity a from the matrix of \([\Delta \pi(\varepsilon; g_t \ldots j3_t):L3_k]\).

Depending upon the selection of the re-routing alternative, \(j3\), it may be necessary to consider other inequalities in addition to 2.75 and 2.76 in determining the re-routing
pattern that minimizes the loss in revenue net variable costs. Suppose that
\[ \Delta \pi(a; b_t \ldots c_t; t; L_3) = \]
\[ \max \max \max \max \Delta \pi(z; g_t \ldots j_t; t; L_3) = \]
\[ L_3^k = L_3^d \]
do notate the option of origin b re-routing commodity "a" in time t from
\[ L_1 \] 
commodity "a" received at \[ L_1 \] in time t is stored until time
\[ u \] 
and shipped to \[ L_2 \] ; and commodity "a" received in time t at \[ L_2 \] is stored until time \[ v \] and shipped to \[ L_j \].
The value of \[ \Delta \pi(a; b_t \ldots c_t; t; L_3) = \Delta \pi(a; b_t \ldots c_t; t; L_1^h) \].
Now, in addition to 2.75 and 2.76 a third inequality is required. If 2.75, 2.76, and
\[ \sum_{z} X(z; h_t \ldots) + X(a; b_t \ldots) \leq SK(h_t \ldots) \] 
are satisfied, re-route \( X(a; b_t \ldots) \); and, delete the row vector of origin "b" shipping commodity "a" from further computations.
If, however, commodity "a" from origin "b" is re-routed from storage in \[ L_2 \] , then 2.76, 2.77, and
\[ \sum_{b} X(z; i_t \ldots) - X(a; b_t \ldots) \geq SK(i_t \ldots) \] 
are the appropriate inequalities to consider. Thus, depending upon the selected re-routing alternative, various inequalities must be considered to determine the re-routing pattern that minimizes the loss in revenue net of variable costs.
The specific inequalities that must be considered for selected re-routing alternatives are as follows: If (after selecting the largest element from \( [\Delta \pi (s; g_t \ldots j_3_t) : L_3_k] \)) we relabel the appropriate indices in Equations 2.59 through 2.78 to be consistent with the selected re-routing option, then the inequalities to be considered with the re-routing alternative defined by Equation 2.59 are inequalities 2.75 and 2.77; Equation 2.60 requires inequalities 2.75 and 2.76; Equation 2.61 requires inequalities 2.75, 2.77, and 2.76; Equation 2.62 requires inequalities 2.75 and 2.76; Equation 2.63 requires inequalities 2.75 and 2.77; Equations 2.64, 2.65, and 2.66 each require inequality 2.75; Equation 2.67 requires 2.78 and 2.77; Equation 2.68 requires 2.78 and 2.76; Equation 2.69 requires inequality 2.78, 2.77, and 2.76; Equation 2.70 requires inequality 2.78 and 2.76; Equation 2.71 requires inequality 2.78 and 2.77; and, Equations 2.72, 2.73, and 2.74 each requires inequality 2.78.

If \( X(a; b_t \ldots) \) cannot be re-routed without violating one of the inequalities, only re-route as much of \( X(a; b_t \ldots) \) as possible without violating the appropriate inequalities. If \( X(a; b_t \ldots) \) is reduced to avoid violating 2.75, excess storage capacity at \( L_{1_h} \), will be zero after the re-routing and the submatrix of \( [\Delta \pi (s; g_t \ldots j_3_t) : L_{1_h}] \) may be deleted from the matrix of \( [\Delta \pi (s; g_t \ldots j_3_t) : L_3_k] \). Because grain may still be transhipped through \( L_{1_h} \), as defined by Equations 2.64,
2.65, 2.66, 2.72, 2.73, and 2.74, columns containing $L_{1h}$, are not removed from the remaining submatrices of $[\Delta \pi(z; g_t \ldots j_{3t}) : L_{3k}]$.

If $x(a; b_t \ldots)$ is reduced to avoid violating 2.76, excess storage capacity at $L_{2f}$ will be zero after the re-routing and all columns of the matrix of $[\Delta \pi(z; g_t \ldots j_{3t}) : L_{3k}]$ containing grain storage options at $L_{2f}$ should be deleted. If $X(a; b_t \ldots)$ is reduced to avoid violating 2.77, excess storage capacity at $L_{1h}$ will be zero following the re-routing; and, all columns of the matrix of $[\Delta \pi(z; g_t \ldots j_{3t}) : L_{3k}]$ containing the option to store grain at $L_{1h}$ should be deleted. And, if $X(a; b_t \ldots)$ is reduced to avoid violating 2.78, excess storage capacity at $L_{2i}$, will be zero following the re-routing and the submatrix of $[\Delta \pi(z; g_t \ldots j_{3t}) : L_{2i}]$ should be deleted from the matrix of $[\Delta \pi(z; g_t \ldots j_{2t}) : L_{3k}]$.

Once the appropriate row and column vectors have been deleted from the matrix of $[\Delta \pi(z; g_t \ldots j_{3t}) ; L_{3k}]$, scan the remaining elements to find the largest element. Re-route grain from the selected elevator with negative excess storage capacity, taking into account the appropriate inequalities of 2.75, 2.76, 2.77, and 2.78; and, making the necessary adjustments in the volume of grain re-routed. After re-routing the grain and deleting the necessary row and column vectors from the matrix of $[\Delta \pi(z; g_t \ldots j_{3t}) : L_{3k}]$, scan the remaining elements to find the largest element. Continue in
the manner until either a) no elevator has negative excess storage capacity; or b) no elevator has unused storage capacity and at least one elevator has negative excess storage capacity.

Let \( \Delta w(z; g_t \ldots j_3_t):L_3_k \) denote the matrix of minimum loss in net prices resulting from re-routing commodity \( z \) in time \( t \) from storage in \( L_3_k \) where the range of \( z, g, \) and \( j_3 \) is determined by the solution of Step 2 of ORA(2,t). Let \( \bar{X}(z; g_t \cdot j_3_t):L_3_k \) denote the matrix of the amounts of commodity \( z \) re-routed from \( L_3_k \) to destination \( j_3 \) in time \( t \) where the range of \( z, g, \) and \( j_3 \) is determined by Step 2 of ORA(2,t).

If no elevator has negative excess storage capacity after making the appropriate re-routings, proceed to Step 4 and compute the change in revenue net of variable costs. If at least one elevator has negative excess storage capacity and no elevator has unused storage capacity after the appropriate re-routings of Step 2, proceed to Step 3.

Step 3: The procedure described in Step 2 re-routes grain subject to the capacity expansion constraint that no elevator can expand storage capacity as long as there exists unused storage capacity at any other elevator. In Step 3 the capacity expansion constraint is not a binding restriction because, following the re-routings of Step 2, no elevator
has unused storage capacity.

The purpose of Step 3 is to determine a) the amount of storage capacity that should be added to country elevators and subterminals with negative excess storage capacity as determined by Step 2 of ORA(2,t), and b) the amount of grain that should be re-routed from storage at elevators with negative excess storage capacity to another marketing alternative. Equations 2.64, 2.65, and 2.66; or Equations 2.72, 2.73, and 2.74 describe various re-routing alternatives given that no elevator has unused storage capacity.

Suppose that following the solution of Step 2, country elevators \( L_{1}, L_{2}, \ldots, L_{n} \) and subterminals \( L_{2}, L_{2}, \ldots, L_{2} \) have negative excess storage capacity; and, all other country elevators and subterminals have no unused storage capacity. Further assume that country elevator \( L_{k} \) receives commodity \( z \) from origin \( g \) in time \( t \), for all \( g \) shipping grain \( z \) to \( L_{k} \); and all of commodity \( z \) received at \( L_{k} \) in time \( t \) is stored at \( L_{k} \) until the end of period \( s \).

If storage capacity is expanded to hold one additional bushel of commodity \( z \) at \( L_{k} \), the loss in net price equals \( S_{2} \), where \( S_{2} \) is the marginal cost of expanding storage capacity. The loss in net price resulting from origin \( g \) re-routing one bushel of commodity \( z \) during time \( t \) from storage in \( L_{k} \) is determined by Equations 2.64, 2.65, or 2.66. Equations 2.64, 2.65, and 2.66 are repeated for each commodity \( z \) shipped.
to \( L_{1,k} \); and for each origin \( g \) shipping commodity \( z \) to \( L_{1,k} \).

Each subterminal with more grain in storage than it's capacity allows it to store, as determined by Step 2 of ORA(2,t), may also expand storage capacity and/or re-route grain from storage. The marginal cost of expanding storage capacity at all elevators, including country elevators and subterminals, is \( S_2 \). The loss in net price resulting from origin \( g \) re-routing one bushel of commodity \( z \) during time \( t \) from storage at \( L_{2,k} \) \( \in \{ESK < 0\} \) is determined by Equations 2.72, 2.73, and 2.74.

Now define a change in net price matrix that may be used to determine the best alternatives between expanding storage capacity and re-routing grain in storage from country elevators and subterminals with negative excess capacity. Let \( L_{4,1}, L_{4,2}, \ldots, L_{4,h}, L_{4,h+1}, L_{4,h+2}, \ldots \)

\( L_{4,h+1} \) denote the set of country elevators and subterminals with negative excess storage capacity as determined by Step 3 of ORA(2,t) where \( L_{4,1} = L_{1,1}, L_{4,2} = L_{1,2}, \ldots, L_{4,h} = L_{1,h}, L_{4,h+1} = L_{2,h+1}, \ldots, L_{4,h+1} = L_{2,1} \). Let

\( \Delta\pi(z; g_{t \ldots 2_t})_{L_{4,k}} \) denote a) the value of Equation 2.64 if \( k<h \); or b) the value of Equation 2.72 if \( k>h \). Let

\( \Delta\pi(z; g_{t \ldots 3_t})_{L_{4,k}} \) denote a) the value of Equation 2.65 if \( k<h \); or b) the value of 2.73 if \( k>h \). Let \( \Delta\pi(z; g_{t \ldots 4_t})_{L_{4,k}} \) denote a) the value of Equation 2.66 if \( k<h \); or b) the value of Equation 2.74 if \( k>h \). And, denote the
loss in net price resulting from expanding storage capacity at \( L_{4,k} \) as \( \Delta \pi(x; g_t \ldots l_t): L_{4,k} \) where

\[
\Delta \pi(x; g_t \ldots l_t): L_{4,k} = -S2 \tag{2.79}
\]

For each origin \( g \) shipping commodity \( z \) to \( L_{4,k} \) compute \( \Delta \pi(x; g_t \ldots j_{4,t}): L_{4,k} \) where \( z = 1, 2, \ldots, Z'' \), \( g = 1, 2, \ldots, G'' \); and \( j_{4,t} = 1, 2, \ldots, 4 \). \( Z'' \) denotes the total number of grains shipped from origin \( g \) in time \( t \) to country elevators and subterminals with negative excess storage capacity as determined by Step 2 of ORA(2, t). Computing the value of \( \Delta \pi(x; g_t \ldots j_{4,t}): L_{4,k} \) for each \( x, g, \) and \( j_{4,t} \) gives us a change in net price matrix,

\[
\begin{array}{c}
\sum_{g=1}^{G''} \sum_{z=1}^{Z''} g_t z \\
\end{array}
\]

\([\Delta \pi(x; g_t \ldots j_{4,t}): L_{4,k}]\), for \( L_{4,k} \). Construct a change in net price matrix for \( k = 1, k = 2, \ldots, k = i''+h'' \).

The change in net price matrix for \( L_{1,k} \) may now be used to determine the amount of storage capacity to add to \( L_{4,k} \) and the amount of grain in storage at \( L_{4,k} \) during time \( t \) to re-route. Scan the change in net price matrix of \( [\Delta \pi(x; g_t \ldots j_{4,t}): L_{4,k}] \) to find the largest element. Suppose that \( \Delta \pi(a; b_t \ldots c_t): L_{4,k} = \max_{g} \max_{z} \max_{j_{4,t}} \Delta \pi(a; g_t \ldots j_{4,t}): L_{4,k} \) where \( c \) represents \( j_{4,t} = 2, 3 \) or 4; and \( L_{4,k} \) denotes country elevator \( L_{1,h} \). If

\[
\sum_{z} \overline{X}(a; g_t \ldots l_t) - \overline{X}(a; b_t h_t \ldots) \geq SK(h_t \ldots) \tag{2.80}
\]

re-route \( \overline{X}(a; b_t h_t \ldots) \) and delete the row vector for origin
b and commodity "a" from the matrix of $[\Delta \pi(z; g_t..j_3 t): L_4]$. $\bar{X}(a; h_{vt}..)$ denotes the amount of commodity "a" in storage at $L_{1h}$, during time $t$ as determined by Step 2 of ORA(2,$t$). $\bar{X}(a; b_t h'..)$ denotes the amount of commodity "a" shipped from origin $b$ to $L_{1h}$, in time $t$ as determined by Step 2 of ORA(2,$t$).

On the other hand, if $\Delta \pi(a; b_t..2_t): L_4_k = \max \max \max \Delta \pi(z; g_t..j_4 t): L_4_k$ where $L_4_k$ denotes subterminal $L_{2k}'$, then the following inequality of Equation 2.81 must be considered. If

$$\sum \bar{X}(z; ..k_{vt}..) - \bar{X}(a; b_t..k'_{vt}..) \geq SK(k'_{vt}) \tag{2.81}$$

re-route $\bar{X}(a; b_t..k'_{vt}..)$ and delete the row vector for origin $b$ and commodity "a" from the matrix of $[\Delta \pi(z; g_t..j_4 t): L_4_k]$. The symbol $\bar{X}(z; ..k_{vt}..)$ denotes the amount of commodity $z$ in storage at $L_{2k}'$, during time $t$ as determined by Step 2 of ORA(2,$t$). The amount of commodity $z$ shipped from origin $g$ to $L_{2k}'$, in time $t$ as determined by Step 2 of ORA(2,$t$) is denoted by $\bar{X}(z; g_t..k'_{vt}..)$.

If inequality 2.80 is violated when re-routing $\bar{X}(a; b_t h'..)$ from country elevator $L_{1h}' e \{ESK < 0\}$, or if inequality 2.81 is violated when re-routing $\bar{X}(a; b_t..k'_{vt}..)$ from subterminal $L_{2k}' e \{ESK < 0\}$, only re-route as much grain as possible without violating the appropriate inequality. If $\bar{X}(a; b_t h'..)$ is reduced to avoid violating 2.80, excess
storage capacity at L_{h}' will be zero following the re-routing, and the matrix of $[\Delta \pi(z; g_t..j_4^t):L_4^k = L_{h}']$ may be dropped from further computation. If $\bar{X}(a; b_t.k'_t..)$ is reduced to avoid violating 2.81, excess storage capacity at L_{2,k}' will be zero following the rerouting and the matrix of $[\Delta \pi(z; g_t..j_4^t):L_4^k = L_{2,k}']$ may be dropped from further computation.

The matrix of $[\Delta \pi(z; g_t..j_4^t):L_4^k]$ cannot be dropped from further computation, however, if excess storage capacity at L_{4,k} is still negative following the re-routing of commodity "a" supplied by origin b. If excess storage capacity is still negative at L_{4,k} following the re-routing, the row vector for origin b and commodity "a" may be dropped from the matrix $[\Delta \pi(z; g_t..j_4^t):L_4^k]$. After removing the appropriate row vector, scan the remaining elements to find the largest element. Continue re-routing grain from L_{4,k} \in \{E_{SK} < 0\} until the addition loss in revenue net of variable costs from re-routing is greater than the additional loss in net revenue from expanding storage capacity.

The additional loss in revenue net of variable costs from re-routing will be greater than the additional loss in net revenue from expanding storage capacity whenever $\Delta \pi(a; b_t..c_t):L_4^k = \max \max \max \Delta \pi(z; g_t..j_4^t):L_4^k$ and $c = 1$. Storage capacity should be expanded until excess storage capacity at L_{4,k} equals zero if this is the case. Once
excess storage capacity at $L_k$ equals zero, the matrix of
$[\Delta \pi(t; \sigma_t \ldots j_t) : L_k]$ may be removed from further computa-
tions.

Let $\hat{\Delta \pi}(d; e_t \ldots k_t) : L_k$ denote the matrix of minimum loss
in net prices resulting from re-routing commodity $d$ in time
t from storage in $L_k \in \{ESK < 0\}$ where the range of $d$, $e$, and
$j$ is determined by the solution of Step 3 of ORA(2,t). And,
let $\hat{X}(d; e_t \ldots j_k) : L_k$ denote the matrix of the amounts of
commodity $d$ re-routed from $L_k \in \{ESK < 0\}$ to destination $j$
in time $t$ where the range of $d$, $e$, and $j$ is determined by
the solution of Step 3 of ORA(2,t).

In short, grain may be re-routed from storage in
$L_k \in \{ESK < 0\}$ until excess storage capacity at $L_k$ equals zero;
storage capacity may be expanded at $L_k$ until excess storage
capacity at $L_k$ equals zero; or some grain may be re-routed
from storage in $L_k$ and some storage capacity may be added to
$L_k$ until excess storage capacity at $L_k$ equals zero. Step 3 is repeated for each $L_k \in \{ESK < 0\}$ where $k = 1,2,\ldots, (i''+h'')$.

Step 4: The objective of Step 4 is to determine the
change in total revenue net of variable costs resulting from
re-routing grain and/or expanding storage as determined by
Step 2 and Step 3 of ORA(2,t). Denote the loss in total
revenue net of variable costs in time $t$ from re-routing
grain and/or expanding storage capacity at $L_k \in \{ESK < 0\}$
as determined by the solution of ORA(2,t) as \( \Delta TRNVC(t \ k') \).
Compute \( \Delta TRNVC(t \ k') \) as follows:

\[
\Delta TRNVC(t \ k') = \{ \sum \sum \sum X(z; g_{t \ j3_t}) \Delta \pi(z; g_{t \ j3_t}) : Ll_k \} \\
+ \{ \sum \sum \sum X(d; e_{t \ j4_t}) \Delta \pi(d; e_{t \ j4_t}) : Ll_k \} \\
+ \{ [SK(k_{t ..}) - \sum X(d; .k_{t ..})] S2 \}
\]

The terms in the first set of \( \{ \} \) of Equation 2.84 denote the re-routing of grain from storage in \( Ll_k \epsilon \{ ESK < 0 \} \) as determined by the solution of Step 2 of ORA(2,t); the terms in the second set of \( \{ \} \) denote the re-routing of grain from storage in \( Ll_k \epsilon \{ ESK < 0 \} \) as determined by the solution of Step 3 of ORA(2,t); and the terms in the third set of \( \{ \} \) denote the cost of expanding storage capacity at country elevator \( Ll_k \epsilon \{ ESK < 0 \} \) as determined by the solution of Step 3 of ORA(2,t).

The loss in total revenue net variable costs in time \( t \) from re-routing grain and/or expanding storage capacity at \( Ll_k \epsilon \{ ESK < 0 \} \) as determined by the solution of ORA(2,t) is denoted by \( \Delta TRNVC(t \ .k') \);
\[ \Delta \text{TRNVC}(t, k') = \{ \sum \sum \bar{x}(m, g_t .. j_{3,t}) \Delta \pi(m, g_t .. j_{3,t}) : L_{2,k'} \} \]

\[ + \{ \sum \sum \hat{x}(d, e_t .. j_{4,t}) \Delta \hat{\pi}(d, e_t .. j_{4,t}) : L_{2,k} \} \]

\[ + \{ \sum k' \in \mathcal{E} \sum d \sum \bar{x}(d, k' .. j_{4,t}) \Delta \hat{\pi}(d, e_t .. j_{4,t}) : L_{2,k} \} \]

The terms in the first set of \{\} of Equation 2.85 denote the re-routing of grain from storage in \( L_{2,k'} \in \mathcal{E} \{ E_{\mathcal{K}} < 0 \} \) as determined by the solution of Step 2 of \( \text{ORA}(2,t) \); the terms in the second set of \{\} denote the re-routing of grain from storage in \( L_{2,k'} \in \mathcal{E} \{ E_{\mathcal{K}} < 0 \} \) as determined by the solution of Step 3 of \( \text{ORA}(2,t) \); and the terms in the third set of \{\} denote the cost of expanding storage capacity at subterminal \( L_{2,k'} \in \mathcal{E} \{ E_{\mathcal{K}} < 0 \} \) as determined by the solution of Step 3 of \( \text{ORA}(2,t) \).

Step 5: Once the optimal marketing pattern has been determined over time and space for each grain \( z \) shipped from each origin in time \( t \), \( \text{TRNVC}(2,t) | \lambda \) can be computed.

\( \text{TRNVC}(2,t) | \lambda \) denotes the maximum total revenue of all producers in time \( t \) net of variable costs as determined by \( \text{ORA}(2,t) | \lambda \). \( \text{TRNVC}(2,t) | \lambda \) is computed as follows:

\[
\text{TRNVC}(2,t) | \lambda = \text{TRNVC}(1,t) | \lambda - \sum_{h \in \lambda} \Delta \text{TRNVC}(t, h) - \sum_{i \in \lambda} \Delta \text{TRNVC}(t, i) \]

(2.86)
Part I: optimal routing pattern

The two routing algorithms ORA(1,t)|λ and ORA(2,t)|λ determine the maximum joint revenue net of variable costs given λ for time t. Our objective, however, is to optimize over a finite time horizon of 12 months. Part I presents fifteen steps integrating the use of ORA(1,t) and ORA(2,t) to determine the optimal routing pattern of grain over time and space given λ. Step 4 of Part I computes the joint revenue of producers net of variable costs over all time periods given λ.

Step 1.1: Set month t = 1.

Step 1.2: Set marginal storage costs at all country elevators and all subterminals equal to marginal operating and maintenance costs of storage.

Step 1.3: Use ORA(1,1)|λ to determine a) the optimal routing of grain shipped from all origins in time 1 to final destinations; and b) the total revenue net variable costs, given λ.

Step 1.4: Compute the excess storage capacity existing at the end of month one for each elevator. See Equations 2.11 and 2.20.

Step 1.5: If ESK(h1.) > 0 for all h∈λ, and ESK(. i1.) ≥ 0 for all i∈λ, go to Step 1.6. Otherwise, if one or more elevators have negative excess capacity at the beginning of month 2, go to Step 1.7.

Step 1.6: The solution of ORA(1,1) is optimal and not
inconsistent with the data. Let $\overline{\text{TRNVC}}(.t)|\lambda$ denote the maximum total revenue of producers in time $t$ net of marginal elevator handling costs and marginal transportation costs as determined by the algorithm chosen to solve for the optimal routing of grain during time $t$. Thus:

$$\overline{\text{TRNVC}}(.1)|\lambda = \overline{\text{TRNVC}}(1,1)|\lambda$$

(2.87)

The optimal routing of grain shipped from origins in month two may now be determined by following the procedures as outlined from Step 2.1 to Step 2.7.

Step 1.7: Use $\overline{\text{ORA}}(2,1)|\lambda$ to determine the optimal routing of grain shipped from all origins in time 1 to final destinations, given $\lambda$. Let $\overline{\text{TRNVC}}(.t)|\lambda$ denote the maximum total revenue of producers in time $t$ net of marginal costs as determined by the algorithm chosen to solve for the optimal routing of grain during time $t$. Thus, since $\overline{\text{ORA}}(2,1)$ was chosen to determine the routing of grain shipped from origins during time 1,

$$\overline{\text{TRNVC}}(.1)|\lambda = \overline{\text{TRNVC}}(2,1)|\lambda$$

(2.88)

The optimal routing of grain shipped from origins in month two may now be determined by following the procedures as outlined from Step 2.1 to Step 2.7.

Step 2.1: Set month $t = 2$. 
Step 2.2: For all \( L_{1h} \in \lambda \) with \( ESK(h_1) > 0 \); and for all \( L_{2i} \in \lambda \) with \( ESK(k_1) > 0 \), set:

\[
\alpha_{BS}(z; h_{2s},) = BS(z; h_{2s},)
\]

and

\[
\alpha_{BS}(z; i_{2u},) = BS(z; i_{2u},)
\]

for all \( s', \ u', \) and \( z \).

For all country elevators or subterminals with no unused storage capacity at the beginning of month 2, set:

\[
\alpha_{BS}(z; h_{2s},) = BS(z; h_{2s},) + S2
\]

and

\[
\alpha_{BS}(z; i_{2u},) = BS(z; i_{2u},) + S2
\]

for all \( s' = 3,4, \ldots, T; \ u' = 3,4, \ldots, T; \) and \( z \). When \( s' = 2 \) and/or \( u' = 2 \), set the marginal cost of storing grain \( z \) equal to only the marginal operating and maintenance costs of storing grain \( z \).

Storage capacity at \( L_{1h} \) at the beginning of month 2 is determined by Equation 2.12. Storage capacity at \( L_{2i} \) at the beginning of month 2 is determined by Equation 2.21.

Step 2.3: Use \( ORA(1,2)|\lambda \) to determine a) the optimal routing of grain shipped from all origins in time 2 to final destinations; and b) the total revenue net variable costs, given \( \lambda \).

Step 2.4: Compute the excess storage capacity existing at the end of month 2 for each elevator.
Step 2.5: If \( ESK(h_i | \lambda) \geq 0 \) for all \( h \in \lambda \), and \( ESK(i | \lambda) \geq 0 \) for all \( i \in \lambda \), go to Step 2.6. Otherwise, go to Step 2.7.

Step 2.6: The solution of \( ORA(1,2) | \lambda \) is optimal. Thus:

\[
\overline{\text{TRNVC}(2)} | \lambda = \overline{\text{TRNVC}(1,2)} | \lambda
\] (2.89)

The optimal routing of grain shipped from origins in month three may now be determined by following the procedures outlined in Step 3.

Step 2.7: Use \( ORA(2,2) | \lambda \) to determine the optimal routing of grain shipped from all origins in time 2 to final destinations, given \( \lambda \). Thus:

\[
\overline{\text{TRNVC}(1)} | \lambda = \overline{\text{TRNVC}(2,2)} | \lambda
\] (2.90)

The optimal routing of grain shipped from origins in month three may now be determined by following the procedures outlined in Step 3.

Step 3.1: The optimal routing of grain shipped from all origins in month 3,4,...,\( T \) given \( \lambda \), may be determined by repeating, for each month, the procedures outlined for month 2. Replace all time subscripts denoting month 2 with the appropriate time index and repeat Step 2.1 to Step 2.7.

Step 4.1: Once the optimal route of grain shipments from all origins, and the maximum total revenue net of variable costs have been computed for each time \( t \), the last step of Part I is to determine the joint revenue of pro-
producers net of variable costs over all time periods given λ.

Denote the maximum joint revenue of producers net of variable costs, given λ, as $\text{TRNVC}|\lambda$ and compute as follows:

$$\text{TRNVC}|\lambda_{mnr} = \sum_t \text{TRNVC}(.t)|\lambda_{mnr}$$  \hspace{1cm} (2.91)

**Part II: optimal number and locational pattern**

For any given number of subterminals and branch rail lines there are many possible locational combinations. Thirty plant sites, for example, taken nine at a time provides 14,307,150 combinations. And, for each locational pattern there will be one optimal marketing option and $\text{TRNVC}$ as defined in Part I. Fortunately, in the selected area all country elevators were in existence at the beginning of the planning horizon, 1971; and only four rail line network patterns were considered as viable alternatives.

The objective of Part II is to select the number and location pattern of subterminals, country elevators, and rail line system for which joint net revenue of producers is maximized. Joint net revenue, II, may be computed for each $\lambda_{mnr}$ as follows:

$$\Pi|\lambda_{mnr} = \text{TRNVC}|\lambda_{mnr} - \sum_{h \in \lambda} \alpha(h) - \sum_{i \in \lambda} \alpha(.i) - \gamma$$  \hspace{1cm} (2.92)

Maximum joint net revenue is found by systematically comparing $\Pi$ for each combination of $\lambda_{mnr}$ and selecting that
constellation of elevators and rail lines for which $\Pi$ is maximum. Denote the maximum joint net revenue of producers as $\Pi$ and compute as follows:

$$\Pi = \max_r \max_n \max_m \pi |_{mnr}$$

It is not necessary, of course, to compare every possible combination of elevators and rail lines to find a global optimum. For a given rail line network, if the best location of 7 subterminals is better than the best location of both 6 subterminals and 8 subterminals, then the best location of 7 subterminals is better than any other number and location of subterminals.

As shown by Ladd (32, p. 8), in the Stollsteimer model any local optimum is also a global optimum. The change in revenue net variable costs between the best location of $n$ subterminals and the best location of $n+1$ subterminals will never be negative. The best location of $n$ subterminals is included in the different locational combinations of $n+1$ subterminals. A decrease in revenue net variable costs from adding an additional subterminal can always be avoided by selecting the best location of $n$ subterminals and refusing to use the $n+1^{st}$ subterminal. Thus, once a local optimum is found, additional comparisons are unnecessary since any local optimum is also global.
Example

Part I and Part II as described by the method of solution for the rail line and plant location model are illustrated by the following example: there are three existing country elevators, two time periods, three terminal markets, five origins and one commodity. Two of the three existing country elevators ($Ll_2$ and $Ll_3$) are potential sites for subterminals.

There are two possible rail line configurations. The first rail network option consists of one major trunk line extending through the production area. There are two potential subterminal sites available, given rail line option one. Producers in the region do not pay a fixed cost for maintaining major trunk lines.

The second rail network option consists of the major trunk line as described for option one plus a branch rail line. With the additional feeder, rail line, three potential subterminal sites are available. Producers in the region pay a fixed cost for maintaining the branch rail line.

Figure 2.1 shows the rail line network and potential subterminal sites for rail line option one. Final destinations are denoted by $\Box$; existing country elevators are denoted by $\bigcirc$; dots, $\bullet$, represent origins; $\Box$'s represent potential subterminal sites; and, $\wedge$ represents a rail line.
\( \lambda_{mn1} \) denotes the \( m^{th} \) locational pattern of \( n \) subterminals given the first rail line option.

Figure 2.2 shows the rail line network and potential sub-terminal sites for rail line option two. \( \lambda_{mn2} \) denotes the \( m^{th} \) locational pattern of \( n \) subterminals given the second rail line option.

Data used for this example are ordered and presented as follows: (1) alternative locational patterns; (2) supply at origin; (3) transportation costs; (4) elevator costs and capacity; and (5) market demand prices.

Alternative locational patterns: alternative locational patterns for country elevators, subterminals, and rail lines used in example problem are defined as follows:

\[
\begin{align*}
\lambda_{111} & : \text{elevators located at L}_{2}, L_{11} \text{ and } L_{13} \\
\lambda_{211} & : \text{elevators located at L}_{23}, L_{11} \text{ and } L_{12} \\
\lambda_{121} & : \text{elevators located at L}_{22}, L_{23} \text{ and } L_{11} \\
\lambda_{112} & : \text{elevators located at L}_{22}, L_{11} \text{ and } L_{12} \\
\lambda_{212} & : \text{elevators located at L}_{22}, L_{11} \text{ and } L_{13} \\
\lambda_{312} & : \text{elevators located at L}_{23}, L_{11} \text{ and } L_{12} \\
\lambda_{122} & : \text{elevators located at L}_{22}, L_{23} \text{ and } L_{11} \\
\lambda_{222} & : \text{elevators located at L}_{21}, L_{23}, L_{11} \text{ and } L_{12} \\
\lambda_{322} & : \text{elevators located at L}_{21}, L_{23} \text{ and } L_{11} \\
\lambda_{132} & : \text{elevators located at L}_{21}, L_{22} \text{ and } L_{11} \\
\end{align*}
\]

Supply at origins: the predetermined supply of commodity
1 at each origin during time 1 and time two is presented in Table 2.1.

Table 2.1. Supply of commodity 1 at origin g time t used for the example problem

<table>
<thead>
<tr>
<th></th>
<th>t=1</th>
<th>t=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X(l; 1_t...)</td>
<td>500000</td>
<td>500000</td>
</tr>
<tr>
<td>X(l; 2_t...)</td>
<td>400000</td>
<td>400000</td>
</tr>
<tr>
<td>X(l; 3_t...)</td>
<td>500000</td>
<td>400000</td>
</tr>
<tr>
<td>X(l; 4_t...)</td>
<td>400000</td>
<td>300000</td>
</tr>
<tr>
<td>X(l; 5_t...)</td>
<td>500000</td>
<td>600000</td>
</tr>
</tbody>
</table>

Transportation costs: Tables 2.2, 2.3, and 2.4 present marginal transportation costs. Marginal transportation costs may vary over time. A rail-barge combination may be possible, for example, during one time period but not another. The minimum annual cost of establishing and maintaining rail line option 1, \(\gamma_1\), equals $0.00. \(\gamma_2\) equals $10000.00.

Elevator costs and capacity: The marginal operating costs of receiving and drying, storing, and loading out commodity one from country elevators (for all \(h\)) and subterminals (for all \(i\)) are as follows:
Table 2.2. Transportation costs from subterminal $L_2^i$ in time $v$ to destination $j$; and, transportation costs from country elevator $L_1^h$ in time $v$ to destination $j$ used in the example problem

<table>
<thead>
<tr>
<th></th>
<th>$L_2^i=1$</th>
<th>$L_2^i=2$</th>
<th>$L_2^i=3$</th>
<th>$L_1^h=1$</th>
<th>$L_1^h=2$</th>
<th>$L_1^h=3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$j_v$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1_1$</td>
<td>.146</td>
<td>.144</td>
<td>.140</td>
<td>.280</td>
<td>.195</td>
<td>.190</td>
</tr>
<tr>
<td>$1_2$</td>
<td>.140</td>
<td>.140</td>
<td>.138</td>
<td>.280</td>
<td>.195</td>
<td>.190</td>
</tr>
<tr>
<td>$2_2$</td>
<td>.198</td>
<td>.212</td>
<td>.208</td>
<td>.300</td>
<td>.245</td>
<td>.240</td>
</tr>
<tr>
<td>$3_1$</td>
<td>.220</td>
<td>.110</td>
<td>.120</td>
<td>.190</td>
<td>.180</td>
<td>.185</td>
</tr>
<tr>
<td>$3_2$</td>
<td>.220</td>
<td>.110</td>
<td>.120</td>
<td>.190</td>
<td>.180</td>
<td>.185</td>
</tr>
</tbody>
</table>

Table 2.3. Transportation costs from country elevator $L_1^h$ in time $t$ to subterminal $L_2^i$; and, transportation costs from origin $g$ in time $t$ to subterminal $L_2^i$

<table>
<thead>
<tr>
<th></th>
<th>$L_1^h=1$</th>
<th>$L_1^h=2$</th>
<th>$L_1^h=3$</th>
<th>$g=1$</th>
<th>$g=2$</th>
<th>$g=3$</th>
<th>$g=4$</th>
<th>$g=5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i_t$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1_1$</td>
<td>.007</td>
<td>.018</td>
<td>.006</td>
<td>.093</td>
<td>.072</td>
<td>.022</td>
<td>.032</td>
<td>.012</td>
</tr>
<tr>
<td>$1_2$</td>
<td>.005</td>
<td>.018</td>
<td>.006</td>
<td>.015</td>
<td>.014</td>
<td>.005</td>
<td>.007</td>
<td>.002</td>
</tr>
<tr>
<td>$2_1$</td>
<td>.026</td>
<td>.000</td>
<td>.005</td>
<td>.029</td>
<td>.080</td>
<td>.012</td>
<td>.022</td>
<td>.050</td>
</tr>
<tr>
<td>$2_2$</td>
<td>.025</td>
<td>.000</td>
<td>.005</td>
<td>.005</td>
<td>.019</td>
<td>.002</td>
<td>.015</td>
<td>.066</td>
</tr>
<tr>
<td>$3_1$</td>
<td>.016</td>
<td>.005</td>
<td>.000</td>
<td>.090</td>
<td>.022</td>
<td>.018</td>
<td>.090</td>
<td>.036</td>
</tr>
<tr>
<td>$3_2$</td>
<td>.016</td>
<td>.005</td>
<td>.000</td>
<td>.061</td>
<td>.007</td>
<td>.004</td>
<td>.061</td>
<td>.008</td>
</tr>
</tbody>
</table>
Table 2.4. Transportation costs from origin \( g \) in time \( t \) to country elevator \( L_{h_{t}} \) in time \( t \)

<table>
<thead>
<tr>
<th>( h_{t} )</th>
<th>( 1_{1} )</th>
<th>( 1_{2} )</th>
<th>( 2_{1} )</th>
<th>( 2_{2} )</th>
<th>( 3_{1} )</th>
<th>( 3_{2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( g=1 )</td>
<td>.054</td>
<td>.012</td>
<td>.029</td>
<td>.005</td>
<td>.036</td>
<td>.011</td>
</tr>
<tr>
<td>( g=2 )</td>
<td>.072</td>
<td>.016</td>
<td>.040</td>
<td>.019</td>
<td>.022</td>
<td>.007</td>
</tr>
<tr>
<td>( g=3 )</td>
<td>.014</td>
<td>.003</td>
<td>.012</td>
<td>.002</td>
<td>.018</td>
<td>.004</td>
</tr>
<tr>
<td>( g=4 )</td>
<td>.014</td>
<td>.001</td>
<td>.032</td>
<td>.015</td>
<td>.040</td>
<td>.009</td>
</tr>
<tr>
<td>( g=5 )</td>
<td>.036</td>
<td>.008</td>
<td>.050</td>
<td>.011</td>
<td>.036</td>
<td>.008</td>
</tr>
</tbody>
</table>

\( \beta R(1; \cdot_{1} \cdot) = .05; \beta R(1; \cdot_{2} \cdot) = .03; \beta S(1; \cdot_{11} \cdot) = .01; \)
\( \beta S(1; \cdot_{12}) = .02; \beta S(1; \cdot_{22}) = .01; \beta L(1; \cdot_{1} \cdot) = .02; \)
\( \beta L(1; \cdot_{2} \cdot) = .02; \beta R(1; \cdot_{1} \cdot) = .05; \beta R(1; \cdot_{2} \cdot) = .03; \)
\( \beta S(1; \cdot_{11}) = .01; \beta S(1; \cdot_{12}) = .02; \beta S(1; \cdot_{22}) = .01; \beta L(1; \cdot_{1} \cdot) = .01; \beta L(1; \cdot_{2} \cdot) = .01. \)

The storage capacity existing at the beginning of time 1 at each country elevator and each subterminal is as follows:
\( SK(1_{1}. \cdot) = 700000; SK(2_{1}. 1) = 700000; SK(3_{1}. 1) = 300000; \)
\( SK(1_{1}. \cdot) = 0; SK(2_{1}. 1) = 700000; \) and, \( SK(3_{1}. 1) = 300000. \)

The marginal cost of expanding storage facilities at a country elevator or subterminal, \( S2 \), is .01. Thus, when considering the locational alternative that includes \( L_{2_{1}}, \)
\( aSS(1; \cdot_{11}) = \beta S(1; \cdot_{11}) + S2, \) or .02.

\( S1, \) the minimum annual average cost of adjustment required to expand storage capacity of an existing country
elevator, is 1000. The total annual average costs of establishing a subterminal located at L2_i as defined by Equation 2.16, are as follows: \( a(.1) = 30000; a(.2) = 20000; \) and \( a(.3) = 60000. \)

Prices at final markets: The per unit prices at terminal markets vary seasonally as well as spatially. Table 2.5 presents prices at final markets for time 1 and time 2.

<table>
<thead>
<tr>
<th>( \pi(l;...1_t) )</th>
<th>( t=1 )</th>
<th>( t=2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi(l;...1_t) )</td>
<td>1.420</td>
<td>1.453</td>
</tr>
<tr>
<td>( \pi(l;...2_t) )</td>
<td>1.504</td>
<td>1.510</td>
</tr>
<tr>
<td>( \pi(l;...3_t) )</td>
<td>1.430</td>
<td>1.430</td>
</tr>
</tbody>
</table>

Part I determines the optimal routings for origin g and the total revenue net variable costs for each constellation of distribution facilities. Origin g has many possible routing combinations over time and space given \( \lambda_{mnr} \). The routing options of origin g given \( \lambda_{111} \) are illustrated in Figure 2.3.

The optimal routing for origin g given \( \lambda_{mnr} \) is determined sequentially. Table 2.6 presents \( \pi(l;...i_{uv}j_{uv}) \). The net price for L2_i when shipping commodity one to destination 1 in time 1 is 1.204. That is,
Figure 2.3. Routing options available to origin $g$ given $\lambda_{111}$
Table 2.6. $\pi_l \ldots \iota_{uv}^j \nu_a$

<table>
<thead>
<tr>
<th></th>
<th>$L2_i=1$</th>
<th>$L2_i=2$</th>
<th>$L2_i=3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_{l_{12}^1_{11}}$</td>
<td>1.204</td>
<td>1.206</td>
<td>1.210</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.233</td>
<td>1.233</td>
<td>1.235</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.234*</td>
<td>1.220</td>
<td>1.224</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.232</td>
<td>1.218</td>
<td>1.222</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.140</td>
<td>1.250*</td>
<td>1.240*</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.130</td>
<td>1.240</td>
<td>1.230</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.263*</td>
<td>1.263</td>
<td>1.265*</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.262</td>
<td>1.248</td>
<td>1.252</td>
</tr>
<tr>
<td>$\pi_{l_{12}^2_{12}}$</td>
<td>1.160</td>
<td>1.270*</td>
<td>1.260</td>
</tr>
</tbody>
</table>

*See Equation 2.46.

*Maximum net price.

$\pi_{l_{12}^1_{11}} = \pi_{l_{12}^1_{11}} - \beta R_{l_{12}^1_{11}} - \alpha \beta S_{l_{12}^1_{11}} - \beta L_{l_{12}^1_{11}} - C_{l_{12}^1_{11}} = 1.42 - .05 - .01 - .01 - .146 = 1.204$.

The maximum net price of commodity 1 at $L2_i$ time 1 is found by selecting the maximum net price in column 2, Table 2.6 for grain received during time 1. Denote the maximum net price by *. Thus, $\pi_{l_{12}^1_{11}} = 1.234$; and $\pi_{l_{12}^2_{12}} = 1.263$. 
For convenience, denote $\pi(l;..i_{-j-}^\top_{-u-V})$ as $\pi(l;..i_{-u-V})$. Tables 2.7, 2.8, and 2.9 present $\pi(1;..h_{sv}^\top_{-j-}l_v)\mid^\top_{\lambda_{mn}}$. Grain received at country elevators may be shipped to subterminals or to final destinations. The subterminals to which grain may be shipped depends upon $\lambda_{mn}$. The net price at $L_{l_1}$ when shipping grain to destination 1 in time one is 1.060. That is, $\pi(l;..l_{11}.l_1) = \pi(l;..l_1) - \beta R(l;l_{11}.) - \alpha \beta S(l;l_{11}.) - \beta L(l;1.l.) - C(l;..l_{11}.)$. The highest net price at $L_{l_1}$ in time one is 1.175. 1.175 results from storing grain, received in time 1, from time 1 to time 2 and then shipping commodity 1 to $L_{22}$. In computing $\pi(l;..h_{11}i_{11}.)$, a per unit cost of drying commodity 1 of .03 is subtracted from marginal transportation costs to avoid the double counting of drying costs. $\pi(l;..h_{12}i_{12}.)$ and $\pi(l;..h_{22}i_{22}.)$ are computed by subtracting a per unit cost of drying commodity 1 of .01 from marginal transportation costs. $\pi(l;..l_{11}^\top_{-j-}l_{1V})$ is found by selecting from column 2, Table 2.7, the highest net price over the range of $s = 1$. $\pi(l;..l_{12}^2_{22}.),$ or $1.175^*$, is computed as follows: $\pi(l;..2_{22}^3_{22}.) - \beta R(l;l_{12}.) - \alpha \beta S(l;l_{12}.) - \beta L(l;1.2.) - C(l;..1.2^2_{22}.)$. Table 2.6 column 2 provides $\pi(l;..2_{22}^3_{22}.)$; $C(l;..1.2^2_{22}.)$ is computed by subtracting .01 from the marginal transportation cost found in Table 2.2; and
Table 2.7. $\pi(1; h_{SV} j_{LV}) | \lambda_{\text{ml}}^a$

<table>
<thead>
<tr>
<th>$\lambda_{111: L_2}$</th>
<th>$\lambda_{211: L_3}$</th>
<th>$\lambda_{121: L_2' L_3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1 h = 1$</td>
<td>$L_1 h = 3$</td>
<td>$L_1 h = 4$</td>
</tr>
<tr>
<td>$\pi(1; h_{11.11})$</td>
<td>1.060</td>
<td>1.150</td>
</tr>
<tr>
<td>$\pi(1; h_{12.12})$</td>
<td>1.083</td>
<td>1.173</td>
</tr>
<tr>
<td>$\pi(1; h_{11.21})$</td>
<td>1.051</td>
<td>1.174</td>
</tr>
<tr>
<td>$\pi(1; h_{12.22})$</td>
<td>1.121</td>
<td>1.180</td>
</tr>
<tr>
<td>$\pi(1; h_{11.31})$</td>
<td>1.160</td>
<td>1.165</td>
</tr>
<tr>
<td>$\pi(1; h_{12.32})$</td>
<td>1.150</td>
<td>1.155</td>
</tr>
<tr>
<td>$\pi(1; h_{11.11'})$</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(1; h_{12.12'})$</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(1; h_{11.22'})$</td>
<td>1.174</td>
<td>1.195*</td>
</tr>
<tr>
<td>$\pi(1; h_{12.23'})$</td>
<td>1.175*</td>
<td>1.185</td>
</tr>
<tr>
<td>$\pi(1; h_{11.33'})$</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(1; h_{12.33'})$</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(1; h_{22.12})$</td>
<td>1.113</td>
<td>1.203</td>
</tr>
<tr>
<td>$\pi(1; h_{22.22})$</td>
<td>1.151</td>
<td>1.210</td>
</tr>
<tr>
<td>$\pi(1; h_{22.32})$</td>
<td>1.180</td>
<td>1.185</td>
</tr>
<tr>
<td>$\pi(1; h_{22.12'})$</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(1; h_{22.22'})$</td>
<td>1.195*</td>
<td>1.215*</td>
</tr>
<tr>
<td>$\pi(1; h_{22.32'})$</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

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*a*See Equation 2.48 and 2.49.

*Maximum net price.*
Table 2.8. $\pi(l; h_{sv}, j_{lv})|\lambda_{ml2}$

<table>
<thead>
<tr>
<th>Combinations of: 1 Subterminal</th>
<th>$\lambda_{112}: L_{21}$</th>
<th>$\lambda_{212}: L_{22}$</th>
<th>$\lambda_{312}: L_{23}$</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$L_{1h=1}$</td>
<td>$L_{1h=2}$</td>
<td>$L_{1h=3}$</td>
</tr>
<tr>
<td>$\pi(l; h_{11}, l_1)$</td>
<td>1.060</td>
<td>1.145</td>
<td>1.150</td>
</tr>
<tr>
<td>$\pi(l; h_{12}, l_2)$</td>
<td>1.083</td>
<td>1.168</td>
<td>1.173</td>
</tr>
<tr>
<td>$\pi(l; h_{11}, l_1)$</td>
<td>1.051</td>
<td>1.169</td>
<td>1.174</td>
</tr>
<tr>
<td>$\pi(l; h_{12}, l_2)$</td>
<td>1.121</td>
<td>1.175*</td>
<td>1.180*</td>
</tr>
<tr>
<td>$\pi(l; h_{11}, l_1)$</td>
<td>1.160</td>
<td>1.170</td>
<td>1.165</td>
</tr>
<tr>
<td>$\pi(l; h_{12}, l_2)$</td>
<td>1.150</td>
<td>1.160</td>
<td>1.155</td>
</tr>
<tr>
<td>$\pi(l; h_{11}, l_1)$</td>
<td>1.177</td>
<td>1.166</td>
<td>1.178</td>
</tr>
<tr>
<td>$\pi(l; h_{12}, l_2)$</td>
<td>1.178*</td>
<td>1.165</td>
<td>1.177</td>
</tr>
<tr>
<td>$\pi(l; h_{11}, l_1)$</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(l; h_{12}, l_2)$</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(l; h_{11}, l_1)$</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$\pi(l; h_{12}, l_2)$</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*See Equations 2.48 and 2.49.
* Maximum net price.
<table>
<thead>
<tr>
<th>Combinations of: 1 Subterminal</th>
<th>( \lambda_{112} : \lambda_{212} : \lambda_{312} )</th>
<th>( L_{1h=1} )</th>
<th>( L_{1h=2} )</th>
<th>( L_{1h=3} )</th>
<th>( L_{1h=1} )</th>
<th>( L_{1h=2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_{112} : \lambda_{212} : \lambda_{312} )</td>
<td>( L_{1h=1} )</td>
<td>( L_{1h=2} )</td>
<td>( L_{1h=3} )</td>
<td>( L_{1h=1} )</td>
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</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \pi(1; h_{22,1}\cdot 2) )</td>
<td>1.113</td>
<td>1.198</td>
<td>1.203</td>
<td>1.113</td>
<td>1.203</td>
<td>1.113</td>
</tr>
<tr>
<td>( \pi(1; h_{22,2}\cdot 2) )</td>
<td>1.151</td>
<td>1.205*</td>
<td>1.210*</td>
<td>1.151</td>
<td>1.210</td>
<td>1.151</td>
</tr>
<tr>
<td>( \pi(1; h_{22,3}\cdot 2) )</td>
<td>1.180</td>
<td>1.190</td>
<td>1.185</td>
<td>1.180</td>
<td>1.185</td>
<td>1.180</td>
</tr>
<tr>
<td>( \pi(1; h_{22,1}\cdot 2) )</td>
<td>1.208*</td>
<td>1.195</td>
<td>1.207</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>( \pi(1; h_{22,2}\cdot 2) )</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.195*</td>
<td>1.215*</td>
<td>0.0</td>
</tr>
<tr>
<td>( \pi(1; h_{22,3}\cdot 2) )</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.199*</td>
</tr>
</tbody>
</table>
Table 2.9. $\pi(1; h_{sv}J_{vl})|\lambda_{m22}, \lambda_{m32}$

<table>
<thead>
<tr>
<th></th>
<th>2 Subterminals</th>
<th>3 Subterminals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\frac{L_{12}}{L_{1}}, \frac{L_{2}}{L_{1}}$</td>
<td>$\frac{L_{1}}{L_{1}}$</td>
</tr>
<tr>
<td></td>
<td>$\frac{L_{12}}{L_{1}}$</td>
<td>$\frac{L_{2}}{L_{1}}$</td>
</tr>
<tr>
<td>$\pi(1; h_{11}, h_{12})$</td>
<td>$1.060$</td>
<td>$1.150$</td>
</tr>
<tr>
<td>$\pi(1; h_{11}, h_{21})$</td>
<td>$1.083$</td>
<td>$1.173$</td>
</tr>
<tr>
<td>$\pi(1; h_{11}, h_{22})$</td>
<td>$1.051$</td>
<td>$1.174$</td>
</tr>
<tr>
<td>$\pi(1; h_{11}, h_{31})$</td>
<td>$1.121$</td>
<td>$1.180$</td>
</tr>
<tr>
<td>$\pi(1; h_{11}, h_{32})$</td>
<td>$1.160$</td>
<td>$1.165$</td>
</tr>
<tr>
<td>$\pi(1; h_{12}, h_{11})$</td>
<td>$1.150$</td>
<td>$1.155$</td>
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<tr>
<td>$\pi(1; h_{12}, h_{12})$</td>
<td>$1.177$</td>
<td>$1.178$</td>
</tr>
<tr>
<td>$\pi(1; h_{12}, h_{13})$</td>
<td>$1.178^*$</td>
<td>$1.177$</td>
</tr>
<tr>
<td>$\pi(1; h_{12}, h_{21})$</td>
<td>$1.174$</td>
<td>$1.195^*$</td>
</tr>
<tr>
<td>$\pi(1; h_{12}, h_{22})$</td>
<td>$1.175$</td>
<td>$1.185$</td>
</tr>
<tr>
<td>$\pi(1; h_{12}, h_{31})$</td>
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<td>$0.0$</td>
</tr>
<tr>
<td>$\pi(1; h_{12}, h_{32})$</td>
<td>$0.0$</td>
<td>$0.0$</td>
</tr>
</tbody>
</table>

*aSee Equations 2.48 and 2.49.

*Maximum net price.
<table>
<thead>
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<th></th>
<th>2 Subterminals</th>
<th>3 Subterminals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda_{122}^{L_{21}}$</td>
<td>$L_{22}$</td>
</tr>
<tr>
<td></td>
<td>$L_{11}^{h=1}$</td>
<td>$L_{11}^{h=3}$</td>
</tr>
<tr>
<td>$\pi(1; h_{22,12})$</td>
<td>1.113</td>
<td>1.203</td>
</tr>
<tr>
<td>$\pi(1; h_{22,22})$</td>
<td>1.151</td>
<td>1.210</td>
</tr>
<tr>
<td>$\pi(1; h_{22,32})$</td>
<td>1.180</td>
<td>1.185</td>
</tr>
<tr>
<td>$\pi(1; h_{22,12}^{-})$</td>
<td>1.208*</td>
<td>1.207</td>
</tr>
<tr>
<td>$\pi(1; h_{22,22}^{-})$</td>
<td>1.195</td>
<td>1.215*</td>
</tr>
<tr>
<td>$\pi(1; h_{22,32}^{-})$</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 2.9 (Continued)
data for the remaining coefficients are presented in the section on elevator costs and capacity.

Denote \( \pi(1; .h_{sv}.\overline{31}_v) \) as \( \pi(1; .h_{sv}...) \).

Tables 2.10 to 2.19 present the net price at origin \( g \) time \( t \) given \( \lambda_{mn} \) when shipping commodity 1 from origin \( g \) to final destination. Origin \( g \) in time \( t \) may ship its grain to a country elevator or to a subterminal. The first three elements in column 2, Table 2.10 are the net prices at origin 1 if origin 1 ships to \( L_{22}, L_{11} \), or \( L_{13} \) given \( \lambda_{111} \).

Since 1.221 is greater than 1.121 and 1.159, origin 1 selects \( L_{22} \) as the elevator to receive \( X(1; 11...). \)

\[ \pi(1; 11.\overline{22}_1) = \pi(1; 11..\overline{22}_1) = 1.250-.029. \] Table 2.6, column 3 identifies 1.250; and .029 is found in Table 2.2.

Table 2.20 presents the highest net price at origin \( g \) time one given \( \lambda_{mnm} \). The maximum net price at origin one given \( \lambda_{111} \) is 1.221 and was selected from Table 2.10, column 2. Of the five best possible routings available to origin 1 time 1 given \( \lambda_{111} \), origin 1 will maximize revenue net variable cost by shipping directly to subterminal \( L_{22} \). Thus, Table 2.20, identifies the optimal routings over time and space for each origin, given \( \lambda_{mnm} \).

Joint revenue net of variable costs for each \( \lambda_{mnm} \) can be determined as specified by Equation 2.46. That is,

\[ TRNVC(1,1) | \lambda = \Sigma [\pi(1; g_1...\overline{j2}_1)X(1; g_1...)] g \overline{j2}_1 \in \lambda. \]

At this point it is necessary to determine if the
Table 2.10. $\pi(1; g_t \cdots j_{2t}) | \lambda_{111}$

<table>
<thead>
<tr>
<th>$\lambda_{111}$</th>
<th>$g=1$</th>
<th>$g=2$</th>
<th>$g=3$</th>
<th>$g=4$</th>
<th>$g=5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi(1; g_{1.21_-})$</td>
<td>1.221*</td>
<td>1.170</td>
<td>1.238*</td>
<td>1.228*</td>
<td>1.200*</td>
</tr>
<tr>
<td>$\pi(1; g_{1.11_-})$</td>
<td>1.121</td>
<td>1.103</td>
<td>1.161</td>
<td>1.161</td>
<td>1.139</td>
</tr>
<tr>
<td>$\pi(1; g_{1.22_-})$</td>
<td>1.159</td>
<td>1.173*</td>
<td>1.177</td>
<td>1.155</td>
<td>1.159</td>
</tr>
<tr>
<td>$\pi(1; g_{2.22_-})$</td>
<td>1.265*</td>
<td>1.251*</td>
<td>1.268*</td>
<td>1.255*</td>
<td>1.204</td>
</tr>
<tr>
<td>$\pi(1; g_{2.12_-})$</td>
<td>1.183</td>
<td>1.179</td>
<td>1.192</td>
<td>1.194</td>
<td>1.187</td>
</tr>
<tr>
<td>$\pi(1; g_{2.31_-})$</td>
<td>1.204</td>
<td>1.208</td>
<td>1.211</td>
<td>1.206</td>
<td>1.207*</td>
</tr>
</tbody>
</table>

*aSee Equations 2.51 and 2.52.

*Maximum net price.

Table 2.11. $\pi(1; g_t \cdots j_{2t}) | \lambda_{211}$

<table>
<thead>
<tr>
<th>$\lambda_{211}$</th>
<th>$g=1$</th>
<th>$g=2$</th>
<th>$g=3$</th>
<th>$g=4$</th>
<th>$g=5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi(1; g_{1.31_-})$</td>
<td>1.154</td>
<td>1.218*</td>
<td>1.222*</td>
<td>1.150</td>
<td>1.204*</td>
</tr>
<tr>
<td>$\pi(1; g_{1.11_-})$</td>
<td>1.115</td>
<td>1.097</td>
<td>1.154</td>
<td>1.155*</td>
<td>1.133</td>
</tr>
<tr>
<td>$\pi(1; g_{1.21_-})$</td>
<td>1.156*</td>
<td>1.145</td>
<td>1.173</td>
<td>1.153</td>
<td>1.135</td>
</tr>
<tr>
<td>$\pi(1; g_{2.32_-})$</td>
<td>1.204</td>
<td>1.256*</td>
<td>1.261*</td>
<td>1.204*</td>
<td>1.257*</td>
</tr>
<tr>
<td>$\pi(1; g_{2.12_-})$</td>
<td>1.187</td>
<td>1.183</td>
<td>1.196</td>
<td>1.198</td>
<td>1.191</td>
</tr>
<tr>
<td>$\pi(1; g_{2.22_-})$</td>
<td>1.205*</td>
<td>1.191</td>
<td>1.208</td>
<td>1.195</td>
<td>1.199</td>
</tr>
</tbody>
</table>

*Maximum net price.
Table 2.12. $\pi(l; g_{t} \cdots j_{2t})|\lambda_{121}$

<table>
<thead>
<tr>
<th>$\lambda_{121}$</th>
<th>$g=\frac{1}{2}$</th>
<th>$g=\frac{2}{3}$</th>
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<th>$g=\frac{4}{5}$</th>
<th>$g=\frac{5}{6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi(l; g_{1}^{1.2_{1}^{1}})$</td>
<td>1.221*</td>
<td>1.170</td>
<td>1.238*</td>
<td>1.228*</td>
<td>1.200</td>
</tr>
<tr>
<td>$\pi(l; g_{1}^{1.3_{1}^{1}})$</td>
<td>1.154</td>
<td>1.218*</td>
<td>1.222</td>
<td>1.750</td>
<td>1.204*</td>
</tr>
<tr>
<td>$\pi(l; g_{1}^{1.1_{1}^{1}})$</td>
<td>1.121</td>
<td>1.103</td>
<td>1.161</td>
<td>1.161</td>
<td>1.139</td>
</tr>
<tr>
<td>$\pi(l; g_{2}^{1.2_{2}^{1}})$</td>
<td>1.265*</td>
<td>1.251</td>
<td>1.268*</td>
<td>1.255*</td>
<td>1.204</td>
</tr>
<tr>
<td>$\pi(l; g_{2}^{1.3_{2}^{1}})$</td>
<td>1.204</td>
<td>1.256*</td>
<td>1.261</td>
<td>1.204</td>
<td>1.257*</td>
</tr>
<tr>
<td>$\pi(l; g_{2}^{1.2_{2}^{1}})$</td>
<td>1.187</td>
<td>1.183</td>
<td>1.196</td>
<td>1.198</td>
<td>1.191</td>
</tr>
</tbody>
</table>

*Maximum net price.

Table 2.13. $\pi(l; g_{t} \cdots j_{2t})|\lambda_{112}$

<table>
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<tr>
<th>$\lambda_{112}$</th>
<th>$g=\frac{1}{2}$</th>
<th>$g=\frac{2}{3}$</th>
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<th>$g=\frac{4}{5}$</th>
<th>$g=\frac{5}{6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi(l; g_{1}^{1.1_{1}^{1}})$</td>
<td>1.141</td>
<td>1.157</td>
<td>1.212*</td>
<td>1.202*</td>
<td>1.222*</td>
</tr>
<tr>
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<td>1.124</td>
<td>1.106</td>
<td>1.164</td>
<td>1.164</td>
<td>1.142</td>
</tr>
<tr>
<td>$\pi(l; g_{1}^{1.2_{1}^{1}})$</td>
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<td>1.135</td>
<td>1.163</td>
<td>1.143</td>
<td>1.125</td>
</tr>
<tr>
<td>$\pi(l; g_{1}^{1.3_{1}^{1}})$</td>
<td>1.144</td>
<td>1.158*</td>
<td>1.162</td>
<td>1.140</td>
<td>1.144</td>
</tr>
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<td>1.249*</td>
<td>1.258*</td>
<td>1.256*</td>
<td>1.261*</td>
</tr>
<tr>
<td>$\pi(l; g_{2}^{1.2_{2}^{1}})$</td>
<td>1.196</td>
<td>1.192</td>
<td>1.205</td>
<td>1.207</td>
<td>1.200</td>
</tr>
<tr>
<td>$\pi(l; g_{2}^{1.2_{2}^{1}})$</td>
<td>1.200</td>
<td>1.186</td>
<td>1.203</td>
<td>1.190</td>
<td>1.194</td>
</tr>
<tr>
<td>$\pi(l; g_{2}^{1.2_{2}^{1}})$</td>
<td>1.199</td>
<td>1.203</td>
<td>1.206</td>
<td>1.201</td>
<td>1.202</td>
</tr>
</tbody>
</table>

*Maximum net price.
Table 2.14. $\pi(1; g_{t^\cdot ..j} 2_{t^\cdot}) | \lambda_{212}$

<table>
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<th>$\lambda_{212}$</th>
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<th>$\frac{g=5}{6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi(1; g_{1^\cdot 2_{1^\cdot}})$</td>
<td>1.221*</td>
<td>1.170</td>
<td>1.238*</td>
<td>1.228*</td>
<td>1.200*</td>
</tr>
<tr>
<td>$\pi(1; g_{1^\cdot 1_{1^\cdot}})$</td>
<td>1.121</td>
<td>1.103</td>
<td>1.161</td>
<td>1.161</td>
<td>1.139</td>
</tr>
<tr>
<td>$\pi(1; g_{1^\cdot 3_{1^\cdot}})$</td>
<td>1.159</td>
<td>1.173*</td>
<td>1.177</td>
<td>1.155</td>
<td>1.159</td>
</tr>
<tr>
<td>$\pi(1; g_{2^\cdot 2_{2^\cdot}})$</td>
<td>1.265*</td>
<td>1.251*</td>
<td>1.268*</td>
<td>1.255*</td>
<td>1.204</td>
</tr>
<tr>
<td>$\pi(1; g_{2^\cdot 1_{2^\cdot}})$</td>
<td>1.183</td>
<td>1.179</td>
<td>1.192</td>
<td>1.194</td>
<td>1.187</td>
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<tr>
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<td>1.204</td>
<td>1.208</td>
<td>1.211</td>
<td>1.206</td>
<td>1.207*</td>
</tr>
</tbody>
</table>

* Maximum net price.

Table 2.15. $\pi(1; g_{t^\cdot ..j} 2_{t^\cdot}) | \lambda_{312}$

<table>
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<tr>
<th>$\lambda_{312}$</th>
<th>$\frac{g=1}{2}$</th>
<th>$\frac{g=2}{3}$</th>
<th>$\frac{g=3}{4}$</th>
<th>$\frac{g=4}{5}$</th>
<th>$\frac{g=5}{6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi(1; g_{1^\cdot 3_{1^\cdot}})$</td>
<td>1.154</td>
<td>1.218*</td>
<td>1.222*</td>
<td>1.150</td>
<td>1.204*</td>
</tr>
<tr>
<td>$\pi(1; g_{1^\cdot 1_{1^\cdot}})$</td>
<td>1.115</td>
<td>1.097</td>
<td>1.154</td>
<td>1.155*</td>
<td>1.133</td>
</tr>
<tr>
<td>$\pi(1; g_{1^\cdot 2_{1^\cdot}})$</td>
<td>1.156*</td>
<td>1.145</td>
<td>1.173</td>
<td>1.153</td>
<td>1.135</td>
</tr>
<tr>
<td>$\pi(1; g_{2^\cdot 3_{2^\cdot}})$</td>
<td>1.204</td>
<td>1.256*</td>
<td>1.261*</td>
<td>1.204*</td>
<td>1.257*</td>
</tr>
<tr>
<td>$\pi(1; g_{2^\cdot 1_{2^\cdot}})$</td>
<td>1.187</td>
<td>1.183</td>
<td>1.196</td>
<td>1.198</td>
<td>1.191</td>
</tr>
<tr>
<td>$\pi(1; g_{2^\cdot 2_{2^\cdot}})$</td>
<td>1.205*</td>
<td>1.191</td>
<td>1.208</td>
<td>1.195</td>
<td>1.199</td>
</tr>
</tbody>
</table>
Table 2.16. $\pi(l; g_{\text{c}}j_{2\text{c}}) | \lambda_{122}$

<table>
<thead>
<tr>
<th>$l$</th>
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<th>$g=\frac{3}{4}$</th>
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<td>1.157</td>
<td>1.212</td>
<td>1.202</td>
<td>1.222*</td>
</tr>
<tr>
<td>$\pi(l; g_{1} 2_{1} \ldots)$</td>
<td>1.221*</td>
<td>1.170</td>
<td>1.238*</td>
<td>1.228*</td>
<td>1.200</td>
</tr>
<tr>
<td>$\pi(l; g_{1} 1_{1} \ldots)$</td>
<td>1.124</td>
<td>1.106</td>
<td>1.164</td>
<td>1.164</td>
<td>1.142</td>
</tr>
<tr>
<td>$\pi(l; g_{1} 3_{1} \ldots)$</td>
<td>1.159</td>
<td>1.173*</td>
<td>1.177</td>
<td>1.155</td>
<td>1.159</td>
</tr>
<tr>
<td>$\pi(l; g_{2} 1_{2} \ldots)$</td>
<td>1.248</td>
<td>1.249</td>
<td>1.258</td>
<td>1.256*</td>
<td>1.261*</td>
</tr>
<tr>
<td>$\pi(l; g_{2} 2_{2} \ldots)$</td>
<td>1.265*</td>
<td>1.251*</td>
<td>1.268*</td>
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<tr>
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<td>1.192</td>
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<td>1.207</td>
<td>1.200</td>
</tr>
<tr>
<td>$\pi(l; g_{2} 3_{2} \ldots)$</td>
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<td>1.208</td>
<td>1.211</td>
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</tr>
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</table>

*Maximum net price.

Table 2.17. $\pi(l; g_{\text{c}}j_{2\text{c}}) | \lambda_{222}$

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</thead>
<tbody>
<tr>
<td>$\pi(l; g_{1} 1_{1} \ldots)$</td>
<td>1.141</td>
<td>1.157</td>
<td>1.212</td>
<td>1.202*</td>
<td>1.222*</td>
</tr>
<tr>
<td>$\pi(l; g_{1} 3_{1} \ldots)$</td>
<td>1.154</td>
<td>1.218*</td>
<td>1.222*</td>
<td>1.150</td>
<td>1.204</td>
</tr>
<tr>
<td>$\pi(l; g_{1} 1_{1} \ldots)$</td>
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<td>1.106</td>
<td>1.164</td>
<td>1.164</td>
<td>1.142</td>
</tr>
<tr>
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<td>1.176</td>
<td>1.158</td>
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<td>1.249</td>
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<td>1.256*</td>
<td>1.261*</td>
</tr>
<tr>
<td>$\pi(l; g_{2} 3_{2} \ldots)$</td>
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<td>1.256*</td>
<td>1.261*</td>
<td>1.204</td>
<td>1.257</td>
</tr>
<tr>
<td>$\pi(l; g_{2} 1_{2} \ldots)$</td>
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<td>1.184</td>
<td>1.177</td>
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<tr>
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<td>1.191</td>
<td>1.208</td>
<td>1.195</td>
<td>1.199</td>
</tr>
</tbody>
</table>

*Maximum net price.
Table 2.18. $\pi(1; g_{\lambda \cdot j^2_{\mu}} | \lambda_{322}$

<table>
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<tr>
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<td>1.221*</td>
</tr>
<tr>
<td>$\pi(1; g_{1\cdot3^1_{1\cdot}})$</td>
<td>1.154</td>
</tr>
<tr>
<td>$\pi(1; g_{1\cdot1^1_{1\cdot}})$</td>
<td>1.121</td>
</tr>
<tr>
<td>$\pi(1; g_{2\cdot2^1_{1\cdot}})$</td>
<td>1.265*</td>
</tr>
<tr>
<td>$\pi(1; g_{2\cdot3^1_{1\cdot}})$</td>
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</tr>
<tr>
<td>$\pi(1; g_{2\cdot1^1_{1\cdot}})$</td>
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</tbody>
</table>

* Maximum net price.

Table 2.19. $\pi(1; g_{\lambda \cdot j^2_{\mu}} | \lambda_{132}$

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<tr>
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</tr>
<tr>
<td>$\pi(1; g_{1\cdot2^1_{1\cdot}})$</td>
<td>1.221*</td>
</tr>
<tr>
<td>$\pi(1; g_{1\cdot3^1_{1\cdot}})$</td>
<td>1.154</td>
</tr>
<tr>
<td>$\pi(1; g_{1\cdot1^1_{1\cdot}})$</td>
<td>1.124</td>
</tr>
<tr>
<td>$\pi(1; g_{2\cdot1^1_{1\cdot}})$</td>
<td>1.248</td>
</tr>
<tr>
<td>$\pi(1; g_{2\cdot2^1_{1\cdot}})$</td>
<td>1.265*</td>
</tr>
<tr>
<td>$\pi(1; g_{2\cdot3^1_{1\cdot}})$</td>
<td>1.204</td>
</tr>
<tr>
<td>$\pi(1; g_{2\cdot1^1_{1\cdot}})$</td>
<td>1.196</td>
</tr>
</tbody>
</table>

* Maximum net price.
solution is consistent with the data. Storage capacities for each country elevator and each subterminal were presented at the beginning of this example. Since we know the supply of commodity 1 shipped from each origin in time 1 from Table 2.1; and Table 2.20 identifies the flow of commodity 1 over time and space given ORA(1,t) | \lambda, we can determine the amount of commodity 1 in storage at each elevator for any time period. If the amount of commodity 1 stored at an elevator is less than the storage capacity of that elevator

<table>
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<th>g=3</th>
<th>g=4</th>
<th>g=5</th>
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<tr>
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<td>1.173</td>
<td>1.238</td>
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<td>1.200</td>
</tr>
<tr>
<td>\lambda_{211}</td>
<td>1.156</td>
<td>1.218</td>
<td>1.222</td>
<td>1.155</td>
<td>1.204</td>
</tr>
<tr>
<td>\lambda_{121}</td>
<td>1.221</td>
<td>1.218</td>
<td>1.238</td>
<td>1.228</td>
<td>1.204</td>
</tr>
<tr>
<td>\lambda_{112}</td>
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<td>1.202</td>
<td>1.222</td>
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<tr>
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</tr>
<tr>
<td>\lambda_{312}</td>
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<td>1.218</td>
<td>1.222</td>
<td>1.155</td>
<td>1.204</td>
</tr>
<tr>
<td>\lambda_{122}</td>
<td>1.221</td>
<td>1.173</td>
<td>1.238</td>
<td>1.228</td>
<td>1.222</td>
</tr>
<tr>
<td>\lambda_{222}</td>
<td>1.179</td>
<td>1.218</td>
<td>1.222</td>
<td>1.202</td>
<td>1.222</td>
</tr>
<tr>
<td>\lambda_{322}</td>
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<td>1.218</td>
<td>1.238</td>
<td>1.228</td>
<td>1.204</td>
</tr>
<tr>
<td>\lambda_{132}</td>
<td>1.221</td>
<td>1.218</td>
<td>1.238</td>
<td>1.228</td>
<td>1.222</td>
</tr>
</tbody>
</table>

^aSee Equations 2.53.
then the value of $\text{TRNVC}(1,1)|_\lambda$ is optimal and consistent with the data of the problem. If the amount of commodity 1 stored at an elevator exceeds the storage capacity of that elevator then a second algorithm, ORA(2,t) must be used to 1) expand storage capacity, 2) re-route grain spatially, 3) re-route grain temporally, or 4) some combination of 1, 2, and 3.

Country elevator \(L_{13}|_{\lambda_{112}}\) was the only elevator that had insufficient storage capacity to store all the grain shipped to \(L_{13}|_{\lambda_{112}}\) for storage. The storage capacity of \(L_{13}\) at the beginning of time 1 is 300000 bushels. Origin 2 shipped 400000 bushels to \(L_{13}|_{\lambda_{112}}\) in time 1 to be stored at \(L_{13}\) until the end of period 2. No other origin shipped to \(L_{13}\) in time 1 given \(\lambda_{112}\). That is, \(ESK(2.\cdot) = SK(2.\cdot) - X(1..32..) = 300000 - 400000 < 0\).

Thus, as specified by ORA(2,1)\(|_{\lambda_{112}}\), several options are available; 1) \(L_{13}\) can expand storage capacity to hold the additional 100,000 bushels if no other elevator or subterminal has unused storage capacity; 2) origin 2 can re-route 100000 bushels of commodity 1 to another elevator; 3) origin 2 can re-route grain temporally at \(L_{13}\), storing 300000 bushels of commodity one to the end of time 2 and transhipping 100000 bushels of commodity 1 through \(L_{13}\) during period 1; or 4) some combination of options 1, 2, and 3.

The marginal cost of expanding storage capacity at \(L_{13}\)
given $\lambda_{112}$ is .01 per bushel. However, the option of expanding storage capacity cannot be considered since $L2_1$, $L1_1$, or $L1_2$ have unused storage capacity. Only the re-routing alternatives as described by Step 2 of ORA(2,t) may be considered.

Note: In this example the storage capacity expansion constraint is not binding. And, likewise, in the Fort Dodge area study the marginal cost of expanding storage capacity was always greater than the marginal cost of re-routing grain over space.

Total revenue net of variable cost for all producers in time 1 given $\lambda_{112}$ equals $\text{TRNVC}(1,1)|\lambda_{112} - \Delta\text{TRNVC}(1,3,..)|\lambda_{112}$. By multiplying the net price at each origin given $\lambda_{112}$, as presented by Table 2.20, and summing over all origins, $\text{TRNVC}(1,1)|\lambda_{112}$ can be computed. That is, \[
\text{TRNVC}(1,1)|\lambda_{112} = (1.146)(500000) + (1.158)(400000) + (1.212)(500000) + (1.202)(400000) = (1.222)(500000) = 2734000.\]
And, $\text{TRNVC}(2,1)|\lambda_{112} = 2734000 - 100 = 2733900$. Total revenue net variable costs for time 1 given $\lambda_{112}$ is presented in Table 2.22, column 2.

If the option to expand storage capacity at $L1_3$ given $\lambda_{112}$ were chosen; and if there were more than two time periods in this example; then the marginal cost of storing grain received at $L1_3$ during period two would need to include a marginal operating cost plus a marginal cost of
expanding storage facilities. The net price from routing grain shipped from origins in time 2 through \( L_{13} \) would need to be recomputed for \( \lambda_{111} \), \( \lambda_{212} \), and \( \lambda_{122} \). After recomputing \( \pi(l; g_{23}^{32} \ldots) \), the best route over time and space for origin \( g \) time 2 would be identified.

Since the example presented here has only two time periods, grain that is received in period two is shipped out in period two and additional storage capacity is not required. Table 2.21 presents the highest net price at origin \( g \), time 2 given \( \lambda_{mn} \).

Joint revenue net of variable costs for time 2 given \( \lambda_{mn} \) is determined as specified by Equation 2.54. Table 2.22, column 3 presents \( \overline{TRNVC}(.2) | \lambda_{mn} \).

The maximum joint revenue net of variable costs given \( \lambda_{mn} \) is computed as follows:

\[
\overline{TRNVC} | \lambda_{mn} = \sum_{t} TRNVC(.t) | \lambda_{mn}
\]

Column 4 of Table 2.22 presents \( \overline{TRNVC} | \lambda_{mn} \). And, as stated, determining \( \overline{TRNVC} | \lambda_{mn} \) is the objective of Part I.
Table 2.21. \( \pi(1; g_2, \ldots, j_2^2) \)

<table>
<thead>
<tr>
<th></th>
<th>( g=\frac{1}{2} )</th>
<th>( g=\frac{2}{3} )</th>
<th>( g=\frac{3}{4} )</th>
<th>( g=\frac{4}{5} )</th>
<th>( g=\frac{5}{6} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_{111} )</td>
<td>1.265</td>
<td>1.251</td>
<td>1.268</td>
<td>1.255</td>
<td>1.207</td>
</tr>
<tr>
<td>( \lambda_{211} )</td>
<td>1.205</td>
<td>1.256</td>
<td>1.261</td>
<td>1.204</td>
<td>1.257</td>
</tr>
<tr>
<td>( \lambda_{121} )</td>
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<td>1.256</td>
<td>1.268</td>
<td>1.255</td>
<td>1.257</td>
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<tr>
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<td>1.261</td>
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<tr>
<td>( \lambda_{212} )</td>
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<td>1.251</td>
<td>1.268</td>
<td>1.255</td>
<td>1.204</td>
</tr>
<tr>
<td>( \lambda_{312} )</td>
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<td>1.261</td>
<td>1.204</td>
<td>1.257</td>
</tr>
<tr>
<td>( \lambda_{122} )</td>
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<td>1.251</td>
<td>1.268</td>
<td>1.256</td>
<td>1.261</td>
</tr>
<tr>
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<td>1.256</td>
<td>1.261</td>
<td>1.256</td>
<td>1.261</td>
</tr>
<tr>
<td>( \lambda_{322} )</td>
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<td>1.256</td>
<td>1.268</td>
<td>1.255</td>
<td>1.204</td>
</tr>
<tr>
<td>( \lambda_{132} )</td>
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<td>1.256</td>
<td>1.268</td>
<td>1.256</td>
<td>1.261</td>
</tr>
</tbody>
</table>

\(^a\)See Equation 2.53.

Part II selects the number and locational pattern of subterminals, country elevators, and rail lines for which joint net revenue of producers is maximized. Table 2.23 presents the various fixed investment costs required to implement alternative grain distribution systems. Given \( \lambda_{111} \), an annual cost of 20000 is required to upgrade \( \lambda_{2} = L_{22} \) to a potential subterminal. Other alternative locational patterns require different investment expenditures. Alternative \( \lambda_{132} \) is, of course, the most expensive.
Table 2.22. $\overline{TRNVC|\lambda_{mn\tau}}^a$

<table>
<thead>
<tr>
<th></th>
<th>TRNVC(.1)</th>
<th>TRNVC(.2)</th>
<th>$\Sigma$ TRNVC(.t)</th>
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<td>5530700</td>
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<tr>
<td>$\lambda_{211}$</td>
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<td>2724700</td>
<td>5464900</td>
</tr>
<tr>
<td>$\lambda_{121}$</td>
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<td>5582700</td>
</tr>
<tr>
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<td>2760200</td>
<td>5494100</td>
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<td>$\lambda_{212}$</td>
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<td>2773500</td>
<td>5574400</td>
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<td>5550900</td>
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<td>5594400</td>
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</table>

$^a$See Equation 2.91.

alternative to implement since all three subterminals $L_{21}$, $L_{22}$, and $L_{32}$ are considered in addition to the fixed annual cost of establishing rail line option two.
Table 2.23. Fixed costs $\lambda_{mnr}$

<table>
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<tr>
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<th>$\gamma_r$</th>
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</thead>
<tbody>
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<td>$\frac{L2}{2}$</td>
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<tr>
<td>$\lambda_{211}$</td>
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</tr>
<tr>
<td>$\lambda_{121}$</td>
<td>0</td>
</tr>
<tr>
<td>$\lambda_{112}$</td>
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</tr>
<tr>
<td>$\lambda_{212}$</td>
<td>0</td>
</tr>
<tr>
<td>$\lambda_{122}$</td>
<td>30,000</td>
</tr>
<tr>
<td>$\lambda_{222}$</td>
<td>30,000</td>
</tr>
<tr>
<td>$\lambda_{322}$</td>
<td>0</td>
</tr>
<tr>
<td>$\lambda_{132}$</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Table 2.24 presents $\text{TRNVC} | \lambda_{mnr}$, fixed costs of investment given $\lambda_{mnr}$, and maximum joint net revenue given $\lambda_{mnr}$. $\text{TRNVC} | \lambda_{mnr}$ is taken from Table 2.22, column 4. The fixed costs of investment are derived from Table 2.23. And, $\Pi | \lambda_{mnr}$, or column 5 in Table 2.24, is computed as specified by Equation 2.93.

The constellation of elevators and rail lines for which $\Pi$ is maximum is determined as specified by Equation 2.93. That is, $\Pi = \max \max \max \Pi | \lambda_{mnr}$. The maximum element in...
Table 2.24. Maximum joint net revenue given $\lambda_{mnr}$ as defined by Equation 2.92

| $\text{TRNVC}$ | $\lambda$ | $\sum_{i \in \lambda} \alpha(i)$ | $\sum_{r \in \lambda} \gamma_r$ | $\Pi | \lambda$ |
|---------------|---------|-------------------------------|-------------------------------|---------------|
| 1  | 2  | 3  | 4  | 5  |
| $\lambda_{111}$ | 5530700 | 20000 | 0 | 5510700 |
| $\lambda_{211}$ | 5464900 | 60000 | 0 | 5404900 |
| $\lambda_{121}$ | 5582700 | 80000 | 0 | 5502700 |
| $\lambda_{112}$ | 5494100 | 30000 | 10000 | 5454100 |
| $\lambda_{212}$ | 5530700 | 20000 | 10000 | 5500700 |
| $\lambda_{312}$ | 5464900 | 60000 | 10000 | 5394900 |
| $\lambda_{122}$ | 5574700 | 50000 | 10000 | 5514400 |
| $\lambda_{222}$ | 5543700 | 90000 | 10000 | 5443700 |
| $\lambda_{322}$ | 5550900 | 80000 | 10000 | 5460900 |
| $\lambda_{132}$ | 5594400 | 110000 | 10000 | 5474400 |

Column 5, Table 2.24 is 5514400. Thus, $\lambda_{122}$ represents the optimal number, size, and location of elevators and rail lines.
CHAPTER III. DATA

Introduction

Data required to evaluate the economics of alternative grain distribution systems using a generalized transhipment plant-location model were implicitly specified in Chapter II.\(^1\) In general the required data include: 1) the supply of each grain forthcoming from each origin in month \(t\); 2) the demand price at each terminal market in month \(v\); 3) elevator grain handling costs for receiving, storing, and load out activities; and 4) transportation costs which account for the upgrading and maintenance costs of alternative rail systems as well as the costs of shipping grain from point to point.

The time horizon over which alternative rail-based grain distribution systems were evaluated extends from 1971 to 1980. Thus, a description of the distribution facilities existing at the beginning of the planning horizon, 1970-71, is necessary to estimate the additional investment requirements needed to implement various marketing systems. A description of the areas' grain distribution facilities is presented simultaneously with discussion of

\(^1\)A copy of the computer program including the source deck and data inputs may be obtained from the author.
data estimation.

The two stage multi-period transhipment plant-location model specified in Chapter II was applied to two different situations. The model was used to estimate the number, size, and location of subterminals; the rail line system; and, the flow of grain over time and space to maximize the 1980 joint net revenue of producers in a specified region. In this case, grain supply was projected to 1980 and alternative distribution systems were compared.

In the second situation the model was used to estimate the flow of grain over time and space to maximize the 1970-71 joint net revenue of producers. In this case, the 1970-71 grain supply was estimated and the existing grain distribution system was taken as given. The purpose of this application of the model was to compare an estimate of actual 1970-71 grain flows with the flows projected by the model. Thus, in addition to developing and presenting data requirements, Chapter III also presents an estimate of actual 1970-71 grain flows from origins within the specified region to terminal markets.

The specific region selected for this study was a 6-1/2 county area in central Iowa around Fort Dodge. This region, referred to in this report as the Fort Dodge area includes the counties of Pocahontas, Hamilton, Humboldt, Webster, Greene, Calhoun, and the west half of Boone County. This
area was selected for a regional analysis of the economics of grain distribution because: 1) It produces a large quantity of surplus grain. In 1970, 71 million bushels of corn and soybeans were shipped to either processing or foreign export markets; and, by 1980 it has been estimated that 118 million bushels will be sold for commercial purposes. 2) There are a large number of light rail lines in the area which, in 1970, were incapable of handling fully loaded hopper cars. Of the 690 miles of rail line in the Fort Dodge area, only 34 percent of the lines were capable of handling fully loaded hopper cars. 3) The financial support and data of farmers and elevator operators located in this region initially made this study possible. And, 4) farmers and elevator operators in the Fort Dodge area requested the study. The Fort Dodge area, the location of country elevators, and the 1971 Iowa rail system are shown in Figure 3.1.

Data requirements for the application of the transhipment plant-location model are presented in this chapter. This chapter presents data regarding: 1) commercial grain supply, 2) estimated 1970-71 grain shipments, 3) market demand prices, 4) grain handling, and 5) grain transportation.
Figure 3.1. Location of country elevators and rail line system in the Fort Dodge area, Iowa, 1971
Commercial Grain Supply

In evaluating the economics of alternative grain distribution systems, one of the first steps is to determine the quantities of grain that will be available for physical distribution from each origin within the Fort Dodge area. In this section, annual grain supplies are first estimated by origin for 1970 and 1980; and secondly, the monthly supply of grain by origin is estimated.

Annual grain supply

Grain produced at origins within the region is either consumed locally or transhipped through elevators and shipped to final markets. For this study commercial grain supply was defined as grain moving out of the local region where it was produced. Grain consumed within the Fort Dodge area by livestock was defined as noncommercial grain. Origins were defined as three mile square production nodes, generally equivalent to one-fourth of a township.

Quantities of commercial grain coming from each township in 1960 and 1970 and projections to 1980 were estimated. Estimates of on-farm corn, oats, and soybeans usage by township were used to estimate commercial grain supply for 1960 and 1970. The difference between reported grain production and estimated usage on farms was assumed to be
sold through commercial channels.

Annual commercial corn sales were defined as corn production minus the amount of corn fed to livestock. Corn fed to livestock was estimated by multiplying the number of head of each type of livestock fed each year by the corn feeding rate for that type of livestock.

Since only a small amount of soybeans are normally used on farms, annual soybean sales were defined as soybean production minus one bushel of soybean seed per acre used for soybean production. Oat sales were estimated by multiplying production times the percent of oats sold off farms as reported in the 1954 U.S. Census of Agriculture. The residual oats were assumed to have been fed to livestock on farms. Corn, soybean and oats sales were added to obtain annual estimates of commercial grain sales for 1960 and 1970.

Recent USDA projections of national grain, livestock and poultry production in 1980 and 1985 served as a base for developing 1980 estimates of the Fort Dodge region production (57). The procedure used in making these estimates was to examine past trends in Iowa shares of U.S. production, to project percentage Iowa shares of national production to 1980, and to translate these shares into production estimates for the state, counties, and townships. The estimates derived using this percentage share procedure were defined as derived demand estimates.
State projections of 1980 production were allocated among counties by multiplying projected state production by each county's projected share of the state total. County projections were allocated among townships within the Fort Dodge region in a similar fashion. Projected county and township shares were derived by computing a linear time trend of production for each county and township to 1980 and then dividing this forecast by the sum of all county or townships' projections. Thus, commercial sales for commodity \( z \) in township \( j \), county \( i \) in year \( y \), denoted as \( X(z; i,j)_y \), were estimated as follows:

\[
X(z; i,j)_y = X(z; i,.)_y \frac{P(z; i,j)_y}{\sum_j P(z; i,j)_y} \tag{3.1}
\]

where \( X(z; i,.)_y \) denotes commercial sales of commodity \( z \), county \( i \), year \( y \); and \( P(z; i,j)_y \) denotes estimated production of commodity \( z \), county \( j \), year \( y \). Index \( z \) varies from 1 to 2 and represents corn and soybeans; and index \( i \) denotes counties within the Fort Dodge area.

County estimates of commercial grain sales, \( X(z; i,.)_y \) for 1970 and projections to 1980, and data concerning feed requirements, crop yield estimates, and cropland available were found in "Estimated Commercial Grain Sales by Counties in Iowa,..." (36). \( P(z; i,j)_y \) was taken from various issues of the Iowa Farm Census (24) up to the year \( y = 1970 \).
1979 and 1980 were estimated using a linear time trend over 1960 to 1970.

All grain projections that were allocated among townships or counties were constrained by the estimated cropland available. If more cropland was needed to satisfy the grain production forecasts for a region than the cropland available in 1967, production estimates for both corn and soybeans were decreased. Production estimates for a region were decreased until the number of acres required to satisfy 1980 projections were equal to the actual cropland available in 1967. In order to satisfy the state's share of national production, the production estimates that were subtracted from regions with acreage constraints were re-distributed among the remaining regions with free or idle acres.

Table 3.1 presents the bushels of grain produced, number of livestock, and estimated bushels of grain marketed through commercial channels in 1960 and 1970 and projections to 1980 in the Fort Dodge area. Time trend projections were reported along with derived demand projections. In general, the 1980 projections based on the derived demand estimates of (7) exceed trend projections. Projections of 1980 commercial corn and soybean sales in the Fort Dodge area used in this thesis were based on the derived demand estimates of (7).

Corn production in the area was projected to reach about 105 million bushels by 1980 according to the derived
demand method. This would be a 36 percent increase from the 1970 level, or an average yearly growth rate of 3.6 percent. Corn sales according to derived demand projections would increase to about 75 million bushels in 1980. This would be an increase of 60 percent over the 1970 level, or an average growth rate of 6 percent per year.

Soybean production, using derived demand projections, was projected to increase 76 percent between 1970 and 1980; soybean sales were projected to increase 79 percent.

Monthly grain supply from origins

Grain is harvested and dried in the fall and stored for consumption that takes place throughout the year. The quantity of commercial grain forthcoming from origins each month depends, to a large extent, on field shelling, expected prices within the marketing year, and on the storage and processing facilities available on-farm and at elevators.

A survey was taken in the Fort Dodge area to estimate the monthly flow of grain from farms to elevators.¹ The monthly flow of grain from farms to elevators, as reported by elevator managers for 1970, was used to estimate the

¹Questionnaire and data may be obtained from the authors of (4).
Table 3.1. Bushels of grain production, number of livestock, and bushels of grain sold through commercial channels in 1960 and 1970 and trend and projections, based on county derived estimates of (7), to 1980 in thousands of units in the Fort Dodge, Iowa area.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Production</td>
<td>70,211</td>
<td>77,351</td>
<td>106,724</td>
<td>104,836</td>
</tr>
<tr>
<td>Soybean Production</td>
<td>12,215</td>
<td>25,186</td>
<td>35,175</td>
<td>44,120</td>
</tr>
<tr>
<td>Oat Production</td>
<td>15,458</td>
<td>3,986</td>
<td>604</td>
<td>812</td>
</tr>
<tr>
<td>Milk Cows</td>
<td>31</td>
<td>7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Beef Cows</td>
<td>43</td>
<td>42</td>
<td>50</td>
<td>59</td>
</tr>
<tr>
<td>Hogs Marketed</td>
<td>928</td>
<td>1,106</td>
<td>1,141</td>
<td>1,113</td>
</tr>
<tr>
<td>Grain Fed Cattle</td>
<td>164</td>
<td>285</td>
<td>413</td>
<td>369</td>
</tr>
<tr>
<td>Sheep and Lambs</td>
<td>90</td>
<td>62</td>
<td>24</td>
<td>37</td>
</tr>
<tr>
<td>Hens and Pullets</td>
<td>1,609</td>
<td>1,651</td>
<td>1,877</td>
<td>2,275</td>
</tr>
<tr>
<td>Turkeys</td>
<td>1,797</td>
<td>1,383</td>
<td>671</td>
<td>987</td>
</tr>
<tr>
<td>Corn Sales</td>
<td>44,599</td>
<td>46,583</td>
<td>61,387</td>
<td>74,807</td>
</tr>
<tr>
<td>Soybean Sales</td>
<td>11,779</td>
<td>24,450</td>
<td>34,396</td>
<td>43,146</td>
</tr>
<tr>
<td>Oat Sales</td>
<td>8,071</td>
<td>2,089</td>
<td>306</td>
<td>416</td>
</tr>
<tr>
<td>Grain Sales</td>
<td>64,449</td>
<td>73,122</td>
<td>96,089</td>
<td>118,369</td>
</tr>
</tbody>
</table>
monthly flow of grain in 1980 for the Fort Dodge region.

A portion of the grain that flows from farm to elevator each month falls under the direction of Commodity Credit Corporation (CCC) policy. It was assumed that by 1980 CCC would not be required to store grain because of increased foreign and domestic demands for corn and soybeans. To reflect the absence of CCC grain storage in 1980, the estimated flow of grain from farm to elevator was adjusted for CCC grain movements.

Over the past several years there has been a significant change in harvesting techniques that has brought a larger volume of grain off the farm during the fall harvesting months. The amount of grain moving off the farm in the fall as a proportion of total grain movement increased from thirty-one percent in 1964 to forty-six percent in 1969 for the state of Iowa. More specifically, in the fifth crop reporting district of Iowa, a twelve county district in which part of the Fort Dodge area is located, the amount of grain moving off the farm in the fall as a proportion of total grain movement increased from twenty-nine percent in 1964 to fifty-nine percent in 1969 (36, p. 58). The increase in the amount of corn moving from the farm to elevators in the fall reflects, to a large extent according to Mikes (36), the increasing use of corn field shelling. Field shelled corn requires the use of aeration and drying equipment, which is often more
accessible at elevators during harvest than on farms.

To obtain the 1980 supply of commercial corn and soybeans, the 1970 estimated monthly flow of grain was adjusted to reflect changes in 1) Commodity Credit Corporation corn and soybean storage, 2) harvesting techniques, and 3) grain production. The adjustments may be summarized by the following: Define $X(z; ijt)^y$ as the commercial supply of commodity $z$ township $i$ in county $j$ month $t$ and year $y$; $CCC(z; ijt)^y$, quantity of CCC grain $z$ in township $i$ county $j$ month $t$ year $y$; $FM_y$, the percent of the year's harvest of corn moving to elevators in the Fall in year $y$; and, as previously defined, $X(z; ij)^y$, the commercial supply of commodity $z$ in township $i$ county $j$ year $y$. Commodity $z=1$ denotes corn, and commodity $z=2$ denotes soybeans. The 1980 monthly supply of commercial corn and soybeans were estimated as specified by Equations 3.2, 3.3 and 3.4:

$$X(1; ijt)_{1980} = \frac{X(1; ijt)_{1970} - CCC(1; ijt)_{1970}}{\sum_{t=1}^{3} (X(1; ijt)_{1970} - CCC(1; ijt)_{1970})}$$

$$[1 + \left(\frac{FM_{1980} - FM_{1970}}{FM_{1970}}\right)] X(1; ij)_{1980}$$

when $t = 1, 2, 3$ and for all $i$ and $j$. Month $t=1$ denotes October, $t=2$ denotes November, and $t=3$ denotes December. From January ($t=4$) to September ($t=12$) the 1980 monthly
supply of commercial corn in township i and county j were estimated as follows:

\[ X(1;ijt)_{1980} = \left[ \frac{X(1;ijt)_{1970} - CCC(1;ijt)_{1970}}{12} \right] \sum_{t=4}^{12} (X(1;ijt)_{1970} - CCC(1;ijt)_{1970}) \]

\[ \times \left[ 1 - \left( \frac{FM_{1980} - FM_{1970}}{FM_{1970}} \right) \right] [X(1;ij)_{1980}] \] (3.3)

when \( t = 4, 5, \ldots, 12 \) and for all i and j.

The 1980 monthly supply of commercial soybeans in township i and county j were estimated as follows:

\[ X(2;ijt)_{1980} = \left[ \frac{X(2;ijt)_{1970} - CCC(2;ijt)_{1970}}{12} \right] \sum_{t=1}^{12} (X(2;ijt)_{1970} - CCC(2;ijt)_{1970}) \]

\[ \times [X(2;ij)_{1980}] \] (3.4)

for all \( t, i, \) and \( j. \)

\( X(z;ijt)_{1970} \) was obtained from the elevator questionnaire. \( CCC(z;ijt)_{1970} \) was not available for the Fort Dodge area. Monthly movements of CCC grain were available, however, for the state of Iowa for the years 1968 through 1971.\(^1\)

\(^1\)CCC data are available upon request from the Iowa Crop and Livestock Reporting Service, Des Moines, Iowa.
This information was used to estimate monthly CCC grain movements in the Fort Dodge region by assuming the ratio of monthly movement of CCC grain to annual grain sales of the state to be equal to the monthly movement of CCC grain to annual grain sales of the Fort Dodge region.

$F_M$ was available by crop reporting district in Iowa up to 1971. Crop reporting district number 5 was chosen to approximate the Fort Dodge area since much of the study area is located within this district.

$F_M_{1980}$ was estimated by assuming a linear relationship between fall movement ($F_M$) and the percent of corn field-shelled ($F_S$). $F_M$ was regressed on $F_S$ by ordinary least squares over the years 1964 to 1972 and it was assumed that by 1980, 95 percent of the corn crop will be picked and shelled in the field. Data used for $F_M$ and $F_S$ were taken from (25).

$X(2;ijt)_{1980}$ was increased 18 percent during October ($t=1$) to reflect the assumption that the expansion of on-farm storage capacity will decline in the future (4). Such a decline in expansion will force relatively more soybeans to elevators during harvest.

To estimate monthly quantities of commodity coming from each origin within a township, $X(z; g_t...)$, it was assumed that grain sales were evenly distributed over the townships. The estimated monthly flow of commercial corn and soybeans sales from farms to elevators for 1970-71 in the Fort Dodge
area and projections to 1980 are presented in Table 3.2.

Estimated 1970-71 Grain Shipments

Historically, grain shipped from elevators to markets was usually shipped to an inspection point for intransit inspection. If, for example, grain is being shipped from

Table 3.2. Estimated monthly commercial corn and soybean shipments from origins to elevators in the Fort Dodge area in 1970-71 and derived demand projections to 1980 in thousands of bushels

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>6,661</td>
<td>7,604</td>
<td>17,954</td>
<td>21,573</td>
</tr>
<tr>
<td>November</td>
<td>12,112</td>
<td>1,638</td>
<td>33,665</td>
<td>2,157</td>
</tr>
<tr>
<td>December</td>
<td>1,677</td>
<td>367</td>
<td>4,488</td>
<td>863</td>
</tr>
<tr>
<td>January</td>
<td>1,304</td>
<td>856</td>
<td>2,244</td>
<td>1,294</td>
</tr>
<tr>
<td>February</td>
<td>1,490</td>
<td>1,223</td>
<td>1,496</td>
<td>1,294</td>
</tr>
<tr>
<td>March</td>
<td>1,024</td>
<td>1,174</td>
<td>748</td>
<td>1,726</td>
</tr>
<tr>
<td>April</td>
<td>1,398</td>
<td>1,858</td>
<td>1,496</td>
<td>2,589</td>
</tr>
<tr>
<td>May</td>
<td>2,097</td>
<td>2,053</td>
<td>1,496</td>
<td>2,589</td>
</tr>
<tr>
<td>June</td>
<td>4,705</td>
<td>2,885</td>
<td>3,740</td>
<td>3,452</td>
</tr>
<tr>
<td>July</td>
<td>5,217</td>
<td>1,907</td>
<td>2,992</td>
<td>2,589</td>
</tr>
<tr>
<td>August</td>
<td>5,451</td>
<td>953</td>
<td>2,992</td>
<td>863</td>
</tr>
<tr>
<td>September</td>
<td>3,447</td>
<td>1,932</td>
<td>1,496</td>
<td>2,157</td>
</tr>
<tr>
<td>Total</td>
<td>46,583</td>
<td>24,450</td>
<td>74,807</td>
<td>43,146</td>
</tr>
</tbody>
</table>
Fort Dodge to the Gulf it may first be billed to Des Moines, inspected in Des Moines and then billed from Des Moines to the Gulf.

Elevator managers usually do not have records showing the routing of grain beyond the first intransit billing. Between May 1971 and April 1972, however, the Interstate Commerce Commission permitted railways to add a charge for each car diverted for intransit inspection. To avoid this additional charge, elevator managers within the Fort Dodge area discontinued intransit inspection during this time period and billed almost all grain directly to markets. Since the intermediate inspection points were by-passed and grain shipments were billed directly to the final destinations, it was possible, for this one year period, to obtain an estimate of the quantity of grain flowing from the Fort Dodge region to various markets.

In the summer of 1972 a census was taken of all elevators within the study area and daily quantities of grain shipped by rail from each elevator to specific terminal destinations were recorded. Information from this census as well as information obtained from the elevator questionnaire, were used to construct Tables 3.3, 3.4, and 3.5.¹

¹Data may be obtained from the authors of (4).
Table 3.3. Estimated commercial corn plus soybean receipts, storage, and shipment by rail and truck at country elevators in the Fort Dodge area in thousands of bushels for 1970-1971 by month

<table>
<thead>
<tr>
<th>Month</th>
<th>Receipts</th>
<th>Storage</th>
<th>Rail</th>
<th>Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>14,265</td>
<td>28,891</td>
<td>2,725</td>
<td>2,214</td>
</tr>
<tr>
<td>November</td>
<td>13,750</td>
<td>37,899</td>
<td>2,977</td>
<td>1,765</td>
</tr>
<tr>
<td>December</td>
<td>2,044</td>
<td>36,388</td>
<td>2,286</td>
<td>1,268</td>
</tr>
<tr>
<td>January</td>
<td>2,160</td>
<td>33,128</td>
<td>4,093</td>
<td>1,328</td>
</tr>
<tr>
<td>February</td>
<td>2,713</td>
<td>31,543</td>
<td>3,252</td>
<td>1,045</td>
</tr>
<tr>
<td>March</td>
<td>2,198</td>
<td>28,226</td>
<td>4,707</td>
<td>809</td>
</tr>
<tr>
<td>April</td>
<td>3,256</td>
<td>26,469</td>
<td>4,285</td>
<td>727</td>
</tr>
<tr>
<td>May</td>
<td>4,150</td>
<td>23,213</td>
<td>6,493</td>
<td>913</td>
</tr>
<tr>
<td>June</td>
<td>7,590</td>
<td>20,412</td>
<td>9,120</td>
<td>1,271</td>
</tr>
<tr>
<td>July</td>
<td>7,124</td>
<td>17,926</td>
<td>8,308</td>
<td>1,303</td>
</tr>
<tr>
<td>August</td>
<td>6,404</td>
<td>17,574</td>
<td>5,671</td>
<td>1,084</td>
</tr>
<tr>
<td>September</td>
<td>5,379</td>
<td>19,565</td>
<td>2,529</td>
<td>859</td>
</tr>
<tr>
<td>Total</td>
<td>71,033</td>
<td>56,446</td>
<td>14,587</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.4. Estimated rail shipments of corn and soybeans by market from the Fort Dodge area in thousands of bushels, October 1970 to September 1971

<table>
<thead>
<tr>
<th>Market</th>
<th>Thousands of Bushels</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Corn</td>
<td>Soybeans</td>
</tr>
<tr>
<td>Central Iowa</td>
<td>3,459</td>
<td>4,153</td>
</tr>
<tr>
<td>Eastern Iowa</td>
<td>12,762</td>
<td>2,541</td>
</tr>
<tr>
<td>Chicago Export</td>
<td>2,684</td>
<td>6,610</td>
</tr>
<tr>
<td>Chicago Domestic</td>
<td>4,137</td>
<td>211</td>
</tr>
<tr>
<td>Central Illinois</td>
<td>3,038</td>
<td>1,174</td>
</tr>
<tr>
<td>Milwaukee Export</td>
<td>2,098</td>
<td>703</td>
</tr>
<tr>
<td>Milwaukee Domestic</td>
<td>1,840</td>
<td>51</td>
</tr>
<tr>
<td>Kansas</td>
<td>2,696</td>
<td>233</td>
</tr>
<tr>
<td>Nebraska</td>
<td>1,604</td>
<td>331</td>
</tr>
<tr>
<td>Missouri</td>
<td>1,331</td>
<td>313</td>
</tr>
<tr>
<td>Gulf</td>
<td>1,224</td>
<td>3,253</td>
</tr>
<tr>
<td>Total</td>
<td>36,873</td>
<td>19,573</td>
</tr>
</tbody>
</table>
Table 3.5. Estimated monthly rail shipments by market for corn and soybean from the Fort Dodge area in thousands of bushels, October 1970 to September 1971

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Iowa</td>
<td>954</td>
<td>756</td>
<td>433</td>
<td>890</td>
<td>514</td>
<td>519</td>
<td>624</td>
<td>1,118</td>
<td>457</td>
<td>565</td>
<td>494</td>
<td>289</td>
<td>7,612</td>
</tr>
<tr>
<td>Eastern Iowa</td>
<td>656</td>
<td>513</td>
<td>885</td>
<td>1,354</td>
<td>1,270</td>
<td>1,750</td>
<td>2,104</td>
<td>1,790</td>
<td>1,624</td>
<td>1,160</td>
<td>1,344</td>
<td>852</td>
<td>15,302</td>
</tr>
<tr>
<td>Chicago Export</td>
<td>407</td>
<td>101</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>35</td>
<td>1,300</td>
<td>3,857</td>
<td>2,784</td>
<td>497</td>
<td>309</td>
<td>9,294</td>
</tr>
<tr>
<td>Chicago Domestic</td>
<td>41</td>
<td>0</td>
<td>79</td>
<td>186</td>
<td>33</td>
<td>91</td>
<td>161</td>
<td>870</td>
<td>949</td>
<td>932</td>
<td>732</td>
<td>274</td>
<td>4,349</td>
</tr>
<tr>
<td>Central Illinois</td>
<td>3</td>
<td>91</td>
<td>137</td>
<td>228</td>
<td>232</td>
<td>186</td>
<td>568</td>
<td>643</td>
<td>706</td>
<td>1,028</td>
<td>168</td>
<td>4,213</td>
<td></td>
</tr>
<tr>
<td>Milwaukee Export</td>
<td>219</td>
<td>301</td>
<td>21</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>31</td>
<td>73</td>
<td>479</td>
<td>725</td>
<td>662</td>
<td>274</td>
<td>2,801</td>
</tr>
<tr>
<td>Milwaukee Domestic</td>
<td>17</td>
<td>31</td>
<td>14</td>
<td>7</td>
<td>0</td>
<td>61</td>
<td>59</td>
<td>336</td>
<td>473</td>
<td>514</td>
<td>308</td>
<td>71</td>
<td>1,891</td>
</tr>
<tr>
<td>Kansas</td>
<td>30</td>
<td>280</td>
<td>190</td>
<td>439</td>
<td>314</td>
<td>496</td>
<td>458</td>
<td>62</td>
<td>78</td>
<td>226</td>
<td>315</td>
<td>38</td>
<td>2,928</td>
</tr>
<tr>
<td>Nebraska</td>
<td>90</td>
<td>419</td>
<td>386</td>
<td>550</td>
<td>108</td>
<td>60</td>
<td>97</td>
<td>47</td>
<td>58</td>
<td>13</td>
<td>22</td>
<td>84</td>
<td>1,935</td>
</tr>
<tr>
<td>Missouri</td>
<td>46</td>
<td>344</td>
<td>40</td>
<td>150</td>
<td>34</td>
<td>98</td>
<td>86</td>
<td>132</td>
<td>284</td>
<td>217</td>
<td>121</td>
<td>92</td>
<td>1,644</td>
</tr>
<tr>
<td>Gulf</td>
<td>263</td>
<td>142</td>
<td>100</td>
<td>278</td>
<td>745</td>
<td>1,403</td>
<td>442</td>
<td>197</td>
<td>217</td>
<td>466</td>
<td>148</td>
<td>77</td>
<td>4,477</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>2,725</td>
<td>2,977</td>
<td>2,286</td>
<td>4,093</td>
<td>3,252</td>
<td>4,707</td>
<td>4,285</td>
<td>6,493</td>
<td>9,120</td>
<td>8,308</td>
<td>5,671</td>
<td>2,529</td>
<td>56,446</td>
</tr>
<tr>
<td><strong>PERCENT OF TOTAL</strong></td>
<td>4.8</td>
<td>5.3</td>
<td>4.0</td>
<td>7.3</td>
<td>5.8</td>
<td>8.3</td>
<td>7.6</td>
<td>11.5</td>
<td>16.2</td>
<td>14.7</td>
<td>10.0</td>
<td>4.5</td>
<td></td>
</tr>
</tbody>
</table>
The procedure used to estimate the 1970-71 monthly grain shipments to various markets from the Fort Dodge area may be summarized as follows:

\[
X(z; j_v)_{1970-71} = \frac{\sum_{h} X(z; h, j_v)_{1972-73}}{\sum_{h} \sum_{w} X(z; h, w, j_v)_{1972-73}}
\]

where \( X(z; h, w, j_v)_{1972-73} \) is the volume of commodity \( z \) shipped from elevator \( L_h \) to destination \( j \) in month \( v \) of 1972-73, was obtained from the census taken in the summer of 1972; and, \( X(z; q_v \ldots)_{1970-71} \) was estimated as defined in the previous section.

Estimated monthly receipts, storage, and shipments by rail and truck from all elevators in the Fort Dodge area from October 1970 to September 1971 are reported in Table 3.3. Cumulative monthly receipts minus cumulative shipments plus grain carried over from the previous year was defined as monthly storage. From the questionnaire it was estimated that 19,565 thousand bushels of grain were carried over from September 1970 to October 1970.

Table 3.4 contains the estimated rail shipments of corn and soybeans by market from the Fort Dodge area in thousands of bushels from October 1970 to September 1971. Table 3.5 contains the estimated monthly rail shipments
by market for corn plus soybeans as from the Fort Dodge region in thousands of bushels from October 1970 to September 1971.

Market Demand Prices

Corn and soybean prices at terminal markets vary in response to changes in the demand and supply of grain. Grain is harvested in the Fall and consumed throughout the year. Prices, therefore, vary over time to reflect various costs of temporal transformations such as storage costs, risk, and costs of shrinkage or damage.

Prices also vary among markets over time. The Chicago export price may be higher than the Gulf export price during one month and lower during another month. Changes in overseas or domestic demands; the freezing of the St. Lawrence Seaway or upper-Mississippi; or any other condition, such as dock-strikes or queues from transportation or processing bottle-necks, which tend to have a greater influence on some markets than on other markets, are a few of the factors that contribute to spatial price variations over time.

In 1970-71 corn and soybean prices varied both within and among markets over time. To illustrate: during the month of January the Chicago domestic and Gulf export prices for corn, net of transportation costs from Jefferson, Iowa were $1.43 and $1.38 respectively. During the month of August the
pricing surface changed and the spot prices at Chicago domestic and Gulf export, net of transportation from Jefferson were $1.06 and $1.12. Table 3.6 presents spot corn prices net of transportation costs by month and selected terminal markets for Jefferson, Iowa in 1970-71. Single-car rail rates from Jefferson to various markets were used for transportation costs.

Table 3.6. Monthly corn prices net of transportation costs in cents per bushel at selected markets for corn originating in Jefferson, Iowa (1970-1971)^a

<table>
<thead>
<tr>
<th>Month</th>
<th>Central Iowa</th>
<th>Chicago Export</th>
<th>Chicago Domestic</th>
<th>Nebraska Domestic</th>
<th>Gulf Export</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>$1.23</td>
<td>$1.23</td>
<td>$1.24</td>
<td>$1.26</td>
<td>$1.25</td>
</tr>
<tr>
<td>November</td>
<td>1.17</td>
<td>1.25</td>
<td>1.28</td>
<td>1.22</td>
<td>1.24</td>
</tr>
<tr>
<td>December</td>
<td>1.27</td>
<td>0.00</td>
<td>1.37</td>
<td>1.30</td>
<td>1.34</td>
</tr>
<tr>
<td>January</td>
<td>1.37</td>
<td>0.00</td>
<td>1.43</td>
<td>1.33</td>
<td>1.38</td>
</tr>
<tr>
<td>February</td>
<td>1.33</td>
<td>0.00</td>
<td>1.38</td>
<td>1.32</td>
<td>1.34</td>
</tr>
<tr>
<td>March</td>
<td>1.33</td>
<td>0.00</td>
<td>1.36</td>
<td>1.30</td>
<td>1.31</td>
</tr>
<tr>
<td>April</td>
<td>1.26</td>
<td>1.34</td>
<td>1.31</td>
<td>1.31</td>
<td>1.30</td>
</tr>
<tr>
<td>May</td>
<td>1.31</td>
<td>1.35</td>
<td>1.36</td>
<td>1.34</td>
<td>1.32</td>
</tr>
<tr>
<td>June</td>
<td>1.38</td>
<td>1.36</td>
<td>1.41</td>
<td>1.37</td>
<td>1.40</td>
</tr>
<tr>
<td>July</td>
<td>1.32</td>
<td>1.32</td>
<td>1.37</td>
<td>1.34</td>
<td>1.32</td>
</tr>
<tr>
<td>August</td>
<td>1.05</td>
<td>1.13</td>
<td>1.06</td>
<td>1.10</td>
<td>1.12</td>
</tr>
<tr>
<td>September</td>
<td>1.01</td>
<td>1.05</td>
<td>1.07</td>
<td>1.08</td>
<td>1.02</td>
</tr>
</tbody>
</table>

^aSource: FGDA Overnight Bids (18) and single car rail rate (23).
Throughout this study final markets refer to 13 geographical areas. Final markets represent either 1) export markets at Chicago, Milwaukee, West Coast, the Gulf, and Norfolk or 2) domestic markets located in Central Iowa, Eastern Iowa, Chicago, Central Illinois, Milwaukee, Kansas, Nebraska, and Missouri.

Spot prices reported in 1970-71 at the various destinations were used to estimate 1980 prices. Friday spot prices for each week from October 1970 to September 1971 were obtained from the Farmer's Grain Dealers Association (FGDA), (18). Spot prices at destinations are given for a specific length of time. A ten-day corn bid at Chicago-export, for example, identifies a specific price for all corn delivered to the Chicago-export market within a ten day period. The highest thirty-day bid for commodity \( z \) in month \( t \) and destination \( j \) as reported by FGDA (18) was selected as an approximation for \( \pi(z; \ldots; j) \). It was assumed that sellers of grain contracting to deliver grain at destination \( j \) during month \( t \) would select the highest bid prevailing during month \( t \).

The following cities were chosen to represent general marketing areas: Portland for the West Coast market, New Orleans for the Gulf, Des Moines for Central Iowa, Cedar Rapids for Eastern Iowa, Pekin for Central Illinois, Kansas City for Kansas, Omaha for Nebraska, and St. Louis for Missouri.
Grain Handling Facilities

This section contains a description of the grain handling facilities in existence in 1971 in the Fort Dodge area and the various costs of handling grain. The number, location, and capacity of elevators are presented including a description of the transportation interface at the elevators such as track capacity and load-out facilities. Handling costs include 1) variable operating and maintenance costs of receiving, storing, and loading out grain; and 2) minimum fixed set-up and expansion costs for a subterminal elevator capable of loading 50-car trains.

Existing facilities

The number, size, and location of elevators in the Fort Dodge area in 1970-71 were determined from the results of 95 elevator questionnaires. In several of the communities in the study area two elevators were located near each other. In ten of these locations the capacity of the two elevators in the community were combined and considered as one elevator. This adjustment along with two additional elevators that were missed by oversight in the elevator survey made a total of 87 elevators in the Fort Dodge area in 1970-71. The location

---

Questionnaire and data may be obtained from the authors of (4).
of the 87 elevators are identified by Figure 3.1.

Storage capacity is often used as an index of elevator size. Such an index, however, fails to reflect the capacity of the elevator in terms of the through-flow of grain over time. In addition to storage capacity, therefore, receiving, drying, and load-out capacities are also important dimensions of elevator size.

Capacity at elevators in 1971 to receive, dry, store, and load out both commercial and noncommercial grain was reported by elevator managers in elevator questionnaires. Commercial grain refers to grain that is shipped out of the Fort Dodge area to terminal markets; and, noncommercial grain is consumed locally by livestock. From the elevator questionnaire it was estimated that nine percent of the corn received at elevators returns to farms for the feeding of livestock. The capacity to receive, dry, store, and load out commercial grain in 1971 was based upon the capacities reported by elevator managers. These estimated capacities are reported in Table 3.7.

Receiving capacity was defined as the number of bushels of commercial corn and soybeans that elevators can receive in one hour. The estimated average capacity of receiving commercial corn was 3,500 bushels per hour for the 95 elevators in the elevator survey. The estimated average capacity of receiving commercial soybeans was 3,800 bushels per hour. The
Table 3.7. Estimated total and average elevator capacity to receive, dry, store, and load-out commercial grain in the Fort Dodge area by storage capacity in thousands of bushels, 1971

<table>
<thead>
<tr>
<th>Activity</th>
<th>Storage Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-400</td>
</tr>
<tr>
<td><strong>Receiving corn</strong></td>
<td></td>
</tr>
<tr>
<td>Total: bu. per hr.</td>
<td>76.0</td>
</tr>
<tr>
<td>Average: bu. per hr.</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Receiving soybeans:</strong></td>
<td></td>
</tr>
<tr>
<td>Total: bu. per hr.</td>
<td>88.7</td>
</tr>
<tr>
<td>Average: bu. per hr.</td>
<td>2.9</td>
</tr>
<tr>
<td><strong>Drying:</strong> bu. per hr.</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21.8</td>
</tr>
<tr>
<td>Average</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6,502.7</td>
</tr>
<tr>
<td>Average</td>
<td>188.7</td>
</tr>
<tr>
<td>Percent Used</td>
<td>96.0</td>
</tr>
<tr>
<td><strong>Load-out:</strong> bu. per hr.</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>113.8</td>
</tr>
<tr>
<td>Average</td>
<td>1.7</td>
</tr>
</tbody>
</table>

total and average receiving capacity of all elevators by storage capacity are reported in Table 3.7.

Restrictions on receiving capacity can come from various factors including leg capacity, number of receiving pits, dryers, and scales. Elevator "legs" refer to conveyor systems used, for example, to move grain from receiving pits to storage bins. Of the 95 elevators surveyed, 48 percent indicated that leg capacity was the main restriction; 38
percent listed dryers as the main restriction; and 27 percent indicated that the number of receiving pits was the main restriction in receiving capacity.

Drying capacity was defined as the total rated capacity of dryers at five percent moisture removal per hour. The estimated average drying capacity for each elevator in 1971 was 1,200 bushels of commercial corn per hour. The total and average drying capacity of elevators for different volumes of storage capacity is reported in Table 3.7.

Storage capacity was reported as the number of bushels of flat and upright storage space available on January 1, 1971. The average storage capacity for commercial grain for elevators was 484,000 bushels. For 1980 it was assumed that 15 percent of 1971 storage capacity was used for grain carried over from one year to the next. The maximum storage capacity used during the harvest season of 1971 was ninety percent. The estimated total and average capacity to store commercial grain and percent of total capacity used during harvest by size class is reported in Table 3.7.

Load-out capacity for the 95 elevators in the Fort Dodge area was estimated by asking each manager the number of bushels of grain they could load-out in an eight hour day by box car, hopper car, and truck. The total and average capacity per hour to load-out commercial grain for all elevators in the
area is reported in Table 3.7.

In 1971 only 58 percent of the elevators in the study area were located next to rail lines that could handle fully loaded 100 ton hopper cars. Of the 95 elevators surveyed, only eight elevators had sufficient rail siding to load twenty or more hopper cars. Forty-two percent of the elevators had rail siding capacity for holding less than ten hopper cars.

A lack of adequate rail siding was listed as the main limitation on capacity to load out rail cars by 41 percent of the elevator managers. Twenty-seven percent of the elevator managers indicated that legs, scale, spout, and storage provided the main limitation on capacity to load out rail cars.

Coopering, the preparation of box cars for grain shipment, was listed by 14 percent of the managers as being the main limitation on capacity to load out rail cars. Fifty elevator managers reported that it takes between thirty to sixty minutes to prepare box cars for shipping grain; and 32 managers reported that coopering requires more than one hour.

**Grain handling costs**

Grain handling costs were delineated at elevators, for the Fort Dodge study, by activity and by elevator type. Grain handling activities were divided into receiving, storing, and load-out. The activity of receiving includes not only the receipt of grain but also the drying and condition of
grain; and load-out activities include blending, sampling, and all operations involved in loading grain out of the elevator into various modes of transportation.

For this study two types of elevators were specified. Country elevators, the first type, received grain from producers and shipped to final destinations either directly or indirectly through other elevators. All corn received during the harvest months was dried. All grain loaded-out was shipped by either truck or rail using single-car rates. Country elevators, by definition, were unable to load-out multiple hopper-car trains either because of the condition of the track that serves the elevator or the receiving and load-out capacity of the elevator.

Subterminal elevators, the second type of elevator, received grain from producers and country elevators, commercial grain received at subterminals was stored and shipped to final destinations. All corn received during the harvest seasons from producers was dried. Grain received from country elevators was assumed to be dryed at country elevators. Sub-terminal elevators had the option of shipping by truck or by rail using multiple-car shipping rates. Sub-terminals could load-out unit trains because of their location on heavy rail lines and load-out capacity.
Marginal operating and maintenance costs at elevators
Marginal operating and maintenance costs were estimated by Baumel et al. (4) analyzing various grain elevator records and by personal interviews with elevator managers. Marginal receiving and load-out operating costs were assumed to be independent of volume handled.

Marginal operating costs of receiving varied by month to reflect various moisture conditions of corn. During October, November, and December it was assumed that corn required 10 points of moisture removed; from January to March 4 points of moisture were removed; and during the remainder of the year, corn, received at elevators from farms, required no drying. Marginal receiving costs assuming 10, 4 and 0 points moisture removed from corn were estimated as 4.58, 2.90, and 1.78 cents per bushel. The marginal operating and maintenance costs of receiving soybeans was estimated to be 1.78 cents per bushel for all months. Thus, \( \beta R(1; h_{t.}) = \beta R(1; i_{t.}) = 0.0458 \) for \( t = 1,2,3 \); \( \beta R(1; h_{t.}) = \beta R(1; i_{t.}) = 0.029 \), for \( t = 4,5,6 \); \( \beta R(1; h_{t.}) = \beta R(1; i_{t.}) = 0.0178 \) for \( t = 7,8,...,12 \); and \( \beta R(2; h_{t.}) = \beta R(2; i_{t.}) = 0.0178 \) where \( z=1 \) denotes corn and \( z=2 \) denotes soybeans.

The variable operating and maintenance costs of receiving grain estimated by Baumel et al. are 0.01 cent higher than the receiving costs of 1.77 per bushel (net of trucking expense) estimated by the Economic Research Service of
Marginal operating and maintenance costs of storing grain varied by commodity and by the length of time the grain was stored. The marginal cost of storing or handling a bushel of corn one month was estimated to be 1.04 cents which includes 0.70 cents for interest costs based on interest rates of seven percent per year and a purchase price of corn of $1.20 per bushel. That is, \( \beta S(1; h_{tt}) = \beta S(1; .i_{tt}) = \$0.0104 \) for \( t = 1,2,\ldots,12 \). The cost of storing a bushel of corn for more than one month was estimated by multiplying the number of months in storage by the monthly storage cost. Thus, for example, \( \beta S(1; h_{1,3}) = \beta S(1; h_{4,6}) = 3 \times \$0.0104 = \$0.0312 \).

The marginal cost of storing a bushel of soybeans was estimated as 1.97 cents per month; or, \( \beta S(2; h_{tt}) = \beta S(2; .i_{tt}) = \$0.0197 \) for \( t = 1,2,\ldots,12 \). The marginal cost of storing a bushel of soybeans includes 1.63 cents for interest costs based on an interest rate of seven percent per year and a purchase price for soybeans of $2.80 per bushel. Soybeans are more costly to store than corn because of the difference in price between the two commodities. A greater interest or opportunity cost of money is incurred when financing the storage of soybeans as compared to corn. The variable storage cost, net of interest expense, of .34 cents per bushel per month estimated by Baumel
Marginal load-out costs of operating and maintenance varied by elevator type. Because the physical design and layout of a sub-terminal is engineered to load-out multiple-car trains in a short period of time, the marginal load-out cost of .55 cents for a sub-terminal elevator (i.e., $\beta L(z; i, t) = .0055$ for $z = 1,2$; and $t = 1,2,...,12$) was less than the per bushel load-out cost of 1.74 cents for a country elevator (i.e., $\beta L(z; h, t) = .0174$ for $z = 1,2$; and $t = 1,2,...,12$). The variable operating and maintenance costs of loading out grain at country elevators was taken from the USDA study of (52).

Table B.1 in Appendix B presents the estimated variable operating and maintenance costs of receiving, drying, and storing grain at subterminals and country elevators, and variable costs of loading out grain at subterminals.

**Total costs of constructing and/or expanding an elevator**

Alternative investments with unequal life expectancies and costs are noncomparable unless they are transformed to an equivalent base. The method used in the Fort Dodge study to compare alternative investments was to express all investments in terms of an annual equivalent cost. Investment costs were transformed to an annual equivalent cost (AEC) by the
following equation:

\[
AEC = B(a/p)_n^i - V(a/f)_n^i
\]  

(3.6)

where \(B\) denotes the present cost or value of an investment, \(V\) is the salvage value at the end of the \(n^{th}\) year, \((a/p)_n^i\) is the capital recovery factor or annual equivalent worth of a present value discounted over \(n\) years at an interest rate of \(i\) percent, and \((a/f)_n^i\) is an annual equivalent worth of a future value discounted over \(n\) years at \(i\) percent (45, p. 99).

More specifically,

\[
(a/p)_n^i = \frac{i(1+i)^n}{(1+i)^n-1}
\]  

(3.7)

and

\[
(a/f)_n^i = \frac{i}{(1+i)^n-1}
\]  

(3.8)

The annual equivalent cost of investment \(B\) with salvage value \(V\) provides the investor the repayment, or recovery, of his initial outlay plus a return on the money invested at \(i\) percent.

Throughout the Fort Dodge study annual equivalent costs were computed using an interest rate of 10 percent. The ten percent discount factor was based on recommendation from railroad officials and elevator managers.

In selecting between alternative investment projects, the additional costs and revenues forthcoming from each alternative were considered regarding past expenditures on
distribution facilities as irrelevant or "sunk". Studies which ignore facilities that exist at the beginning of the planning horizon presuppose either costless mobility of resources or facilities that are completely divisable requiring no initial set-up costs. In the event that plant expansion is discontinuous or resources can not be moved without cost, then such studies may bias the solution in favor of new facilities.

In the Fort Dodge region there were 87 elevators and 690 miles of rail line in existence at the beginning of the planning horizon, 1970. Some elevators and rail lines were neither of the best location nor size to minimize variable assembly, handling, or distribution costs. Any savings, however, that may result from expansion and/or relocation must be weighed against the costs of adjustment.

To illustrate, consider an elevator already in existence handling two million bushels of grain annually. Assume an annual equivalent cost of $50,000 necessary to expand or relocate the existing facility to take advantage of lower variable assembly, processing, or distribution costs. The savings from expansion or relocation, given the same annual volume, would have to exceed two cents per bushel. In the event that the savings were less than two cents per bushel it would not be profitable to expand or relocate that facility. Failure to account for the sunk costs of existing facilities
may lead to recommendations not in the best interest of the industry.

The total cost of establishing a subterminal depends on the site or location. If a country elevator exists at \( L_{2i} \), then the cost of establishing a subterminal at \( L_{2i} \), by expanding existing facilities, will not be as great as establishing a subterminal at a location where grain handling facilities do not exist.

Minimum capacities required to receive, dry, and load out grain at subterminals were specified. In the event that receiving, drying, and load out capacity existing at a subterminal site in 1971 were less than the capacity requirements of a subterminal, then the following equations were used to estimate the total costs of establishing a subterminal.

The annual total cost of establishing receiving facilities for a subterminal located at \( L_{2i} \), if \( RRK > RK(.i,u) \), was estimated by Equation 3.9.

\[
\alpha_R(.i) = \$9842 + \$0.978 \times [RRK - RK(.i,u)] \tag{3.9}
\]

The annual total cost of establishing drying facilities at \( L_{2i} \), if \( RDK > DK(.i,u) \), was estimated by Equation 3.10.

\[
\alpha_D(.i) = \$2186 - \$7.986 \times [RDK - DK(.i,u)] \tag{3.10}
\]

The annual total cost of establishing load out facilities at \( L_{2i} \), if \( RLK > LK(.i,u) \), was estimated by Equation 3.11.
\[ aL(.i) = 5,296 + 1.769 [RLK-LK(.i,u)]. \quad (3.11) \]

The capacity to store commercial grain at an elevator during October 1980 was predetermined. The capacity to store commercial grain at an elevator during the months following October was determined by the solution of the model. Both country elevators and subterminals were allowed to expand storage capacity. The annual total cost of expanding storage capacity of country elevator \( h \) located at \( L_1 \)—denoted as \( aS(h.) \)—was estimated by Equation 3.12.

\[ aS(h.) = 8638 + 0.086 \sum ESK(h_s) \quad (3.12) \]

where the range of \( s \) includes only those periods for which \( ESK(h_s) < 0 \).

The annual total cost of expanding storage capacity of subterminal \( i \) located at \( L_2 \)—denoted at \( aS(.i) \)—was estimated by Equation 3.13.

\[ aS(.i) = 8638 + 0.086 \sum ESK(.i_u) \quad (3.13) \]

where the range of \( u \) includes only those periods for which \( ESK(.i_u) < 0 \). Thus, for both country elevators and subterminals, \( S1 = 8638 \) and \( S2 = 0.086 \).

Annual costs of establishing facilities to receive, dry, and load out grain at subterminals were estimated based on handling capacity existing in 1971 and minimum
capacity requirements of a subterminal. Minimum capacities required to receive, dry, and load out grain at subterminals were specified by elevator managers and elevator engineering consultants.

It was estimated that loading multiple-car train units at a subterminal would require a receiving capacity (RRK) of 15,000 bushels per hour; drying capacity (RDK) of 3,000 bushels per hour; and load out capacity (RLK) of 20,000 bushels per hour. Annual expansion costs of receiving, drying, and loading out grain at country elevators were assumed to be zero since all 87 country elevators considered in the model existed at the beginning of the planning horizon, 1971.

Variables in the expansion cost functions were defined in Chapter II. Capacities of facilities existing at the beginning of the planning horizon, 1971, were estimated from the questionnaires. Coefficients for the expansion cost functions were estimated by Baume1 et al. (4).

Expansion costs were estimated by synthetically constructing various size elevators and determining the coefficients through regression analysis. Appendix B contains expansion costs for receiving, drying, storing, and loading out grain in Tables B.2, B.3, B.4, and B.5.
Transportation Network

This section describes the transportation system used in the Fort Dodge area to transport grain from farms to terminal markets in 1971; and, presents alternative transportation systems for 1980. Maintenance costs for road and railways, operating costs for different modes of transportation, and a brief review of containerized and pipeline distribution systems are presented. Comparative energy requirements and pollution emission between trucks and trains are also discussed.

Road system

In 1971 there were 6,812 miles of rural roadway in the Fort Dodge area. An estimated 21 percent of the grain shipped from elevators was moved over the roadway by truck; and, of course, all of the grain assembled from farms to elevators was moved using the road network.

All roads in the Fort Dodge area were classified by six surface types of road which include: interstate rigid, other primary rigid, high flexible, intermediate flexible, surface treated flexible, and secondary unpaved.

Interstate rigid includes all interstate portland concrete cement paved roads. Only 23 miles of the 6812 miles of roadway were classified as Interstate Rigid. Other Primary rigid includes all primary portland concrete cement paved roads which account for 249 miles of roadway. High flexible
includes secondary portland concrete cement paved roads. Intermediate flexible includes all asphaltic concrete paved roads. Twelve percent of the total roadway was paved with asphalt. Surface treated flexible includes secondary low type bituminous surfaced roads and accounts for 112 miles. Secondary unpaved includes all dirt and gravel surfaced roads. Twenty-six percent of the rural roadway in the Fort Dodge area was dirt and gravel surfaced in 1972 (26).

The road net-work in the Fort Dodge area during 1970 and the road system as projected by the Iowa Highway Commission for 1980 are presented in Maps C.1 and C.2 in Appendix C.

Road maintenance costs For this report it was assumed that construction and maintenance costs for road surface and structures depend primarily on road use. Each of the six road pavement classifications as described above represent various road structures and, each pavement structure can withstand only a certain number of truck loads before resurfacing and/or maintenance is required.

The Iowa Highway Commission has developed construction and maintenance costs per truck-mile for different size trucks and by pavement type (27). The maintenance costs estimated by the Iowa Highway Commission were used for this study. The procedure used may be summarized as follows: The maintenance and resurfacing cost per truck mile was computed by dividing
the per mile cost of maintenance and resurfacing by the number of truck passes the pavement could handle before needing resurfacing. Road resurfacing and maintenance costs per truck per mile were calculated by this manner for different size trucks and pavement structure.

For the Fort Dodge area study it was assumed that grain was hauled from elevators in 800 bushel trucks. To account for the road resurfacing and maintenance costs resulting from trucks moving grain from elevator to elevator within the study area it was assumed that trucks were loaded with grain only one way. A 36 ton, or 800 bushel, three-axle tractor with tandem axle trailer hauling grain on an interstate freeway will produce road costs of approximately 0.3 cents per mile for resurfacing and 0.1 cents per mile for maintenance. An empty 800 bushel truck weighs only twelve tons and, of course, the road resurfacing and maintenance costs per mile from the empty truck are much less than the loaded truck. Table 3.8 presents, for different types of pavement, miles of roadway in the Fort Dodge area and the additional road-use cost that results from an 800 bushel truck transporting grain one mile and returning to origin empty.

The magnitude of additional costs of highway resurfacing and maintenance resulting from an elevator shipping all of its grain by truck can be illustrated by the following example: An elevator hauls 1.6 million bushels of grain a year to sub-
terminals or processing plants located, on the average 20 miles away. If trucking routes are chosen to avoid unpaved and low type bituminous surfaced roads, then the average road-use cost, weighted by the number of miles of different surface types in the Fort Dodge area, is seven cents per mile per round trip pass or $.035 per mile per pass. To haul 1.6 million bushels of grain with 800 bushel trucks, 2000 trips would be required. In this example the additional road-use cost to haul grain by truck from an elevator to destinations is $2,800 per year.

Table 3.8. Number of rural highway miles in 1972, and estimated additional annual highway construction and maintenance cost per mile per round-trip pass for a tractor with an 800-bushel tandem axle trailer by pavement type in the Fort Dodge, Iowa area (26, 27)

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Road Miles</th>
<th>Construction Cost</th>
<th>Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate rigid</td>
<td>23</td>
<td>$.003</td>
<td>$.001</td>
</tr>
<tr>
<td>Other primary rigid</td>
<td>249</td>
<td>.007</td>
<td>.001</td>
</tr>
<tr>
<td>High flexible</td>
<td>439</td>
<td>.020</td>
<td>.002</td>
</tr>
<tr>
<td>Intermediate flexible</td>
<td>799</td>
<td>.117</td>
<td>.002</td>
</tr>
<tr>
<td>Surface treated flexible</td>
<td>112</td>
<td>.385</td>
<td>1.226</td>
</tr>
<tr>
<td>Secondary unpaved</td>
<td>5190</td>
<td>.000</td>
<td>.042</td>
</tr>
</tbody>
</table>
Trucks are taxed to defray road-use costs. In 1971 a 36 ton tractor-trailer was required to pay $1260 for annual registration in the state of Iowa and a fuel tax of 8 cents per gallon for diesel and 7 cents per gallon for gas (50). Approximately 97 percent of the registration and fuel tax is used for road-use costs. If a truck travels four miles per gallon on diesel fuel and the road-use costs are $0.035 per mile, then the road and upgrading costs will be covered by the truck's registration fee and fuel tax up to 76,388 miles per year.

In this study, therefore, the additional road-use costs resulting from truck and/or wagon use were accounted for in the transport cost matrix by including fuel tax and registration fee.

**Trucking costs**

Various modes of transportation may be used to assemble the grain to elevators and distribute it to terminal markets. During the peak harvest months of October and November much of the grain is moved from farms to local elevators by tractor-wagon or by 300 bushel trucks. During the harvest months the fields are sometimes wet and it is often easier to assemble the grain by tractor-wagon than by large 800 bushel trucks.

Once harvesting pressures subside there is a greater incentive to use trucks capable of hauling greater distances
than the tractor-wagon. Thus, for this study it was assumed that during the peak harvest months tractor-wagons would be used to move grain from farms to elevators up to six miles; and grain hauled beyond six miles was shipped in 300 bushel trucks. During nonharvest months both 450 bushel trucks and tractor-wagons would be used. To move grain from elevators to other elevators within the area or to final markets it was assumed that 800 bushel trucks were used if grain is moved by road.

Costs of operating tractor-wagons, and various size trucks were estimated by Baumel et al. by a synthetic analysis of physical operations for the different vehicles (4). The cost of operating two 450 bushel wagons was estimated as $.0012 per bushel per mile. This estimate assumes that each wagon travels 1000 miles per year and that the average speed is 12 miles per hour. The wagons are assumed to have a life expectancy of 12 years and the only repair or maintenance required for the wagons is the cost of new tires at the end of six years. Wagons require no insurance or licensing fee. It was assumed that 12 percent of total tractor use was for grain shipment and only the variable costs of operating the tractor while hauling the grain were included. Driver's wages for driving a 140 horse-powered tractor was assumed to be three dollars per hour; and loading and unloading costs were assumed to be two dollars per trip.
The cost of operating a 300 bushel truck was estimated to be $.0036 per bushel per mile. The 300 bushel truck is used primarily on the farm. Thus, it was assumed that the truck would travel 2,000 miles per year at an average speed of 20 miles per hour. Average maintenance and repair costs were estimated to be $90 per year. A breakdown of the costs for the 300 bushel truck is included in Table B.6, Appendix B.

The cost of operating a 450 bushel truck was estimated to be $.0008 per bushel per mile; an 810 bushel truck was estimated to cost $.0006 per bushel-mile. For both the 450 bushel and 800 bushel truck it was assumed that each truck travels 55,000 miles per year. The purchase price and salvage of an 810 bushel tractor-trailer were assumed to be $31,300 and $10,900 respectively; for a 450 bushel truck $14,000 and $3,500 were used for the estimated purchasing price and salvage value. Both trucks were assumed to have a life expectancy of five years, and the annual equivalent cost was based on a 10 percent discount factor.

Annual license fees, insurance, loading and unloading costs, and management expenses for the 450 bushel and 810 bushel trucks were estimated to be $3,835 and $5,050 respectively. Variable operating costs including fuel, oil, tires, wages, repairs, and maintenance were estimated to be
$.203 and $.254 per mile for the 450 bushel and 810 bushel trucks.

The operating cost for an 810 bushel tractor-trailer truck for long distances was also estimated. Assuming one trip per day and an average round trip distance of 400 miles; an average speed of 55 miles per hour; and an average wage of $4.50 per hour, the operating cost per mile per bushel was estimated as $.00035.

Table B.6, Appendix B, presents the operating costs of various size trucks and tractor-wagons.

Nonrail shipments from the Fort Dodge area to the Gulf were assumed to be trucked to Dubuque, Iowa; elevated on a barge; then barged to the Gulf down the Mississippi River. Elevation charges at the river were assumed to be 3.8 cents per bushel. The per bushel costs of barging from Dubuque to the Gulf were estimated by Baumel et al. as 11.13 cents for corn and 11.93 cents for soybeans (4).

Trucking costs were verified through personal conversations with Umthum Trucking Company, a mid-western common carrier. Umthum estimated that in 1972 the average cost per truck per mile was 45 cents. The estimate was based on the annual costs of owning and operating 259 tractors and 373 trailers travelling 1.5 million miles per month. Assuming an 800 bushel truck, the cost per bushel was .0005.¹

Rail system

In 1971 seventy-nine percent of the grain exported from the Fort Dodge area was shipped by rail. The market areas to which the grain was shipped are reported in Table 3.5. Four rail companies provided the service to link the Fort Dodge area with terminal markets. The rail companies included the Chicago and North Western (C&NW); Chicago, Milwaukee, St. Paul and Pacific (CMSP&P); Chicago, Rock Island and Pacific (CRI&P); and the Illinois Central Gulf (ICG).

The rail network serving the Fort Dodge area in 1971 is presented by Figure 3.1. Within the area there were 690 miles of track. Of the 690 miles of line only 34 percent, or 233 miles, of the existing track was of sufficient grade and quality to handle fully loaded, 100 ton hopper cars. The remaining 457 miles of rail line had a carrying capacity of less than 263,000 lbs. and thus, were not capable of carrying loaded 100 ton covered hopper cars. Rail lines were classified as heavy lines if the rail line could handle loaded covered hopper cars; otherwise, the lines were classified as light rail lines.

In addition to the 457 miles of light rail in the Fort Dodge area, 58 miles of rail were also considered as branch rail lines. The rail line extending through Hamilton County serving elevators L138, L150, L160, and L171; and the rail line from Fort Dodge through Lohrville were considered
as branch rail lines and not a part of the major trunk rail system serving the area. Figure D.3 in Appendix D identifies the major trunk lines serving the Fort Dodge area.

**Rail upgrading costs** The cost of upgrading the light branch lines to handle loaded covered jumbo hopper cars depends upon many factors. The condition of the roadbed and cross ties, the weight of the rail, and the number of bridges or roads the line crosses are a few of the factors that influence the cost of upgrading a branch rail line. For most of the light branch rail lines in the Fort Dodge area in 1971, upgrading to handle loaded jumbo hopper cars would require adding ballast to the roadbed and replacing ties and anchors and increasing the weight of the rails from 60 or 80 pounds per yard to 90 or more pound rails.

The cost of upgrading different sections of rail line to handle fully loaded jumbo hopper cars in the Fort Dodge area have been estimated by several rail companies. Estimates of the upgrading costs were obtained by personal conversations with executives of those railroad companies. The branch line extending from Farnhamville to Gowrie, a distance of 5.6 miles, would cost 298,800 dollars to upgrade the line from 210,000 pounds carrying capacity to 263,000 pounds carrying capacity. Using a ten percent discount rate and a 25 year life expectancy, the annual equivalent cost of
upgrading this line would be 5,869 dollars per mile. The upgrading between Gowrie and Farnhamville would include new 90 pound rail, fifty percent new cross ties, removing the old rail, grading, new surface ballast, anchors, and labor.

The estimated cost of upgrading the rail line from Gowrie to Sibley, a distance of 54 miles, was 2.5 million dollars. Assuming a 25 year time horizon, at ten percent, the annual equivalent cost would be 5,093 dollars per mile. Since the line from Gowrie to Sibley was longer and probably more representative of the type and condition of lines requiring upgrading in the Fort Dodge area than the Farnhamville-Gowrie line, $5,093 was used to approximate the annual cost per mile of upgrading all light branch rail lines in the Fort Dodge area.

The salvage value of rail line was estimated as $2700 per mile for light rail and $4910 for heavy rail (20). Over 25 years, at 10 percent, the annual equivalent salvage values are $297 for light and $540 for heavy rail.

**Rail maintenance cost** To maintain a rail line at a given carrying capacity requires certain annual expenditures. Weeds need to be controlled; ditches and drains require cleaning; cross ties have to be replaced and tie bolts need to be tightened periodically.
The annual cost of maintaining a mile of rail line in the Port Dodge area in 1972 was estimated, by one of the railroad companies serving the area, as $2100. In addition to the $2100, railroads must also pay an estimated $2493 per mile per year to rehabilitate the exiting light lines in order to make them capable of safely handling 40-foot box cars (40b).

The estimated annual maintenance cost, net of taxes, of $2100 was found to be similar to an $1245.70 estimate based on a study by Gitlin (20). The Gitlin estimate does not, however, include the costs of public improvement maintenance and health and welfare costs as does the $2100 estimate.

Gitlin estimated that to clean spray, mow, grub or kill weeds and brush on track would cost $395.00 per mile each year. Cleaning the ditches and drains would cost $244.00 per mile each year; and to patrol the track, watch the bluff and right-of-way, and to rent a Sperry detector car would cost $40.80 per mile per year.

In the Gitlin study a survey was taken to determine the number of cross ties needed to be replaced each year per mile of track. The survey indicated that between 50 and 120 cross ties per mile per year required replacing to maintain a rail line. Using the average of 50 and 120 ties per mile per year; a purchase cost of $5.00 per tie; and $1.46 per tie for handling, unloading, and installation, the cost per year for
replacing cross ties was estimated as $549.10 per mile. Tightening tie bolts once every three years costs 42.00 dollars, or, using a ten percent discount rate, $16.80 per mile per year.

The annual cost of maintaining a rail line in the Fort Dodge area, excluding the annual property tax, was based on the estimate of one of the railroad companies serving the area and was assumed to be $2,100. The annual property tax was excluded from the annual cost of maintaining a branch rail line because the tax is ad valorem in nature and, as ruled by regulatory agencies, does "not constitute a savable expense in abandonment proceedings" (12, p. 269).

**Rail rates**

The rail tariffs available in the Fort Dodge area until the summer of 1972 were all single car rates. The single car rate is often referred to as a random car rate because one or more cars may be shipped randomly at the discretion of the shipper. Following the summer of 1972 other tariffs were introduced. The IC, for example, offered a special export rate to the Gulf if three or more cars were shipped as a unit. The C&NW introduced 50 and 25 car rates to export markets; the CRI&P railroad offered 5, 27, and 54 car rates; and the CMSP&P introduced 25 and 50 car rates.

Actual rail rates for shipping corn and soybeans during 1971 were used to analyze the economics of grain distribution in the Fort Dodge area for the 1970-1971 period. Various
tariffs were examined and the lowest published rates from elevators in the Fort Dodge area to markets were selected. Single car rates for intrastate movements were obtained from a published mileage rate tariff (23); and, in the event that corn rates were available but soybean rates were not, it was assumed that the rate for shipping soybeans, adjusted for weight differences, was the same as corn. Since rates were specified by mileage zones, the same rate was used for all elevators within a specified zone when shipping to any one of the markets located in another specified zone.

The 1980 random car rate was assumed to be identical to the 1971 single car rates. All elevators with access to a rail line, regardless of the carrying capacity of the line, had the option of using the single car rate.

It was assumed that by 1980 a 50 car rail rate would be available from the Fort Dodge area to all markets except markets in Iowa and Nebraska; and could be used only by sub-terminal elevators with access to rail lines capable of handling loaded hopper cars. The lower per bushel-mile rates offered to shippers when loading out 50 cars or unit trains rather than single cars was assumed to reflect various alleged savings in cost that result from shipping multiple cars as a unit over distances greater than those to local markets in Iowa and Nebraska.

Quantity discounts in shipping may be justified for several
reasons. The number of switchings and couplings are reduced as the number of cars shipped as a unit increase. The costs of control and coordination are also reduced as the number of cars shipped as a unit from origin increase. A car shipped separately from origin to market requires, to a large extent, the same control and coordination as fifty cars shipped as a unit. And, in most cases, single cars experience greater delays in route than unit trains.

Single cars are delayed in switching yards until they can be linked with other cars going to the same destination; and, during this delay they are sometimes "lost" or "forgotten." Unit trains, on the other hand, are not easily lost in switching yards and avoid the delays of linking with other cars going to the same destination.

With fewer switchings, couplings, and delays of car coordination and linkage, unit trains usually have a faster turn around time than single cars. In 1973, for example, the average time required for a single car to go from Fort Dodge to the Gulf and return varied between 20 and 24 days; the average turnaround time for a fifty-car train to travel the same route varied between seven and ten days. Improved turnaround time, of course, also reduces railroad costs through increased car utilization.

The 1972 published fifty car rates, which were specified
for export markets only, were used to estimate the 1980 fifty car rates from all elevators to all markets except central Iowa, Eastern Iowa, and Nebraska. Rates to non-export markets were estimated by multiplying the elevator to Chicago export rate by the miles from the elevator to the nonexport market divided by the miles from the elevator to Chicago.

**Rail abandonment options**

Several abandonment and/or upgrading options are possible for 1980 in the Port Dodge area. One option would be to upgrade all light branch lines to handle jumbo hopper cars. This option would provide all elevators the opportunity of shipping grain in multiple-hopper car shipments with the corresponding lower shipping rates per bushel-mile. Offsetting the lower rate advantage from this option are the costs that are necessary for upgrading the branch rail lines and expanding elevator load-out facilities.

A second rail network option would be to maintain the existing trunk and branch lines at their 1971 handling capacities. The light branch lines would preclude elevators using those lines from shipping loaded hopper cars. Either box cars or partially loaded hopper cars could be used to move the grain by rail on a light branch line, but the shipping rate would be higher than the shipping rate of elevators.
shipping on heavy trunk lines.

In addition to shipping directly to terminal markets by rail, elevators located on light branch lines may also truck grain to sub-terminal elevators using trunk lines for transhipment to terminal markets. For this study, as previously described, elevators on light branch lines are defined as county elevators; elevators with capacity to receive from country elevators, facilities to load-out multiple-hopper car shipments, and located on rail lines capable of handling loaded hopper cars are defined as sub-terminal elevators.

A third option for rail abandonment and/or upgrading in the Fort Dodge area would be to abandon all existing branch lines and retain only major trunk lines that as of 1971 had the capacity to handle loaded hopper cars. This option, which would eliminate 75 percent of the rail lines in the area, would not be inconsistent with the recommendations and proposals of the four rail companies servicing the area. This option would eliminate the annual maintenance cost of branch lines; provide some revenue from the salvage value of the abandoned lines; and, with the reduction of elevators requiring rail service, the number of train stops, switchings, and problems of coordination may also be reduced.

Elevators located on heavy lines whose volume of grain
increases as a result of the branch line abandonment would be able to take advantage of not only the economies of scale in handling grain as well as the economies of scale in rail shipping. The savings that may result from any rail abandonment must, however, be evaluated in light of the increased cost of trucking grain from country elevators to either sub-terminals or to final destinations.

A fourth option for rail abandonment and/or upgrading would be a combination of the above. Some branch lines could be abandoned; others upgraded; and some could be left at their 1971 carrying capacity. Figure D.4 in Appendix D delineates a rail net-work option that reflects the interests of many of the elevator managers in the Fort Dodge area.

The additional costs of upgrading and/or maintaining 457 miles of light and 58 miles of heavy branch rail lines in the Fort Dodge area for different rail net-work options, may be approximated by assuming annual equivalent costs of $2100 per mile for maintenance, excluding property tax, $2493 per mile for rehabilitating light rail lines, and $5,093 per mile for upgrading a rail line. Based upon these costs, Option I would cost $3,409,000 per year to upgrade and maintain all 515 miles of branch rail lines in the area. It would cost $2,201,000 per year to maintain the 515 miles of branch rail line as specified by Option II; in Option III all branch lines are abandoned and, thus, there would be no annual
$167,000. Option IV would cost $44,000 per year to maintain 34 miles of light rail. Salvage value for Option IV would be $148,000.

In Appendix D the four rail network options are delineated by Figures D.1 through D.4.

**Containerized and pipeline systems**

In addition to the traditional means of transporting grain by rail and truck, other methods of grain transportation are possible. Transporting grain by containers or through pipes are two methods that are stimulating thought and interest in the grain distribution industry.

A containerized grain distribution system involves loading a container with grain either at the point of production or at an assembly point and then transporting the container by truck, rail, barge, or any truck-rail- barge combination to a final destination. In 1973 a trucking firm in Hospeth, Iowa hauled grain in containers from Marcus, Iowa to Sioux City, Iowa, a distance of 45 miles. In Sioux City the grain containers were transferred from the trucks and loaded on flat rail cars to be transported to the West Coast. Special permits, however, were required and specific routes were specified by the Iowa Highway Commission for the trucking firm to transport the containers because the legal maximum weight for axle loads was exceeded.
Baumel and Wallize discuss the advantages and disadvantages of using containers to move bulk grains (6). From their analysis they conclude that the greatest potential for containers appears to be in moving high value specialty grain products.

The Trans-Southern Pipeline Corporation estimated the cost of transporting grain through a pipeline system (16). The system was designed to move 118 million bushels of grain per year 200 miles from Fort Dodge to Dubuque, Iowa, and backhaul fertilizer at a minimum ratio of 4 to 1, corn to fertilizer. The system would cost, in 1973, an estimated $170,507,000 for materials and installation and $8,244,822 per year for operating costs.

To estimate the cost per bushel per mile of transporting grain from Fort Dodge, one-fifth of the total power costs of $6,089,342, included in the annual operating cost estimate, was subtracted to account for the costs associated with backhauling fertilizer. Discounting the capital requirements at 10 percent over 50 years and adjusting the operating costs for fertilizer hauling operations, the annual equivalent cost for set-up and maintenance of the pipeline would be $.001 per bushel per mile.

The cost estimate of Trans-Southern Pipeline Corporation does not include right-of-way costs, sales tax, or storage facilities located at loading or unloading stations. The
pipeline would consist of two 48" pipelines housing a conveyor-belt system.

The Goodyear Tire and Rubber Company has also considered the feasibility of shipping grain by a covered conveyor belt system. The estimated cost of shipping grain 255 miles from Storm Lake, Iowa to McGregor was .00098 dollars per bushel per mile (19). Both the Goodyear Tire and Rubber Company cost estimate and the estimate of Trans-Southern Pipeline Corporation exceed the 1972 trucking and rail rates for shipping grain over the same distance.

Energy Requirements and Pollution Emissions

Approximations for relative pollution levels between trucks and rail carriers have been made by Battelle (14). An estimation was made of the air-pollutant emissions from locomotive and truck engines which included carbon monoxide, unburned as partially burned hydrocarbons, oxides of nitrogen, and oxides of sulfur. The study concludes that based on a per-ton-mile, railroad exhaust emissions are substantially lower than truck exhaust emissions. It was estimated that railroad emissions in 1970 were 1.03 grams per net ton-mile. Truck exhaust emissions were estimated as being 3.7 times as high as those of railroad locomotives or 3.76 grams per net ton-mile. It was estimated that by 1980 railroad emissions would decrease to .91 grams per net ton-mile.
because of the economies of scale associated with longer trains; and, truck emissions would increase to 4.06 grams per net ton-mile because of increasing average truck speeds.

The impact of rail abandonment on air pollution resulting from additional truck emissions may be illustrated by considering an elevator, in 1980, transshipping 1.6 million bushels (44,800 tons) of grain 20 miles by truck which prior to the rail closure shipped all grain by rail. Prior to the rail abandonment 815,360 grams (44,800 x 20 x .91) of exhaust emissions were produced transporting the grain 20 miles by rail. In 1980, 3,637,760 grams (44,800 x 20 x 4.06) of exhaust emission would result from trucking the 44,800 tons of grain over the same distance. The additional air-pollutant emissions, therefore, for this one elevator would be 2,822,400 grams.

Battelle has also estimated the energy requirements for freight movement by truck and by rail (15). It was estimated that 280 net ton-miles of freight per gallon may be hauled by rail and 77 net ton-miles of freight per gallon by 5-axle diesel-truck. In light of the concern for the depleting reserves of nonreplaceable energy resources, the following illustration is of interest: Using the previous example of an elevator transshipping 1.6 million bushels (44,800 tons) of grain 20 miles by truck which prior to the closing of its
rail line shipped all grain by rail, the additional energy requirements resulting from the rail abandonment would be 8,436 gallons.
CHAPTER IV. RESULTS AND CONCLUSIONS

Results

The economic analysis of alternative rail-based grain distribution systems was based on the transhipment plant-location model as specified in Chapter II and data as presented in Chapter III. In Chapter IV the investment requirements and maximum joint net revenue for alternative rail line networks in the Fort Dodge area in 1980 are presented. As suggested previously, the transhipment plant-location routing algorithm was applied to the 1970-71 grain distribution system of the Fort Dodge area. Results of this application are also presented in Chapter IV.

The results are followed by a concluding section which presents policy implications and recommendations regarding rail line abandonment; suggests possible extensions of the transhipment plant-location model; and, provides a brief summary of the Fort Dodge area study.

Maximum joint net revenue: 1980

Alternative rail-based grain distribution systems were evaluated by comparing the maximum joint net revenue of producers for various rail line networks. For each rail line network option, the optimal number, size, and location of plants were determined. Increasing the number of plants lowered the costs of grain assembly and distribution. The transportation savings were balanced against the increased
capital requirements of the additional plants.

Alternative rail line systems vary in cost to establish and maintain. A rail line network with a high density of lines is more costly to establish and maintain than a system with relatively fewer lines. A rail system with many heavy rail lines, however, provides more potential subterminal sites than a rail system with only a few main rail lines. Thus, in addition to the investment requirements resulting from increasing the number of subterminals, the transportation savings were also balanced against the costs of upgrading and maintaining the rail lines necessary to sustain the additional plants.

**Rail line Option I** For the first rail line option, all light rail lines existing in 1971 were upgraded to handle multiple-car shipments. This option provided the largest number of potential subterminal sites.

The maximum joint net revenue estimated for rail line Option I was $225,592,000 per year using projected 1980 grain volumes. This solution included 21 subterminals located at $L_{21}, L_{22}, L_{23}, L_{24}, L_{25}, L_{26}, L_{29}, L_{210}, L_{211}, L_{212}, L_{213}, L_{214}, L_{215}, L_{219}, L_{220}, L_{221}, L_{222}, L_{224}, L_{225}, L_{226},$ and $L_{230}$. The next best solution for 21 subterminals replaced $L_{20}$ with $L_{13}$. The difference between the net revenues for these two solutions was $25,000.
The best of 20 subterminals provided $225,583 thousand joint net revenue, or $9,000 less than the best location of 21 subterminals; and the best location of 22 plants provided $225,581,000. The best location of 22 plants was the same as 21 except for the addition of L227.

Rail line Option II For the second rail line option, the rail line system existing in 1971 was maintained to 1980. Thus, Option II provided fewer potential subterminal sites than Option I; but, country elevators located on light rail lines were still permitted to ship by rail in single-car shipments; and, the rail system of Option II required no upgrading costs.


Total net revenue for n = 17, 18, 19, 20, and 21 subterminals was also determined as $226,574; $226,523; $226,495; $226,444 and $226,424 thousand. The difference between the best of 15 plants and the best location of 21 plants for Option II is $192,000. The difference between the best
location of 21 plants for option II and the best of 21 plants for Option I is $832 thousand. And the difference between Options I and II in total net revenue is $1,024,000 or .87 cents per bushel.

**Rail line Option III** For the third rail line option, all light rail lines and 58 miles of heavy rail were abandoned. Subterminal sites were restricted to the major truck rail lines serving the Fort Dodge area. Of all rail line options evaluated, the rail line network of option III was the least expensive to establish and maintain; in fact, $167,000 of annual revenue were generated from the salvage value of the abandoned rails.

The maximum joint net revenue for Option III was less than 1 percent higher than the net revenues of Options I and II. The best location of 14 plants provided $228,887 thousand joint net revenue for Option III. The 14 subterminals were located at L_{21}, L_{22}, L_{23}, L_{24}, L_{25}, L_{26}, L_{29}, L_{213}, L_{216}, L_{219}, L_{220}, L_{222}, L_{225}, and L_{229}. The best of 13 plants provided $228,768 thousand; and the best location of 15 plants provided $228,872 thousand joint net revenue. Thus, for, option III, the optimal number of plants is 14 as compared to 21 for Option I and 15 for Option II.
Rail line Option IV

Comparing only rail line Options I, II, and III, one would be tempted to conclude that the abandonment of all light and heavy branch rail lines in the Fort Dodge area would be consistent with maximizing joint net revenue of producers. As the number of miles of heavy rail lines decreased from 690 miles in Option I to 175 miles in Option III, maximum joint net revenue of producers increased from $225,592 thousand to $228,887 thousand.

In Option IV, however, the branch line from Fort Dodge to Moorland (L221); and the branch line serving L218, L150, L223, and L171 were added to the rail line network specified by Option III. By adding these two rail lines the maximum net revenue increased from $228,887 thousand in Option III, to $228,894 thousand in Option IV. The optimal number of plants as compared with Option III increased by one, adding L223, and L221 replaced L216. L221 replaced L216 not because L221 was necessarily geographically preferable; but, because a new subterminal would be required at L216 costing $91,347 per year, as compared to an annual investment of $80,880 required to upgrade existing facilities at L221.

Two additional rail line options were also considered in evaluating the influence of alternative rail line systems on joint net revenue. In both cases, however, the maximum joint net revenue was less than that for either Options III or IV.
In one case the rail line from $L_{21}$ to $L_{20}$ was upgraded. Subterminals $L_{21}$, $L_{27}$, and $L_{30}$ were added to the optimal number of Option IV and joint net revenue dropped to $228,540. And the extension of the rail line from $L_{21}$ to $L_{24}$ also added more cost than revenue to joint net revenue.

**Annual investment requirements**  
In Table 4.1 the investment requirements and maximum joint net revenue for alternative rail line networks in the Fort Dodge area are presented. The distribution system specified by Option III required less investment in handling facilities and rail lines than any of the other options. The 14 subterminals of Option III required investments of $172,000 for elevator receiving facilities; $191,000 for drying facilities; and $336,000 for load out facilities. The expansion of storage facilities for all elevators and subterminals to meet 1980 demand required an investment of $3,906,000. Since all light lines and 58 miles of heavy branch lines were abandoned in Option III, an annual flow of $167,000 was generated from the salvage value of the abandoned rail lines. Thus, the total annual investment necessary to implement the rail-based grain distribution system of Option III was $4,438,000.

The investment requirements of Option IV were greater than those of Option III by $157,000 per year. Adding 34 miles
Table 4.1. Estimated annual investment requirements and maximum joint net revenue for alternative rail line networks in Fort Dodge, Iowa, area, in thousands of dollars

<table>
<thead>
<tr>
<th>Rail Line Options</th>
<th>( \lambda_{mn1} )</th>
<th>( \lambda_{mn2} )</th>
<th>( \lambda_{mn3} )</th>
<th>( \lambda_{mn4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment Requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevator Receiving</td>
<td>295</td>
<td>192</td>
<td>172</td>
<td>192</td>
</tr>
<tr>
<td>Elevator Drying</td>
<td>312</td>
<td>207</td>
<td>191</td>
<td>207</td>
</tr>
<tr>
<td>Elevator Storage</td>
<td>3,906</td>
<td>3,906</td>
<td>3,906</td>
<td>3,906</td>
</tr>
<tr>
<td>Elevator Loadout</td>
<td>588</td>
<td>367</td>
<td>336</td>
<td>367</td>
</tr>
<tr>
<td>Rail Net Work</td>
<td>8,409</td>
<td>2,201</td>
<td>-167</td>
<td>-77</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8,510</td>
<td>6,873</td>
<td>4,438</td>
<td>4,595</td>
</tr>
<tr>
<td>Maximum Net Revenue</td>
<td>225,592</td>
<td>226,616</td>
<td>228,887</td>
<td>228,894</td>
</tr>
</tbody>
</table>

\( \lambda_{mn} \) denotes the optimal number and location of subterminals and country elevators given the \( r \)th rail line network. The four rail line options representing \( r = 1,2,3, \) and 4 are presented in Appendix D.

of rail line to Option III, however, permitted the possibility of using two more subterminals, and provided two other country elevators direct access to a rail line. With the additional subterminal sites provided by Option IV, the total assembly and distribution costs were lowered by $164,000 per year. Thus, the additional investment required to implement Option IV relative to Option III increased net revenue from $228,887 thousand to $228,894 thousand.
thousand per year.

Option I required the greatest expenditures on elevator handling facilities and rail line maintenance and upgrading. An annual investment of $8,510,000 was required to implement a rail system capable of sustaining 21 subterminals. The large number of subterminals, of course, reduced the assembly costs of shipping grain from origins to subterminals, and from country elevators to subterminals. For Option I the annual revenue net of investment requirements was $225,592,000 compared to $226,616,000 for Option II. In this case, the additional savings resulting from upgrading all light rail lines existing in 1971 were less than the additional costs.

Routing of grain over time and space The routing of grain from farms to elevators varied by month and by the rail-based grain distribution system being evaluated. During the first month, regardless of the distribution system, all elevators were approximately filled to capacity. During the second month of harvest some country elevators were bypassed and grain was shipped from origins directly to subterminals. Other origins shipped grain to country elevators to be stored and transhipped to subterminals at a later date. This required some country elevators to expand storage facilities. Figure 4.1 shows the spatial flow of corn from origins to country elevators and subterminals in November,
given the best number and location of subterminals for Option IV.

In December, grain coming from farms was shipped directly to subterminals, by-passing all country elevators. Grain received at subterminals during December was transhipped immediately to final destinations. Figure 4.2 shows the spatial flow of corn from farms during the month of December when the rush of harvest had subsided, given the best location and number of plants for Option IV.

The flow of grain from the Fort Dodge area for Option IV is summarized in Tables 4.2 and 4.3. From Option IV, nearly 27 percent of the grain shipped from the Fort Dodge area goes to local markets in Central Iowa. Chicago domestic received 60.8 percent of the grain primarily because of the assumption that by 1980 Chicago markets will be capable of receiving 50 car shipments. Export markets received 9.9 percent of the grain based on the 1971 price level.

The temporal flow of grain from the Fort Dodge area for Option IV centers basically around the two months of January and July. Within the first four months of October, November, December, and January, 50.7 percent of the grain was shipped out of the Fort Dodge area. During the last four months, 6.3 percent was shipped during June; 36.6 during July; 3.3 during August; and 3.1 during September.

Restrictions were not placed on the capacity of the
Figure 4.1. Estimated flow of commercial corn from origins in the Fort Dodge area to country elevators and/or subterminals in the Fort Dodge area during November, given Option IV.
Figure 4.2. Estimated flow of commercial corn from origins in the Fort Dodge area to country elevators and/or subterminals in the Fort Dodge area during December, given Option IV.
railroad and trucking industry to haul grain from the Fort Dodge area. The temporal flow of grain, therefore, may be interpreted as the seasonal demand for rail and truck transportation, given no seasonal variations in rates.

Table 4.2. Percent of commercial corn plus soybean shipments from the Fort Dodge area by market as estimated from an elevator questionnaire for 1970 and as determined by a plant location model for 1970 and 1980, rail line Option IV

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Iowa</td>
<td>13.5</td>
<td>29.6</td>
<td>26.8</td>
</tr>
<tr>
<td>Eastern Iowa</td>
<td>27.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Chicago Export</td>
<td>16.5</td>
<td>9.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Chicago Domestic</td>
<td>7.7</td>
<td>48.8</td>
<td>60.8</td>
</tr>
<tr>
<td>Central Illinois</td>
<td>7.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Milwaukee Export</td>
<td>5.0</td>
<td>4.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Milwaukee Domestic</td>
<td>3.4</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Kansas</td>
<td>5.2</td>
<td>0.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Nebraska</td>
<td>3.3</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Missouri</td>
<td>2.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Gulf</td>
<td>7.9</td>
<td>4.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Total Percent</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

a No commercial grain was shipped from the Fort Dodge area to export markets at Norfolk and Portland.

b Estimated from Table 3.4.

c Based on the optimal locational pattern of elevator and rail lines.
Table 4.3. Percent of commercial corn plus soybean shipments from the Fort Dodge area by month as estimated from an elevator questionnaire for 1970 and as determined by a plant location model for 1970 and 1980, rail line Option IV

<table>
<thead>
<tr>
<th>Month</th>
<th>Census&lt;sup&gt;a&lt;/sup&gt; 1970</th>
<th>Model 1970</th>
<th>Model 1980&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>4.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>November</td>
<td>5.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>December</td>
<td>4.0</td>
<td>0.0</td>
<td>3.8</td>
</tr>
<tr>
<td>January</td>
<td>7.3</td>
<td>30.6</td>
<td>45.6</td>
</tr>
<tr>
<td>February</td>
<td>5.8</td>
<td>2.1</td>
<td>1.3</td>
</tr>
<tr>
<td>March</td>
<td>8.3</td>
<td>1.4</td>
<td>0.0</td>
</tr>
<tr>
<td>April</td>
<td>7.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>May</td>
<td>11.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>June</td>
<td>16.2</td>
<td>11.6</td>
<td>6.3</td>
</tr>
<tr>
<td>July</td>
<td>14.7</td>
<td>37.7</td>
<td>36.6</td>
</tr>
<tr>
<td>August</td>
<td>10.0</td>
<td>9.9</td>
<td>3.3</td>
</tr>
<tr>
<td>September</td>
<td>4.5</td>
<td>7.6</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>Total Percent</strong></td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup>Estimated from Table 3.5.

<sup>b</sup>Based on the optimal locational pattern of elevators and rail lines.
Social costs of rail abandonment. From the transshipment plant-location model it was determined that the abandonment of some rail lines in the Fort Dodge area would increase joint net revenue of producers. Maximum joint net revenue of producers given the locational pattern of 690 miles of rail line specified by Option II, was $226,616,000. In Option IV, 257 of the 690 miles of rail line existing in 1971 were abandoned. Closing 257 miles of branch rail lines increased joint net revenue $2,278,000 over the $226,616,000 of Option II.

Closing a rail line, however, imposes various costs on society. The additional use of the road system by trucks resulting from rail abandonment adds to road congestion, and requires additional public investment to upgrade and maintain the road network. Increased truck usage may also increase the noise and smoke pollution around the road system, and may also result in an increase in energy requirements to transport grain. As stated by Judge Reidy: "The record is persuasive that the alternate mode of transportation which would remain after abandonment, motor carriage, has a greater polluting effect than rail. It also consumes greater energy and increases noise pollution. While admittedly that total impact is likely to be insubstantial, nevertheless there will be some adverse environmental effect" (3). In the Fort Dodge study the additional costs of upgrading and main-
taining the road network, 2) energy requirements, and 3) pollution emissions resulting from the abandonment of rail lines may be estimated from the solution of the model.

For each rail line option, the model determined the optimal routing of grain from origin to final destination. From the solution of the model, therefore, the volume of grain hauled from elevators by truck to specific locations was determined. In Option I where all light rail lines were upgraded, 7,196 thousand ton-miles of grain were hauled by truck from country elevators. In Option I all of the grain shipped by truck from country elevators was hauled to subterminals to be transhipped by rail in unit trains to final destinations.

In Option II the optimal number of subterminals was 15 as compared to the 21 subterminals of Option I. Thus, some country elevators transhipping grain by truck were forced to haul grain further in Option II than in Option I. In Option II, 10,780 thousand ton miles of grain were hauled by truck from country elevators to subterminals.

In rail Options III and IV some branch rail lines were abandoned and country elevators shipped grain by truck to both subterminals and to final destinations. Total ton-miles of grain hauled by truck from country elevators in Option III and IV were 48,648 thousand and 46,777 thousand respectively. The estimated flow of commercial corn received at country elevators during October and November, and shipped from
country elevators by truck to subterminals during January, given rail line Option IV is presented in Figure 4.3.

By knowing the ton miles of grain hauled by truck from elevators for different rail line options it was possible to estimate some of the social costs resulting from rail abandonment. Costs of using the road system within the Fort Dodge area, due to trucks hauling grain from country elevators, was estimated for each rail line option. The upgrading and maintenance costs of the road system increased from $3,352 thousand in Option II to $9,550 thousand in Option IV. In Option IV 257 miles of the 690 miles of rail line existing in 1971 were abandoned. Road use costs for Options I and III were estimated as $2,553,000 and $9,775,000.

As discussed in Chapter III, trucks require more gallons per net ton-miles of grain hauled than do trains. As rail lines are abandoned, causing an increase in net ton-miles of grain hauled by trucks, more energy is required to ship grain than prior to the abandonment. The total estimated diesel fuel requirements to truck grain within the Fort Dodge area from elevators was 93,000 gallons for Option I; 140,000 gallons for Option II; 632,000 gallons for Option III; and 607,000 gallons for Option IV.

The increase in net ton-miles of grain hauled by truck between rail line Option II and Option IV is 35,997,000. The
Figure 4.3. Estimated flow of commercial corn received at country elevators during October and November, and shipped from country elevators to subterminals during January, given rail line network Option IV, 1980.
increase in net ton miles hauled by truck requires 467,000 gallons of fuel. Shipped by train, 35,997,000 net ton miles requires 129,000 gallons of fuel. The increase in fuel requirement, thus, between Option II and IV is 338,000 gallons.

As discussed in Chapter III, it has also been estimated that pollution emissions are greater for trucks per net ton-miles than for trains. The total estimated pollution emissions within the Fort Dodge area due to trucks hauling grain from elevators was 29,216 thousand grams for Option I; 43,767 thousand grams for Option II; 197,506 thousand grams for Option III; and 189,915 thousand grams for Option IV.

The increase in truck pollution emission between rail Option II and IV is 146,148 thousand grams. The decrease in train pollution emissions between Option II and III is 32,997 thousand grams. The net increase, therefore, of pollution emissions resulting from abandoning 399 miles of rail line from Option II is 113,151 thousand grams.

The transhipment plant location model specified in Chapter II accounts for the social costs of upgrading and maintaining the road system, and the relative difference in fuel requirements for trucks and trains. The social costs of upgrading and maintaining the road system were internalized by including an estimated road use cost in the marginal cost of trucking grain.

In light of recent concern regarding fuel shortages,
the additional energy requirements resulting from rail line abandonment could play a deciding role in rail line abandonment regulations. The relative difference in fuel requirements between truck and rail transportation was accounted for by assuming that the market price of fuel reflects both private and social costs. Fuel costs are included in the marginal costs of shipping grain by truck and rail. In the event that the market price of fuel failed, for example, to account for potential fuel shortages, the marginal costs of transportation used in the transhipment plant-location model would require adjusting.

In Table 4.4 the estimated net ton-miles of grain hauled within the Fort Dodge area by trucks from elevators are presented for various rail line options. Table 4.4 also presents the total road upgrading and maintenance costs, energy requirements, and pollution emissions within the Fort Dodge area due to trucks hauling grain from elevators.

**Maximum joint net revenue: 1970**

The 1970-71 grain distribution system was taken as given and the transhipment plant-location model was used to estimate the flow of grain over time and space to maximize the 1970-71 joint net revenue of producers in the Fort Dodge area. The purpose of this application was to compare an estimate of actual 1970-71 grain flows with the flows
Table 4.4. Estimated net-tong miles of grain hauled by truck from elevators; road upgrading and maintenance costs, energy requirements, and pollution emissions from trucks hauling grain from elevators for alternative rail line networks in the Fort Dodge, Iowa, area, in thousands of units.

<table>
<thead>
<tr>
<th>Rail Line Options</th>
<th>$\lambda_{m1}$</th>
<th>$\lambda_{m2}$</th>
<th>$\lambda_{m3}$</th>
<th>$\lambda_{m4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net ton-miles</td>
<td>7,196</td>
<td>10,780</td>
<td>48,647</td>
<td>46,777</td>
</tr>
<tr>
<td>Road costs (dollars)</td>
<td>2,553</td>
<td>3,352</td>
<td>9,775</td>
<td>9,550</td>
</tr>
<tr>
<td>Energy requirements$^b$ (gallons)</td>
<td>93</td>
<td>140</td>
<td>632</td>
<td>607</td>
</tr>
<tr>
<td>Pollution emissions$^c$ (grams)</td>
<td>29,216</td>
<td>43,762</td>
<td>197,506</td>
<td>189,915</td>
</tr>
</tbody>
</table>

$^a_{\lambda_mnr}$ denotes the optimal number and location of sub- terminals and country elevators given the $r$th rail line network.

$^b_{(Net\ ton\text{-}miles)}(1/77)$.

$^c_{(Net\ ton\text{-}miles)}(4.06)$.

Projected by the model.

The temporal and spatial flows as determined from the questionnaires and plant-location model are presented in Tables 4.2 and 4.3. Table 4.3 presents the percent of commercial corn plus soybean shipments from the Fort Dodge area by month. And, Table 4.2 presents the percent of commercial corn plus soybean shipments from the Fort Dodge area by market.
From the questionnaires it was estimated that 21.4 percent of the grain was shipped out of the Fort Dodge area by rail during the months of October, November, December, and January. During the same four month period the model suggested that 30.6 percent of the grain to be shipped out in order to maximize joint net revenue. During the last four months of June, July, August, and September, 66 percent of the grain was shipped as determined by the model compared to 45.4 percent as estimated from the questionnaire.

The spatial distribution of grain from the Fort Dodge area as determined by the model also differs somewhat from the flows of grain as estimated from the questionnaire. From both methods of estimation the majority of grain flows to Iowa and Illinois. From the questionnaire, 40.6 and 31.7 percent of the grain shipped by rail from the Fort Dodge area moved to destinations in Iowa and Illinois respectively. The solution of the model suggests 29.6 percent to remain in Iowa and 58.4 percent to be shipped to Illinois to maximize joint net revenue of producers.

Differences between actual flows of 1970-71, as determined from the questionnaire, and flows as determined by the transhipment plant-location model may be due to several reasons: For the model, the monthly prices were taken as given and known with certainty. Prices, however, vary within the
month both temporally and spatially. And, prices at destinations may be neither independent of volume nor known for certain in the future. And secondly, the transportation costs from elevators to final destinations were taken as given. Capacity limitations of the transportation system outside of the specified region were not explicitly taken into account.

Conclusions

Policy implications and recommendations

Rail line abandonment regulation is concerned with activities and elements influenced by rail abandonment that affect "public convenience and necessity" and railroad companies seeking certificates of approval. The range of activities affected by rail abandonment relative to "public convenience and necessity" has typically been identified on a case by case basis.

The disadvantages to the public brought about by rail line abandonment are weighed and balanced against the advantages that would accrue to the railroad seeking the abandonment. The interests of the public are usually expressed in qualitative terms. The interests of the railroad carriers are typically expressed in quantitative terms. Railroad carriers attempt to justify abandonment by considering the operating expenses and revenues generated on the line sought to be abandoned. Thus, a quantitative analysis of
rail carrier interests are usually balanced against interests of the public expressed in qualitative terms. Such a lack of quantification requires subjectivity and judicial discretion in balancing the advantages and disadvantages of rail line abandonment that may lead to inconsistent regulation.

This study has shown the feasibility of quantifying, to a large extent, the impact of rail abandonment. The savings that would accrue to the rail road from abandonment were weighed against the additional costs to the producers of the area due to the closure of various rail lines. The grain distribution industry was considered as a system and, thus, the impact of rail abandonment on inter and intramodal competition was taken into account.

Quantification of the impact of rail line abandonment not only helps to identify the optimal rail line system; but, information is also obtained regarding the range over which maximum net revenue is relatively insensitive to structural changes in the distribution system. It is of interest to note that the difference between the maximum net revenue of the best rail network option, Option IV, and the rail option with the lowest net revenue, Option I, was $3,302,000 per year. That is, the best of Option IV was 1.02 percent higher than the best of Option I. On a per bushel basis, the difference between Option IV and I was 2 cents.

For any given rail network option, the difference between
the best number of plants and a sub-optimal number of plants is also of interest. The optimal number of plants for Option II was 15. Having 14 and 16 plants at the best location decreased net revenue by only $6,000 and $17,000 respectively per year. The difference between the best location of 21 subterminals and 15 subterminals, given Option II, was only $192,000, or .08 percent of the maximum net revenue of Option II.

Thus, maximum joint net revenue in the Fort Dodge area varies, at the most, only 1 or 2 percent over a wide range of plant numbers and rail line options. Such information is important to those responsible for regulating the abandonment of rail lines. Knowing that joint net revenue is only slightly influenced by changes in plant numbers or locations of rail lines, facilitates regulatory officials in making subjective judgments regarding the influence of factors difficult to quantify such as safety, pollution, and oligopoly power.

The scope of abandonment activities subject to Interstate Commerce Commission regulation is nearly all encompassing from the standpoint of the railroad industry. From the standpoint of the transportation industry, however, the scope is relatively narrow. Intermodal competition, for example, plays an important role in determining the supplies of resources available for each mode to transport. The increasing use of
motor carriers is often a major cause of rail line abandonment. Even though the I.C.C. is an intermodal regulatory agency, intermodal regulation presently falls beyond the scope of rail abandonment regulation.

The method of analysis used in this study permits not only an evaluation of the impact of rail abandonment on inter and intramodal competition but it also provides the tools to evaluate the regulation of inter and intramodal competition on rail abandonment. Through sensitivity analysis, one may determine the range over which rail rates may vary for stations located along lines sought to be abandoned without affecting the flow of grain and/or optimal number, size, and location of handling facilities.

Depending upon the elasticity of demand with respect to rail rates, the I.C.C. could permit railroads to raise or lower rail rates along unprofitable lines to generate sufficient revenue to meet expenses. Such a policy may be appropriate if it were in the "public interest and convenience" for the I.C.C. to deny abandonment.

In light of the nature and economics of the grain distribution industry, the following two modifications to existing laws and policies are suggested as an approach to the regulation of rail line abandonments in the Fort Dodge area. 1) Quantitatively estimate the impact of rail line abandonment. This estimate would aid in cases requiring
judicial discretion and should include, as a minimum, the
delineation of the geographical area served and economic
activities influenced by the line sought to be abandoned;
an accounting of resources that flow to the line; the
available markets to which the resources may be transported;
resources that are shipped into the area from distant
markets; the nature and degree of inter and intra-modal
competition; and, alternative modes or means of transporta-
tion that could be used as a substitute if the line were
abandoned. 2) Permit rail carriers some flexibility in
establishing special rates for those rail lines sought to be
abandoned but maintained for the public convenience and
necessity. This policy could be designed to assist the rail
carriers to maintain their share of exiting traffic or,
perhaps, to recapture traffic lost to other modes of trans-
portation.

In short, the first recommendation strengthens the
criteria for decision making by quantifying public interests
as well as rail carrier interest, and explicitly takes into
account inter and intra-modal competition. The second
recommendation enlarges the scope of activities subject to
rail abandonment regulation by including inter and intra-
modal flexibility. Quantitatively estimating the impact of
rail abandonment on the economy based on a systemic analysis,
and permitting some degree of rate-flexibility for rail carriers forced to operate weak lines should, hopefully, help provide for the general transportation needs of the Fort Dodge area.

**Model extensions**

The two stage multi-period transhipment plant-location model specified for this study is an extension and generalization of the transhipment plant-location model developed by Ladd (33). In his article "A Fifth Variation on a Theme by Stollsteimer", Ladd proposed algorithms to account for demand prices at final destinations which vary by volume received, and marginal transport costs that decline with increasing volume. The extension and application of these algorithms to the two stage multi-period a model developed for the Fort Dodge area study are a possibility for future research.

The model as presented in Chapter II takes into account the capacity of existing elevators and the additional costs of expansion once capacity has been reached. Another appropriate extension of the model would also account for the existing capacity of the transportation system. Such an extension would determine the optimal capacity of the transportation system taking into account peak demands.

Questions concerning the time phasing of rail abandon-
ments or elevator expansion often arise. An extension of the model to answer such questions is appropriate. I have written a working paper that specifies a model to determine 1) the number, size, and location of plants; and 2) the time phasing of investments to maximize discounted joint net revenue of producers over a finite time horizon of $T$ years. Conceptually the model is easy to solve but operationally very expensive to use because of the potentially large number of different commodity routings and expansion paths that must be compared.

In the Fort Dodge area the flow of commodities into the area was considered too insignificant to effect the solution of the model. In some areas, however, the back-haul or flow of commodities into a region may be as large as the outflows. In the event of large back-hauls by various modes of transportation, the model would need to be expanded and re-specified.

If necessary to enlarge the geographical scope of the problem, the model as presently specified may still be used by either increasing the number or size of origins. If the state of Iowa, for example, were delineated as the relevant marketing area, counties could be designated as origins. And, instead of considering the capacity of specific elevators and branch rail lines, an aggregated capacity of distribution facilities within counties could be used.
Further work could also be done to analyze the effect of various parametric changes on the solution of the model. Transportation costs and grain prices have changed significantly since 1972. The foreign demand for grain has also increased since 1972. The results of such changes on the flow of grain and on the spatial structure of the grain distribution system are unknown. Through parametric analysis, however, helpful information and insights could be provided.

Parametric analysis could also provide information for long run, strategic planning by looking at various "what if" type questions. What would be the impact on the grain distribution system if, for example, the foreign demand for grain on the West Coast were to increase? Or, what would be the consequences if transportation costs would continue to increase? The sensitivity of the model solution to various parametric changes may be illustrated by considering two levels of rail maintenance costs. If the cost of maintaining a rail line is estimated at $2100 per mile, as was the case for this study, then rail line Option IV is optimal. If, however, the level of rail line maintenance costs are increased to $2400 per mile, the optimal rail line network changes from Option IV to Option III. Clearly, additional work in parametric and sensitivity analysis on the location-allocation model developed for this study would be useful.
Summary

Innovations in grain handling and transportation, and changes in the supply of and demand for feed grains are factors disrupting the grain distribution system. Neither the pricing system nor regulatory policies are adequately designed to coordinate the needed industry adjustments to insure an efficient physical distribution system and provide for the general transportation needs of the grain industry.

The objective of this study was to determine and evaluate the advantages and investment requirements of alternative rail-based grain distribution systems by analysis of actual production, storage, and transportation elements within a given region.

Alternative rail-based distribution systems were evaluated using a two stage multi-period transhipment plant-location model. The model was specified to determine the number, size, and location of country elevators and grain subterminals; the rail line network; and the flow of grain over time and space to maximize joint net revenue of the grain distribution industry within a 6-1/2 county region around Fort Dodge, Iowa. The model was solved by using a sequential search algorithm which systematically compared various feasible solutions, taking into account grain handling
and transportation facilities existing at the beginning of the planning horizon.

The results of the analysis suggest the abandonment of 257 miles, or 38 percent, of the rail line in the Fort Dodge area; and the use of 15 subterminals to maximize joint net revenue of producers in 1980. Country elevators incapable of loading multiple car trains should generally be used as storage facilities and tranship the grain to market through one of 15 subterminals. Producers patronize local country elevators during months of peak harvest; and by-pass local country elevators in favor of subterminals once the demands of harvest subside. The total annual investment necessary to implement this rail-based grain distribution system was $4,595,000. Other distribution systems were less expensive to implement, but such systems required greater assembly costs of grain from origins to elevators.

The study measured the impact of alternative rail abandonment options and, thus, provides regulatory officials a quantitative base from which rail abandonment decisions can be made. Additional energy requirements, road use costs, and pollution emission resulting from rail line abandonment were also estimated. And, it was determined that maximum joint net revenue in the Fort Dodge area varies only 1 or 2 percent (1 to 2 cents per bushel) over a wide range of abandonment options. Such information also facilitates regulatory abandon-
ment decisions when it is necessary to consider trade-offs of nonquantitative factors.

Two modifications to the existing policies of rail abandonment regulation were suggested. 1) Strengthen the criteria for decision making by quantitatively estimating the impact of rail abandonment based on a systemic analysis, taking into account inter and intra-modal competition. And, 2) enlarge the scope of activities subject to rail abandonment regulation by including inter and intra-modal rate flexibility designed to assist rail roads forced to operate weak lines for "public convenience and necessity".
REFERENCES

1. "Act to Authorize the Re-location of Railroads." Iowa General Assembly Acts and Resolutions, Chapter 118, 1876.


40b. Reid, M. S. Personal letter to C. Phillip Baume1, August 14, 1973.


ACKNOWLEDGMENTS

I wish to express appreciation to the chairman of my graduate committee, Dr. George W. Ladd. His writings, guidance and advice provided the inspiration and basis of this thesis. Special acknowledgment is also made to Dr. C. Phillip Baumel who served as project administrator. I am grateful for his encouragement and support during all phases of the study. I also wish to acknowledge Dr. Lehman C. Fletcher for the support and help he freely offered through all stages of my graduate program. Appreciation is also expressed to Drs. James Stephenson, William H. Thompson, and Keith L. McRoberts for serving as graduate committee members.

I am indebted to the Federal Railroad Administration for the financial support (Project No. DOT-FR-20025) that made this study possible. Parts of this thesis were used in the final report of the DOT contract. Special recognition is also due to Mrs. Marsha Conley for her programming of the computer model and to John C. Miller, Won Koo, and Thomas P. Drinka for their help and assistance throughout the project.

I am particularly indebted to my wife, Margaret, and my children. I thank them for their patience and continuous encouragement throughout my graduate program.
APPENDIX A: HISTORICAL SKETCH OF RAIL ABANDONMENT REGULATION

Prior to 1920, public intervention in the decision making process of rail line abandonment was exercised by and limited to individual states. Rail line abandonments were controlled, primarily, to protect the interests of the communities and industries within the state that became dependent upon rail service.

In 1876 the 16th General Assembly of the State of Iowa passed a law to authorize the relocation of railroads (1, pp. 107-108). The Act provided that all railroads seeking to change or remove any rail lines must file a petition in the district or circuit court; serve notice to communities in which the line is located; repay money to those who had invested in the rail line; receive consent of lien-holders; and level the land where the lines were located.

The concern of regulatory agencies to maintain a viable state rail system is reflected in State of Iowa v. Old Colony Trust Co. (47). In 1912 the Fort Dodge, Des Moines and Southern Railroad Company owned and operated 125 miles of rail line from Goddard to Rockwell City, Iowa which was considered to be of "large public importance." The rail company also owned and operated a connecting line 27 miles long from Goddard to Des Moines Junction for which, allegedly,
there were insufficient revenues to cover operating expenses and little public necessity for its operation.

Consistent with Iowa's laws of railroad abandonment, the Fort Dodge, Des Moines and Southern Railroad Company filed a petition with the district court to receive permission to abandon the 27 miles of line from Goddard to Des Moines Junction. Some of the patrons along the line to be abandoned, the railroad commissioners, and the state of Iowa, however, intervened and petitioned the court to deny the railroad the authority to abandon any of its line. Their argument, in part, was that the railroad company, because of the rights, privileges, and franchises granted to it by the state, had a responsibility to provide service to the public on all lines even if pecuniary losses should occur.

Judge Adams ruled in favor of the railroad and concluded by stating:

A railroad corporation is in an important sense a public corporation. It is dependent upon the public for its franchises to exist and carry on business, and in consideration of these franchises it assumes and must perform certain duties and obligations for the benefit of the public. Among them, as a general rule, is the duty of maintaining its entire line of road in a reasonably safe and operative condition and for a fair consideration to carry passengers and freight over it at all reasonable times whenever requested to do so. These propositions are elemental and lay down a general rule which cannot be gainsaid or denied. But there are some conditions which necessarily excuse full compliance with the requirements of these rules and, in our opinion, the present case affords a striking example of such conditions. Here is a case where the
line sought to be abandoned is not only not self-supporting, but its continued operation jeopardizes the successful operation of the entire system of which it is merely a part. Moreover, its continued operation in its present condition is dangerous to life and property and there is no money or financial ability to improve its condition. Not only so, but there is little public necessity for its continued operation, whereas, there is a great public necessity for the continued operation of the balance of the system (47).

Intrastate regulation of rail abandonment, however, was often too narrow in scope and adversely influenced interstate commerce. As articulated by Mr. Brandeis in Colorado v. United States, intrastate regulation was often based on local interests which forced rail companies to make intrastate expenditures at the expense of interstate service. Forcing rail companies to subsidize unprofitable branch lines in one state at the expense of an interstate system may "...compel the carrier to raise reasonable interstate rates, or to abstain from making an appropriate reduction of such rates, or to curtail interstate service, or to forego facilities needed in interstate commerce" (13).

Thus, to insure the viability of a national transportation system necessary to sustain interstate commerce, national regulation of rail abandonment was formalized in 1920 when congress passed the Transportation Act. The Act gave the Interstate Commerce Commission, I.C.C., the authority to regulate rail abandonment by providing that no rail company "...shall abandon all or any portion of a line of railroad,
or the operation thereof, unless and until there shall first have been obtained from the Commission a certificate that the present or future public convenience and necessity permit of such abandonment" (51, p. 11870).

Litigation since 1920 has provided a source of judicial interpretations of sections 18-20, sections concerned with rail abandonment, of the Transportation Set. Beginning with Colorado v. United States it has been acknowledged that:

The sole test prescribed is that abandonment be consistent with public necessity and convenience. In determining whether it is, the Commission must have regard to the needs of both intrastate and interstate commerce. For it was a purpose of Transportation Act, 1920, to establish and maintain adequate service for both.... The benefit to one of the abandonment must be weighed against the inconvenience and loss to which the other will thereby be subjected. Conversely, the benefits to particular communities and commerce of continued operation must be weighed against the burden thereby imposed upon other commerce (13, p. 157).

The Interstate Commerce Commission, in 1968, basically, repeated the same criteria for authorizing rail abandonment as articulated by Judge Brandeis in Colorado v. United States. The Ahnapee and Western Railway Company, A. & W., sought authority from the I.C.C. to abandon a segment of its line. Opposition was expressed by municipal, county, and state government, 31 commercial interests, and railway labor organizations. After weighing the advantages and disadvantages of the abandonment the Commission concluded:
Even though abandonment of the branch will inconvenience some users of transportation, will increase the costs of doing business, will narrow the profit margin, impair some investments, and affect the growth of the communities, the examiner is not persuaded that the injury to the few would outweigh the injury which may be sustained by the general public resulting from the inability of the A. & W. to discharge its common carrier responsibility in interstate commerce" (2, p. 414).

Finance Docket No. 20175 (12) presents an abandonment case that has relevancy to the grain industry in the Port Dodge area. The Chicago, Rock Island and Pacific Railroad Company in 1959 applied to the Interstate Commerce Commission for permission to abandon 87 miles of rail line in Kansas and Nebraska. The rail company contended that approximately $1.5 million would be required to upgrade and maintain the 87 miles of line; each elevator had access to Federal or State highways and could transport grain, therefore, by truck to nearby elevators on other rail lines; and operating costs of the line exceed revenues generated thereon.

Grain producers in the area were opposed to the abandonment because it may cause elevators along the abandoned line to close and, thus, force farmers to haul grain greater distances; there were not enough trucks in the area to move the fall harvest to elevators on main lines; most terminal elevators did not have facilities to receive trucks; it had been projected that grain production in the future would increase; and, finally, by excluding ad valorem property taxes
from the railroad operating expenses, which the applicant would pay irrespective of abandonment, railroad operations over the 87 miles of line sought for abandonment were profitable during the past 18 months. In light of the evidence and high probability of increased grain traffic in the future, application for abandonment was denied.

Balancing the advantages of abandonment with the disadvantages for each applicant has proven to be time consuming and difficult. Various "per se" rules for granting authority to abandon a rail line have been proposed. Two recent proposals for rail abandonment regulation which would allow all rail lines that met certain minimal levels of requirements to close are the Surface Transportation Act of 1971 and The Transportation Regulatory Modernization Act of 1971.

The original version of the Surface Transportation Act of 1971 was written as a joint effort by members of the transportation industry but has since been modified by the Senate Commerce Committee. One purpose of the Act is to expedite the procedures for abandonment of rail spur lines or branch lines.

The modified Senate bill requires rail carriers to announce their intentions of abandonment to all stations located along the line under consideration for abandonment. If complaints are filed "evidencing substantial injury to
the complaining party" the I.C.C. will investigate to determine if such abandonment is "consistent with public convenience and necessity." If the findings of the investigation indicate that the abandonment is not in the public interest, then the petition for abandonment will be denied. The investigation of the I.C.C. includes the following:

...losses in operating the line proposed to be abandoned, as measured by total costs of service including capital and maintenance cost to continue the line at a physical standard necessary to provide safe, reliable, and efficient service; extent to actual use and need for the line by shippers or receivers; and the development of an efficient and economical transportation system: Provided, however, that no such finding shall be made unless continued operation of the line proposed to be abandoned will produce sufficient revenue to cover the relevant variable costs of handling traffic to, from, and beyond the line (42 pp. 31-32).

The Transportation Regulatory Modernization Act was initiated and sponsored by the Department of Transportation (43). The bill would affect several principal areas of transportation by amending the Interstate Commerce Act to provide for increased reliance on competition; and, to liberalize entry and exit in the surface transportation industry. Included in the bill are criteria for the abandonment of uneconomical rail lines and facilities.

The rules for abandonment require a railroad carrier to publish for three consecutive weeks its abandonment plans in each county through which the line under consideration for closure operates. Following this announcement and 30 days
prior to the scheduled date of abandonment the rail line petitions the I.C.C. for their approval. In the event that no complaint is filed with the I.C.C. during the 30 days prior to the scheduled date of abandonment, the I.C.C. will give permission to the carrier to abandon the line.

If a complaint is filed and substantial economic injury to the user is demonstrated then the I.C.C. will suspend the proposed abandonment up to six months. During this period the I.C.C. will investigate the proposal to determine if over the year prior to the filing of the notice: 1) the line in question has generated at least one million gross ton miles of traffic per mile; 2) revenues attributable to the line under consideration exceed variable costs and 3) there exists effective, alternative and competitive forms of transportation other than over the line under consideration.

Unless one of the above conditions is violated, the I.C.C. will issue a certificate authorizing the abandonment of the line. Such rules establish a set of minimum requirements which form the basis for "per se" abandonment.
APPENDIX B: COST DATA
Table B.1. Estimated variable operating and maintenance costs of receiving, drying, storing and loading out grain at a subterminal, 1972^a

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Receiving^b (¢/bu.)</th>
<th>Drying (¢/bu./pt.)</th>
<th>Storage^c (¢/bu./mo.)</th>
<th>Loadout (¢/bu.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct labor^d</td>
<td>1.03</td>
<td>.10</td>
<td>.05</td>
<td>.15</td>
</tr>
<tr>
<td>Repairs and maintenance</td>
<td>.10</td>
<td>.02</td>
<td>.08</td>
<td>.08</td>
</tr>
<tr>
<td>Fuel, power and lights</td>
<td>.13</td>
<td>.05</td>
<td>.09</td>
<td>.15</td>
</tr>
<tr>
<td>Drier fuel</td>
<td>-</td>
<td>.11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Administrative expense^e</td>
<td>.52</td>
<td>-</td>
<td>.08</td>
<td>.17</td>
</tr>
<tr>
<td>Insurance on grain</td>
<td>-</td>
<td>-</td>
<td>.04</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL COST PER BUSHEL</strong></td>
<td><strong>1.78</strong></td>
<td><strong>.28</strong></td>
<td><strong>.34</strong></td>
<td><strong>.55</strong></td>
</tr>
</tbody>
</table>

^aSource: (4).
^bVariable operating and maintenance costs of receiving corn or soybeans net of drying costs.
^cVariable operating and maintenance costs of storing corn or soybeans net of interest costs.
^dIncludes payroll taxes and employee benefits.
^eIncludes administrative labor, office supplies, telephone, audit, advertising, etc.
Table B.2. Estimated installed and annual cost of elevator receiving facilities, 1972a

<table>
<thead>
<tr>
<th></th>
<th>Installed Costs</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Years for</td>
<td>10,000</td>
<td>20,000</td>
<td>40,000</td>
</tr>
<tr>
<td></td>
<td>Deprec. bu./hr.</td>
<td>bu./hr.</td>
<td>bu./hr.</td>
<td>bu./hr.</td>
</tr>
<tr>
<td>Scale House &amp; Office</td>
<td>20</td>
<td>$12,500</td>
<td>$12,500</td>
<td>$17,500</td>
</tr>
<tr>
<td>Truck Scale (s)</td>
<td>20</td>
<td>15,000</td>
<td>15,000</td>
<td>30,000</td>
</tr>
<tr>
<td>Sampler, Tester, etc.</td>
<td>5</td>
<td>3,000</td>
<td>3,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Truck Hoists</td>
<td>20</td>
<td>18,000</td>
<td>48,000</td>
<td>61,000</td>
</tr>
<tr>
<td>Dump Pits</td>
<td>30</td>
<td>17,500</td>
<td>25,500</td>
<td>42,500</td>
</tr>
<tr>
<td>Belt in Pits</td>
<td>10</td>
<td>6,750</td>
<td>9,000</td>
<td>15,750</td>
</tr>
<tr>
<td>Legs</td>
<td>10</td>
<td>22,000</td>
<td>34,000</td>
<td>67,000</td>
</tr>
<tr>
<td>Distributors</td>
<td>10</td>
<td>8,375</td>
<td>8,375</td>
<td>16,750</td>
</tr>
<tr>
<td>Belt to 1st Storage Bin</td>
<td>10</td>
<td>4,400</td>
<td>6,600</td>
<td>8,800</td>
</tr>
<tr>
<td>Spouting and Misc.</td>
<td>5</td>
<td>5,400</td>
<td>5,400</td>
<td>10,900</td>
</tr>
<tr>
<td>Total Installed Cost</td>
<td></td>
<td>$112,925</td>
<td>$162,375</td>
<td>$276,200</td>
</tr>
</tbody>
</table>

| Annual Equivalent Cost    | 5 yrs.          | $2,216  | $2,216  | $4,458  |
|                           | 10 yrs.         | 6,758   | 9,435   | 17,626  |
|                           | 20 yrs.         | 5,344   | 8,281   | 12,744  |
|                           | 30 yrs.         | 1,856   | 2,705   | 4,508   |

| Annual Insurance & Tax @ 3.6% of Installed Cost |
|                                                | $20,239          | $28,482  | $49,279 |

<table>
<thead>
<tr>
<th>Total Annual Cost</th>
</tr>
</thead>
</table>

aSource: (4).
Table B.3. Estimated installed and annual cost of elevator drying facilities^a

<table>
<thead>
<tr>
<th></th>
<th>Installed Costs</th>
<th></th>
<th>3,000</th>
<th>6,000</th>
<th>12,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deprec.</td>
<td>bu./hr.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driers</td>
<td>10</td>
<td>$106,400</td>
<td>$212,800</td>
<td>$425,600</td>
<td></td>
</tr>
<tr>
<td>Cleaners</td>
<td>10</td>
<td>7,500</td>
<td>11,500</td>
<td>15,500</td>
<td></td>
</tr>
<tr>
<td>Legs, Conveyors &amp; Spouts</td>
<td>10</td>
<td>17,500</td>
<td>28,000</td>
<td>52,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total Installed Cost</strong></td>
<td></td>
<td><strong>$131,400</strong></td>
<td><strong>$252,300</strong></td>
<td><strong>$493,100</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Annual Equivalent Cost</strong></td>
<td>10 yrs.</td>
<td></td>
<td>21,385</td>
<td>41,062</td>
<td>80,252</td>
</tr>
<tr>
<td><strong>Annual Insurance &amp; Tax</strong></td>
<td></td>
<td>4,730</td>
<td>9,083</td>
<td>17,751</td>
<td></td>
</tr>
<tr>
<td>@ 3.6% of Installed Cost</td>
<td></td>
<td><strong>$26,115</strong></td>
<td><strong>$50,145</strong></td>
<td><strong>$98,003</strong></td>
<td></td>
</tr>
</tbody>
</table>

^aSource: (4).

Table B.4. Estimated installed and annual cost of elevator storage facilities, 1972^a

<table>
<thead>
<tr>
<th></th>
<th>Installed Costs</th>
<th></th>
<th>300,000</th>
<th>500,000</th>
<th>1,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deprec.</td>
<td>bu.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silos and Tunnel</td>
<td>50</td>
<td>$210,000</td>
<td>$300,000</td>
<td>$550,000</td>
<td></td>
</tr>
<tr>
<td>Aeration and Heat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection Equip.</td>
<td>10</td>
<td>10,500</td>
<td>17,000</td>
<td>28,000</td>
<td></td>
</tr>
<tr>
<td>Conveyors</td>
<td>10</td>
<td>16,720</td>
<td>33,440</td>
<td>66,880</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>-</td>
<td>10,000</td>
<td>10,000</td>
<td>12,500</td>
<td></td>
</tr>
<tr>
<td><strong>Total Installed Cost</strong></td>
<td></td>
<td><strong>$247,220</strong></td>
<td><strong>$360,440</strong></td>
<td><strong>$657,380</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Annual Equivalent Cost</strong></td>
<td>10 yrs.</td>
<td></td>
<td>4,430</td>
<td>8,209</td>
<td>15,442</td>
</tr>
<tr>
<td></td>
<td>50 yrs.</td>
<td>21,181</td>
<td>30,258</td>
<td>55,473</td>
<td></td>
</tr>
<tr>
<td><strong>Annual Insurance &amp; Tax</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 3.6% of Installed Cost</td>
<td></td>
<td>8,900</td>
<td>12,976</td>
<td>23,666</td>
<td></td>
</tr>
<tr>
<td><strong>Total Annual Cost</strong></td>
<td></td>
<td><strong>$34,511</strong></td>
<td><strong>$51,443</strong></td>
<td><strong>$94,581</strong></td>
<td></td>
</tr>
</tbody>
</table>

^aSource: (4).
Table B.5. Estimated installed and annual costs of elevator loadout and cleaning facilities, 1972

<table>
<thead>
<tr>
<th></th>
<th>Installed Costs</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Years for Deprec.</td>
<td>2,000 bu./hr.</td>
<td>10,000 bu./hr.</td>
<td>20,000 bu./hr.</td>
<td>40,000 bu./hr.</td>
</tr>
<tr>
<td>Rail Siding &amp; Switches</td>
<td>50</td>
<td>$30,500</td>
<td>$64,250</td>
<td>$124,500</td>
<td>$274,750</td>
</tr>
<tr>
<td>Trackmobile or Equiv.</td>
<td>15</td>
<td>10,000</td>
<td>25,000</td>
<td>25,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Scales</td>
<td>20</td>
<td>5,800</td>
<td>18,000</td>
<td>30,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Loadout Legs and Belts</td>
<td>10</td>
<td>10,300</td>
<td>25,300</td>
<td>40,600</td>
<td>81,200</td>
</tr>
<tr>
<td>Cleaners</td>
<td>10</td>
<td>6,800</td>
<td>15,000</td>
<td>25,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Spouts and Misc.</td>
<td>5</td>
<td>3,900</td>
<td>4,900</td>
<td>5,900</td>
<td>11,800</td>
</tr>
<tr>
<td>Total Installed Cost</td>
<td></td>
<td>$67,300</td>
<td>$152,450</td>
<td>$251,000</td>
<td>$527,750</td>
</tr>
<tr>
<td>Annual Equivalent Cost</td>
<td>5 yrs.</td>
<td>$1,029</td>
<td>$1,293</td>
<td>$1,556</td>
<td>$3,113</td>
</tr>
<tr>
<td></td>
<td>10 yrs.</td>
<td>2,783</td>
<td>6,559</td>
<td>10,676</td>
<td>21,343</td>
</tr>
<tr>
<td></td>
<td>15 yrs.</td>
<td>1,315</td>
<td>3,287</td>
<td>3,287</td>
<td>6,574</td>
</tr>
<tr>
<td></td>
<td>50 yrs.</td>
<td>3,076</td>
<td>6,480</td>
<td>12,557</td>
<td>27,711</td>
</tr>
<tr>
<td>Annual Insurance and Tax</td>
<td>@ 3.6% of Installed Cost</td>
<td>2,423</td>
<td>5,488</td>
<td>9,036</td>
<td>18,999</td>
</tr>
<tr>
<td>Total Annual Cost</td>
<td>$10,626</td>
<td>$23,107</td>
<td>$37,112</td>
<td>$77,750</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Source: (4).
<table>
<thead>
<tr>
<th></th>
<th>Tractor-Tractor Truck</th>
<th>Tractor-Wagon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.E.C.</td>
<td>$1,149.73</td>
<td>$3,122.00</td>
</tr>
<tr>
<td>License</td>
<td>310.00</td>
<td>590.00</td>
</tr>
<tr>
<td>Insurance</td>
<td>150.00</td>
<td>750.00</td>
</tr>
<tr>
<td>Management expense</td>
<td>150.00</td>
<td>150.00</td>
</tr>
<tr>
<td>Highway use tax</td>
<td>120.00</td>
<td>220.00</td>
</tr>
<tr>
<td>Total</td>
<td>$1,609.73</td>
<td>$4,732.00</td>
</tr>
<tr>
<td>Variable Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel and oil</td>
<td>$0.052</td>
<td>$0.049</td>
</tr>
<tr>
<td>Tire</td>
<td>0.021</td>
<td>0.012</td>
</tr>
<tr>
<td>Wage</td>
<td>0.100</td>
<td>0.129</td>
</tr>
<tr>
<td>Maintenance and repair</td>
<td>0.045</td>
<td>0.013</td>
</tr>
<tr>
<td>Total</td>
<td>$0.218</td>
<td>$2,801.00</td>
</tr>
<tr>
<td>Transfer Cost</td>
<td>1.080</td>
<td>0.340</td>
</tr>
<tr>
<td>Average cost/mile</td>
<td>0.0036</td>
<td>0.00078</td>
</tr>
</tbody>
</table>

^Source: (4).
APPENDIX C: FORT DODGE AREA ROAD SYSTEM
1972 PRIMARY HIGHWAY FACILITIES INFORMATION

LEGEND

SYSTEM DESIGNATION

OTHER PRIMARIES

NUMBER OF LANES

2 LANES

4 LANES

TYPE OF PAVEMENT

INTERSTATE HIGHWAY

OTHER PRIMARY HIGHWAY

HIGH FLEXIBLE PAVEMENT

INTERMEDIATE FLEXIBLE PAVEMENT

SURFACE TREATED FLEXIBLE PAVEMENT

Figure C.1. 1972 primary highway facilities, Fort Dodge area, Iowa (2.7)
Figure C.2. Estimated 1980 primary highway facilities, Fort Dodge area, Iowa (27)
APPENDIX D: FORT DODGE AREA RAIL SYSTEM
Figure D.1. Country elevators, potential subterminal sites, and rail line systems given Option I ($\lambda_{mn1}$): All light rail lines upgraded to handle multiple-car train, Fort Dodge area, 1980
Figure D.2. Country elevators, potential subterminal sites, and rail line system given Option II (λ^mn2): All rail lines maintained at 1971 capacities, Fort Dodge area, 1980.
Figure D.3. Country elevators, potential subterminal sites, and rail line system given Option III ($\lambda_{mn3}$): All branch rail lines abandoned, Fort Dodge area, 1980
Figure D.4. Country elevators, potential subterminal sites, and rail line system given Option IV ($\lambda_{mn4}$): Some branch rail lines abandoned, Fort Dodge area, 1980.