# METHODOLOGICAL ANALYSES OF THE EXPORT TRANSPORTATION NETWORK FLOWS:

## HARD RED WINTER WHEAT

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METHODOLOGICAL ANALYSES OF THE EXPORT
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# PREFACE

This study was undertaken to analyze the export flow of hard red winter wheat and to determine the flows associated with 1) the transportation rate structure and 2) the grain storage and handling facilities. The overall objective of the study was to use existing spatial equilibrium and transportation networks to identify cost minimization export flows for hard red winter wheat from harvest to port terminal by utilization of network analyses and methodologies. The results were obtained by formulating constrained network models of the export grain marketing and transportation system, and generating analytical solutions to these models by the use of the Out-of-Kilter Algorithm. The models include, but by no means all, important spatial and temporal interrelationships involved in export grain marketing.

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Finally, a very special word of thanks is due my family--to my wife, Dolores, for her patience, encouragement, support, and understanding throughout my graduate program, and to my son, Stephen, for his innocent encouragement when he recently asked, "What are you going to be when you grow up, Daddy?"

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# CHAPTER I

# INTRODUCTION

Agricultural products have an enormous impact on the state of Oklahoma's economy as well as on the economies of the other Plains States. Commercial agriculture and agricultural commodity production are not isolated industries because the revenue generated from the sale of farm products, such as livestock and grain, is transferred to other firms and other individuals. Therefore, the marketing process, including the distribution phase, can mean success or failure for the agricultural sector of the economy.

Hard red winter wheat, a grain commodity suited to the soils and climate of the Plain States, is a principal crop in the value of production among these centrally located states. In Oklahoma alone, the 1977 winter wheat crop reports a production value of 404 million dollars, second in value behind cattle and calves whose value was $670 million, and represents 23 percent of Oklahoma's total value of agricultural production of $1753 million.[1] The 1977 wheat crop reveals an all-time record of 175.5 million bushel harvested from 6.5 million acres. As a source of cash receipts from farm marketings of livestock and livestock products, crops, and government payments, wheat receipts total $466.3 million, or 23.2 percent of farm cash receipts.[2] These figures are not merely applicable to Oklahoma but also indicate the relative magnitude and importance of hard winter wheat to the economies of the neighboring

Plains States. Therefore, the marketing and distribution of hard red winter wheat is vital to the success of the agricultural economy.

## The Problem Setting

The heart of the interregional movement of wheat from the producing regions to the consumer, especially in the export marketing sector of the industry, is an intricate and complex transportation and distribution system whose cost of transport accounts for more than seven percent of the cost of marketing farm products.[3] The production and distribution of wheat has four basic components: 1) the production or supply of quantities and qualities or grades of wheat at particular locations and times; 2) the demands for the quantities and qualities of wheat at specific location and times; 3) storage facilities at particular locations with specified capacities and a variety of merchandising and handling services; and 4) transportation facilities with capacity constraints operating in fixed networks and with an array of services, all components being subject to environmental and institutional restraints.

A typical wheat flow schematic from harvest to export is depicted in Figure 1. Wheat is capable of storage either on the farm where harvested or at any location along the market distribution chain until the demand at some subsequent activity, i.e., a livestock feed lot, a country elevator, a commercial flour miller, an inland terminal elevator, or an export terminal, necessitates transfer of the commodity. Once storage is interrupted, transportation is necessary and the mode of transportation is typically either truck, rail, or barge. The mode used depends on such factors as distance, quantity shipped, loadout and receiving facilities, urgency of delivery, and the transportation rate structure.

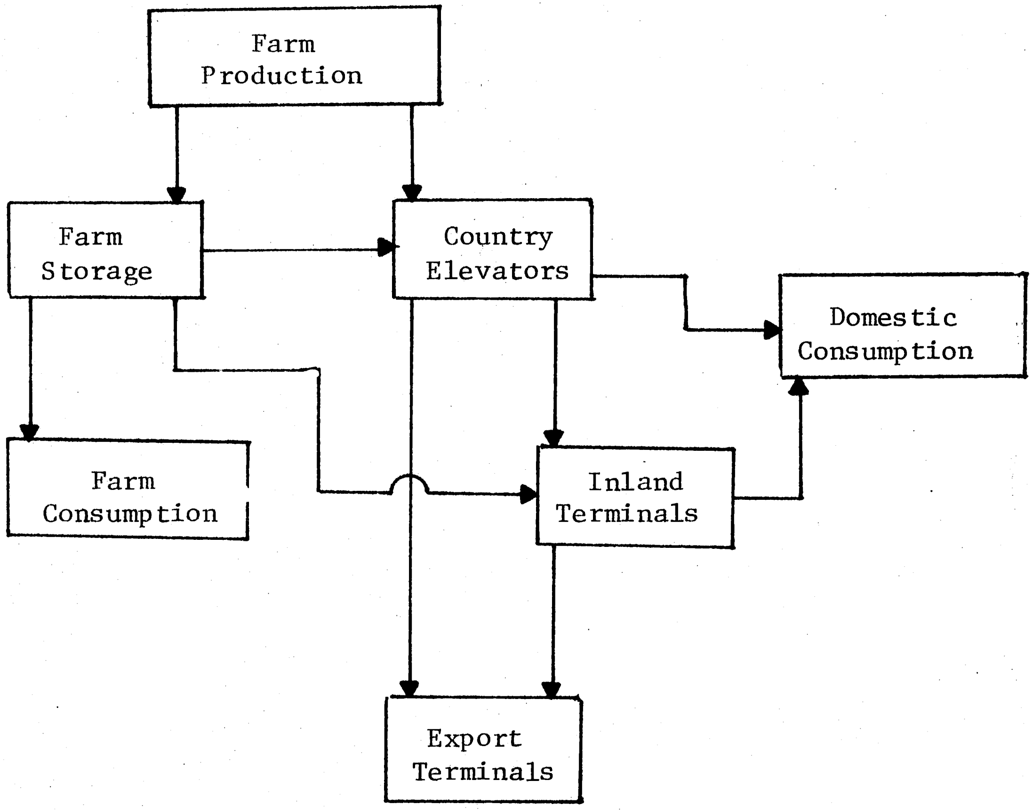


Figure 1. Typical Grain Transportation Network

Some considerations in the distribution process are not within the shipper's control due to competition for transportation services and for shipments of merchandise. "Shocks" to the historical transportation network for winter wheat have restricted or bottlenecked the wheat flow from harvest to export terminals. Examples of these "shocks" which have occurred in the Plains States in the last decade include rail line abandonment, seasonal use (harvest only) of some rail lines, shortage of covered hopper cars at elevators and grain terminals, excessive turnaround time for returning rail cars upcountry, substitution of standard box cars for hoppers, energy considerations (55 mph speed limit and increased fuel costs), dust explosions curtailing operations at inland and export terminals, and the "Russian wheat deal". Some of these shocks are difficult to quantify when building a grain transportation and distribution model while the impacts of others can be evaluated in analyzing alternative routes and modes so as to maintain the desired volume of commodity flow.

In some respects relative to the sensitivity of commodity flow, wheat is the most liquid agricultural commodity known in transportation. The grades or qualities of wheat have long been standardized commercially. The transportation rate structure should permit wheat to move freely in all directions. Rates on wheat are closely related to one another, and even a slight change in one will ordinarily effect the movement governed by other rates. Generally speaking, all of the rates on wheat may be likened to a huge blanket covering the entire country, and the effect of a pull on any part of this blanket to the extent of one or two cents per hundred pounds, sometimes even a fraction of a cent, will be felt in every other part.[4]

## Objectives of the Study

The purpose of this study is to determine and analyze alternative distribution patterns for hard red winter wheat necessary to maintain the volume of grain flow for the demands within the wehat marketing industry by utilizing other routes or modes or transportation cost structures. This will provide information and planning data for the management of marketing and transportation firms as well as depict spatial distribution relationships to policy-makers.

The specific issues and objectives of this study are to:

1) Develop an operational transportation network capable of analyzing a multi-mode, multi-region, and multi-stage transportation problem of the hard red winter wheat marketing system.

2) Determine interregional flows of wheat consistent with available regional transportation and storage capacities.

3) Determine an efficient distribution pattern which will minimize the total cost of receiving, processing (handling and/or storage), load-out, and transporting the hard red winter wheat.

4) Determine an efficient transportation distribution network pattern which will maximize the flow of grain from harvest or production areas to export terminals.

5) Determine an efficient distribution pattern which will minimize total time required for the flow of hard red winter wheat through the marketing system.

6) Analyze the effects upon the efficient distribution pattern determined in (3) when modal transportation rates are altered to reflect a change in the competitive rate structure or the use of peak load pricing.

7) Analyze the effects upon the efficient distribution pattern determined in (4) when the existing distribution facilities and the means of grain flow are altered, i.e., rail line abandonment, extension of the Arkansas River Waterway or the Trinity River Waterway, or enforcement of highway speeds and load limits.

8) Analyze the effects upon the efficient distribution pattern determined in (4) when a selected grain handling facility's services are terminated or curtailed due to an incumberance of the form of a dust or humidity related explosion, or an OSHA or EPA mandate, or a financial constraint, or seasonal (harvest only) operations.

These objectives accentuate the versatility and flexibility of network analyses as an analytical tool in evaluating spatial and temporal interrelationships in agricultural commodity marketing and transportation issues, as well as aiding traffic managers and financial analysts in distribution and marketing policy decisions. The awareness of network analysis and its applications is the inherent thrust of the study.

The remainder of this study is divided into five chapters. Chapter II includes a review of early developments in the theory of location and a discussion of transportation economics as it relates to commodity distribution. Network analysis as a general transportation model is also described, and previous applications in grain distribution and transportation models are reviewed.

Chapter III contains the development of the capacitated "Out-of-Kilter" network model, which is used as a basis for the model presented in this study. Hypothetical marketing-transportation problems utilizing the "Out-of-Kilter" algorithm are formulated and solved, and selected assumptions of the interregional model are presented.

Chapter IV describes the regional demarcation employed in this study. The regional data relating to the supplies, demands, capacities, and marketing costs of wheat needed for implementation of the capacitated transportation network model developed in Chapter III is subsequently presented.

Chapter V annotates the results obtained from the analyses prescribed in the objectives of the study.

The final chapter, Chapter VI, contains a summary of the study and a discussion of the conclusions and implications of the analyses. The limitations of the study are also considered as well as some suggestions for future research using models similar to the model developed for this study.

# FOOTNOTES

[1] Oklahoma State Department of Agriculture, Oklahoma Agricultural Statistics, 1977 (Oklahoma City, 1978), p. 2.

[2] Ibid., pp. 80-1.

[3] Harold F. Breimyer, Economics of the Product Markets of Agriculture (Ames, 1976), p. 158.

[4] Marvin L. Fair and Ernest W. Williams, Jr., Economics of Transportation (New York, 1959), p. 410.

# CHAPTER II

# THEORETICAL CONSIDERATIONS

A review of commodity distribution and related areas of study is presented in this chapter. Four developmental areas of study are reviewed in order to provide a theoretical framework and basic understanding of the problem. The areas of consideration, in the sequence presented, include: location theory as a basis for transportation; transportation economics, including costs of service; network analysis as a transportation modeling tool; and grain distribution models and techniques of analysis.

## Location Theory

Location theory is embodied in transportation economics and, as such, reinforces the economic validity of this study by providing a theoretical framework for the formulation and analysis of the problem. Another reason for location theory's importance is that it aids in explaining the particular location patterns of grain marketing and grain distribution industries.

The principal elements to location theory include the natural endowments, the consumer location, and the producer location. Considered in the natural endowments are the natural resources of manufacturing or processing including labor, the state of the arts, and the political processes. Quality of life, whether catering to the psychic income or to the real income, and the cost of living are factors in consumer location. A mix of the procurement or assembly, processing, and distribution of material are relevant activities to the element of producer location.

The pioneering theoretical works in location analysis are usually categorized under two classical approaches. First is the "fixed market" approach or "adaptation _of_ the industry" in which the objective is to determine the optimum location of an enterprise in order to maximize profits with respect to the fixed markets of an industry.[1] The other classical approach is the "market area" approach or "adaptation _to_ the location".[2] The goal of the latter is to determine the optimal marketing focus given the locational pattern of the enterprise or industry in order to maximize profits.

The spadework of J. H. von Thunen in 1826 for agriculture, and Launhardt in 1882 and Alfred Weber 27 years later for industrial operations is considered classical for the "fixed market" approach to location analysis, whereas Frank A. Fetter, August Losch, Walter Isard, and Edgar Hoover have done almost equally classic work in the "market area" approach.

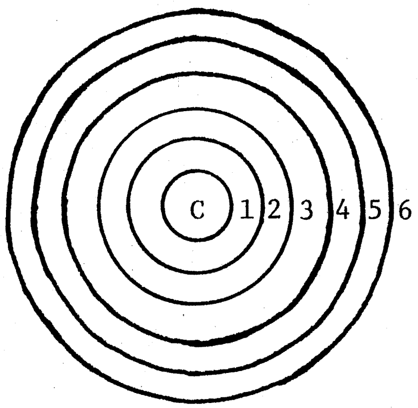
Johann Heindrich von Thunen, a German farm owner and operator, is considered the founder of the economic theory of location, especially as economics relates to agricultural location. He assumed an "isolated state" made up of one central city located in the center of a large fertile plain capable of cultivation throughout its vastness.[3] The problem addressed by von Thunen is the determination of what kind of agricultural production would occur in what parts of the plain.

The assumptions inherently stated in attacking the problem include: 1) the farmers are profit maximizers; 2) the market prices are given and are the same to all farmers for the goods delivered to the city; 3) profit equals market price minus the sum of production costs and transportation costs; and 4) transportation costs vary directly with the distance from the city, using freight rates set on a straight ton mileage basis regardless of the product hauled.

The results of von Thunen's analysis indicate perishable products and agricultural products heavy in relation to their value will be produced nearer the market (city) than those products being less perishable and those of more value relative to weight such as grain and livestock. The zones to von Thunen's productive plain are illustrated in Figure 2.[4]

* With respect to marginal analysis and factor-product relationships, the analysis implies land near the city or market can be made more profitable with intensive applications of variable resources of labor and capital, and extensive agriculture is more profitable as the distance from the market increases. The financial result is that maximum net earnings are attained when the intensity of cultivation is proportioniate to the net price to farmers, i.e., the gross city price minus the transportation cost.

In 1882, Launhardt, a German professor of engineering, contributed to the location theory by way of mathematic and geometric applications of determining the point location of a plant or an enterprise. Launhardt considered numerous factors other than transportation costs which would influence a given fixed activity location. Included in these factors were different prices for site acquisition, availability of a source of power, inequalities in living conditions and worker's wages, availability of a trained work force, and others, as stated in a translated text entitled "The Determination of the Optimum Location of a Business Enterprise".[5]



C = city market

1 = perishables (fresh dairy products, vegetables)

2 = forest (lumber, firewood)

3 = grain (alternating with fodder)

4 = grain (alternating with fallow and pasture)

5 = grain (alternating with fallow) and pasture

6 = pasture (livestock, cheese)

Figure 2. The Zones to von Thunen's Productive Plain

Alfred Weber, in the early 1900's, is responsible for a systematic and comprehensive treatment of economic location as it affected point industrial location. Weber defined a "locational factor" as an advantage (a saving of cost) which is gained when an economic activity takes place at a particular point or at several such points rather than elsewhere, and he delineated two types of locational factors. General factors are those factors affecting all industries, and these factors include transportation, capital, labor, rent, etc., regardless of the product. Special factors are those factors affecting only certain industries, and examples of special locational factors are weather and perishability. All "locational factors", whether general or special, are further classified according to the influence exercised as 1) regional factors, such as costs of transportation and geographic differences in labor, which determine the regional distribution of the industry, and 2) agglomerative factors which determine either the concentration of the industry at certain points within a region or the dispersion of the industry over a wide area.[6]

An abstract consideration of the general factors of location analysis contain the following stages, according to Weber: 1) securing the place of location and the fixed capital for equipment; 2) securing the materials, power and fuel materials; 3) the manufacturing process; and 4) the shipping of the goods.[7]

The assumptions incorporated by Weber are: 1) equal transport accessibility and straight-ton mileage rates regardless of the product (the same assumption as in von Thunen's study); 2) prices of fuel and raw materials equal at all deposits; 3) no mobility of labor and the labor supply at a particular location is perfectly elastic; and 4) the geographic nature of demand or consumption is also treated as a given phenomenon.[8]

The problem faced by Weber was therefore to determine where the processing activities should be located so as to minimize total transfer costs of materials and finished products plus labor costs of processing. The technique utilized has become known as Weber's Locational Triangle, Figure 3.[9] Consider a situation involving one market and two raw materials. Assume that both raw materials are "gross" (capable of losing weight during processing rather than being "pure") and "localized" (found only in certain localities, as opposed to being a "ubiquity") at different sources away from the market. In Figure 3, $M_1$ and $M_2$ represent the raw material sources and C is the consumer market. Except in the cases where one material happens to be so important as to affect the increased transport distance of the other material, ton mileage will be minimized if processing occurs somewhere within the triangle, such as at point P. Just where P will be as the least cost location is determined by a combination of the relative quantities of each of the materials used and by their respective weight-losing characteristics. Weight-losing material draws industry toward the raw material sources, as does the material used in the greatest quantity.

Weber further relaxed the assumption of equal labor costs in all regions and analyzed the effects of locational differences in labor costs upon the optimum location determined by transport cost minimization. He concluded that a site change could occur if the savings in labor costs at the new location offset the additional transportation costs to be incurred.[10]

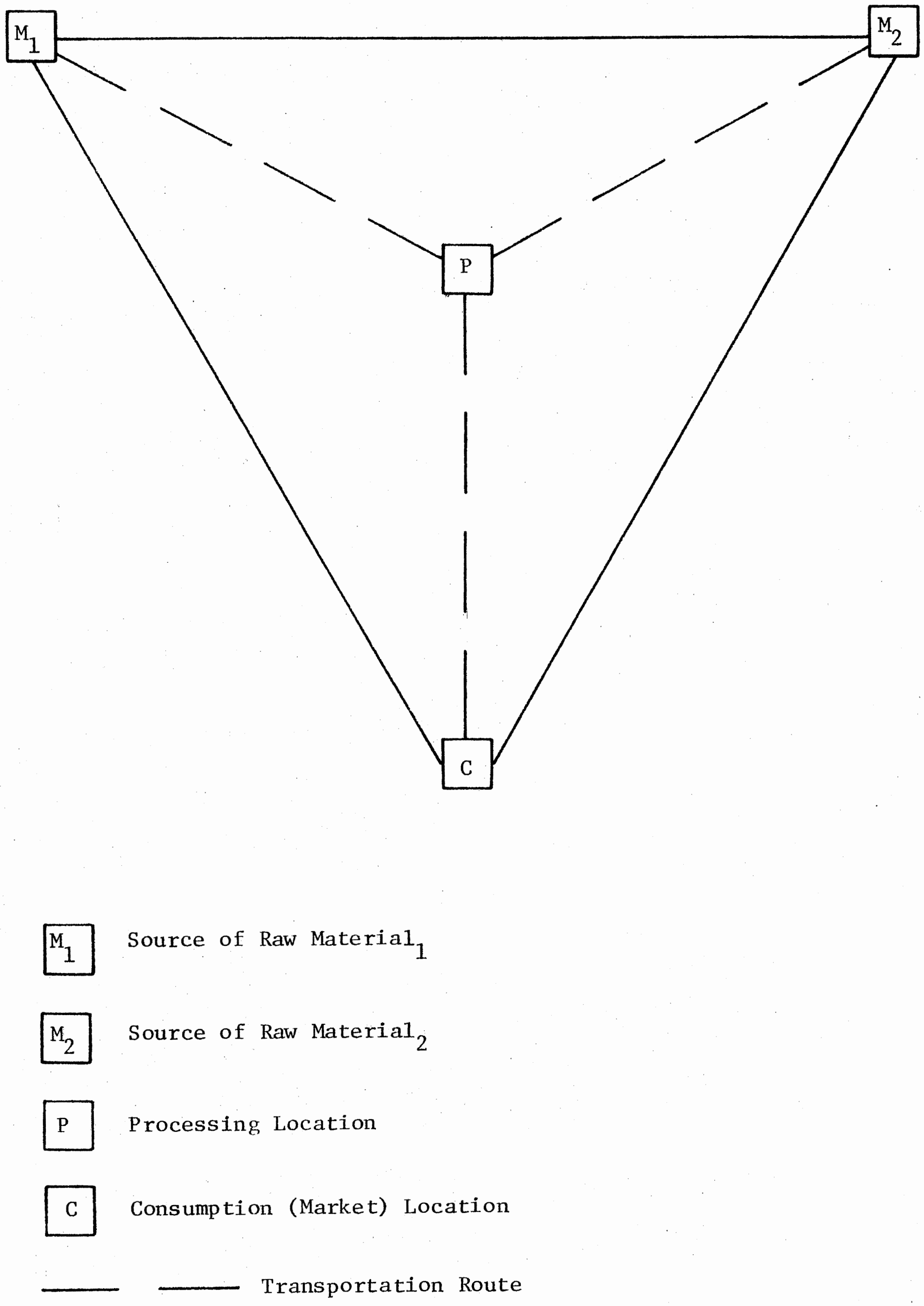


Figure 3. Weber's Locational Triangle

Thus far, this section has dealt with the "fixed market" approach to location theory while early proponents of the "market area" approach include August Losch, Walter Isard, and Edgar Hoover.

August Losch is noted for his location economics theory which can be described as a general equilibrium system incorporating the interrelationships of all locations. Losch was critical of Weber's emphasis on costs and the neglect of demand and price in his analysis.[11]

The assumptions used by Losch as the basis of his theory of the "market area" included the following: 1) raw materials are evenly distributed throughout a wide plain and the plain is homogeneous in all respects, including the population density and 2) each producer on the plain has a natural market area within which he has a delivered cost or price advantage over all competitors when all production costs and transportation costs are included.[12]

The problem faced by Losch is to determine the size and shape of each producer's natural marketing areas. His analysis results in patterns and a clustering of the population and other aggregations. Examples of his implications are presented in Figure 4.[13]

Walter Isard had a magnanimous objective, even if it is regarded as not too realistic, as he attempted to bring all location theory together into a single general doctrine which could be fused with existing production, price, and trade theory.[14] Isard is given credit for incorporating terminal, handling, and other service charges, as well as incorporating different transport rates for raw materials versus finished products into his market area analysis.

The simplifying assumptions by Isard for the transport-oriented equilibrium of a firm were: 1) the firm's productive activities do not

One Seller,
Straight Mileage Rate

Two Sellers,
Equal Straight Mileage Rates
and "Other" Costs

Two Sellers,
Straight Mileage Rates Higher
From X than from Y, Equal
"Other" Costs (Broken line
at Equidistance Points
Between Sellers)

Two Sellers,
Straight Mileage Rates from X
Straight Mileage Rates from Y
Modified by Blanket Beginning
at Equidistance Points, "Other"
Costs Equal

Many Sellers (at Center Points)
Equal Straight Mileage
Rates and Equal "Other"
Costs

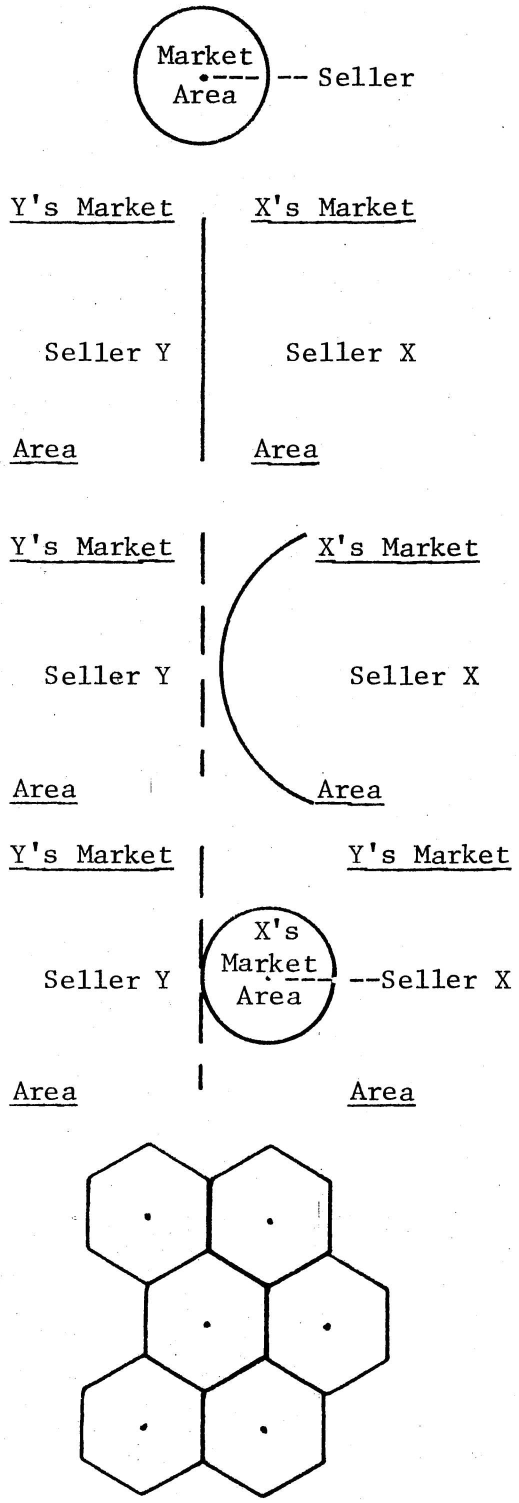


Figure 4. Transportation Costs and Natural Marketing Areas

affect the locus of consumption, transport rates, prices of raw materials, labor and other factors and products, and agglomeration economies and other locational variables and 2) the firm's actions do not provoke retaliatory measures by other producers.[15]

Edgar Hoover's works in location theory and the market area indicate extended applications and analysis in supply areas. Hoover realized Weber's contribution in the theory of relative attractive forces of materials and markets; however, Hoover claims Weber made serious analytical errors by failing to appreciate the full significance of route layouts, junctions, and long-haul economies.[16] As a consequence of Hoover's studies, the boundary lines deciding the supply area among competing firms are determined by the transportation costs and the delivered price at the processing plants.

As an example of a supply area, Hoover cites a situation which indicates grain elevators have supply areas in real life. When sellers are small and highly scattered (i.e., wheat producers) so that an individual buyer has to buy from more than one seller in order to operate on a large enough scale so as to survive, the interindustry locational relationship appears as a system of supply areas rather than market areas.[17]

A microeconomic summation to location theory indicates that to see what factors might change the optimum location of a plant or industry, one should find those factors which are important in determining the site at which the plant maximizes profit. The prices of the inputs and the transportation cost of the inputs to the site of production determine the position of the isocost (equal outlay) lines. The least-cost combination depends upon isocost lines and the production function. Total revenue depends upon individual consumer demands, transportation costs, and distance of the plant from the market. These are the basic determinants of an optimum location.[18]

Location theory, as a separate theory of marketing transportation, can be summarized as seen in Figure 5 in which the component theories of locations and their interaction on regional economics is shown.[19]

## Transportation Economics

To what places will industry be attracted? From the prior discussion on location theory, an industry will clearly be drawn to those locations which have the combined lowest costs of labor and transportation, having regard both for the place of consumption and the place of deposits of raw materials.

Early location theoreticians, such as von Thunen and Weber, assumed those fundamental factors which determine transportation costs are the weight to be transported and the distance to be traversed. Although the assumption is valid, this list of factors of transportation costs is not all inclusive. Nonetheless, these early works pointed out the impact of transportation as a cost of production and that transportation service increases the value of the product by the creation of place utility. Time and form utility are relevant considerations in the development of rate structures and transportation costs.

There are two kinds of transportation costs, according to Weber: transportation costs in the sense of political economy, i.e., the total amount of goods and labor that are absorbed in affecting such a shipment, and transportation costs as understood by the business man paying for the shipment of goods in the sense of the monetary payment made to those furnishing the transportation.[20]

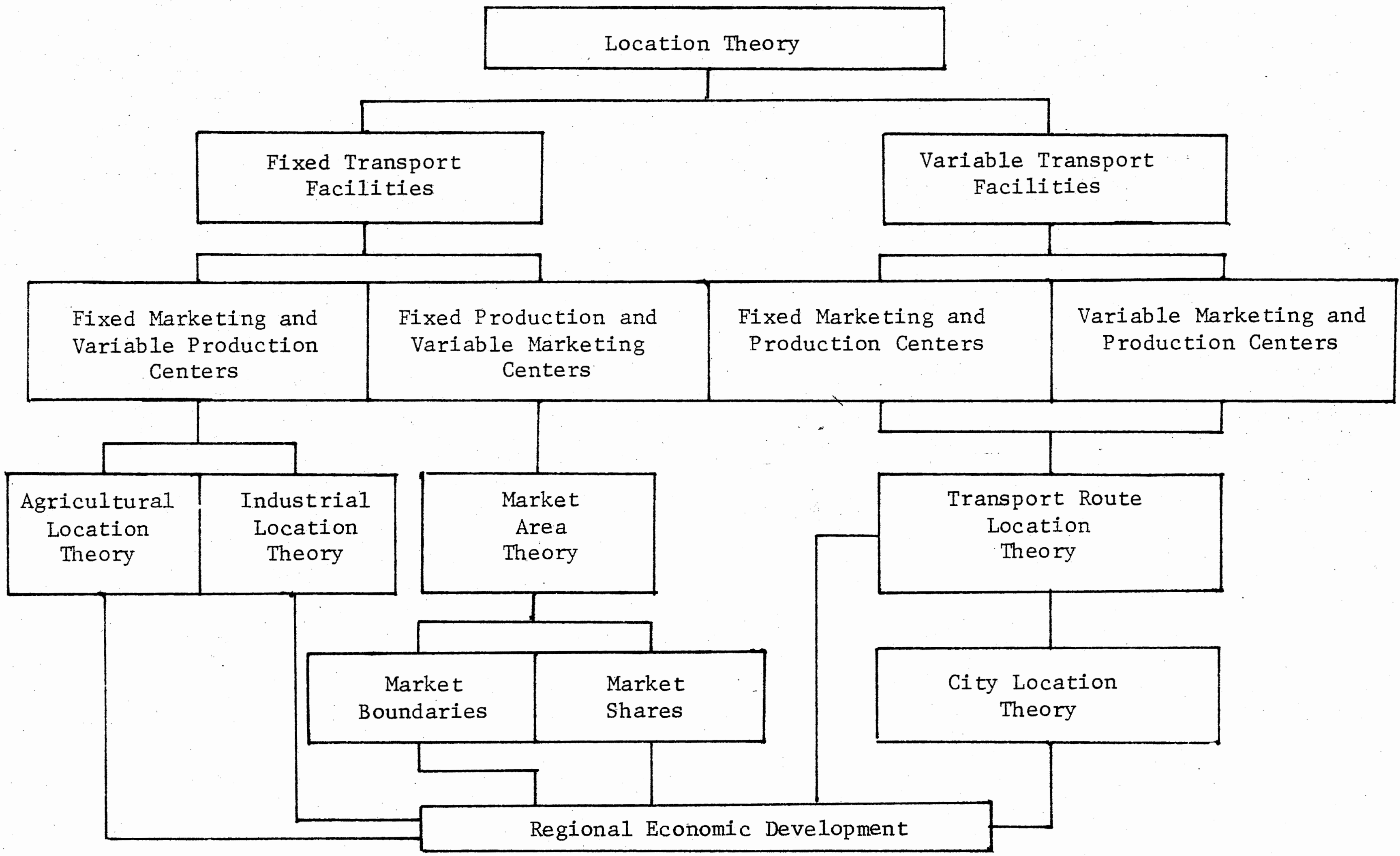


Figure 5. Component Theories of Location

Economic reasoning indicates that in addition to weight and distance, the cost of transportation depends upon the following factors: 1) the type or mode of the transportation system and the extent of its use; 2) the nature or geography of the region and the available transportation network; and 3) the nature of the merchandise itself.

The economic basis for assessing transportation costs to the business man is the use of transportation rates. These rates are prices charged by the freight carriers for performing their services. As simple as the subject of rates and rate-making may appear at the outset, problems of supply and demand of transportation, or of costs and value of service, or of regulation and legal obligations, or of competition and capacity are entwined in an intricate complexity as every offer by every transportation mode and by every transportation company to every consumer for every specific piece of transportation may be different.

Costs are the underlying basis of the supply schedule of transportation services. However, there is considerable disagreement concerning what costs are relevant. A brief overview of pertinent transportation costs reveals the following terminology.

A firm which can cover its variable costs and has sufficient additional revenues to apply toward its fixed costs will prefer to operate in this manner in the short run rather than to cease operations completely. In a competitive situation, then, this gives a short run pricing advantage to firms which have relatively high fixed costs as compared to high variable cost-firms, assuming total costs are approximately the same. Since a long run is made up of a series of short runs, pricing policies which are economically logical in the short run may never cover total costs, leading ultimately to bankruptcy or subsidization. This is the reasoning supportive of regulatory agencies establishing minimum carrier rates deemed by some individuals as excessive profit-granting.

Out-of-pocket cost refers to the added costs incurred in performing an additional service. Economists refer to this as a marginal cost. Nonetheless, in the short run and with excess capacity, a transportation mode can handle any additional traffic which does not contribute more to direct costs than to revenues, while in the long run, capacity should not be replaced unless all costs associated with the capacity and its employment can be recovered.

Common costs and joint costs arise as unallocable costs when two or more kinds of production or output are so interrelated that some costs can not be separated to either one on a rational economic basis. Examples of unallocable costs include portions of fixed and variable costs of hauling more than one type of product per shipment or of back-hauling. As a result, a price for a particular movement can not be based on its specific cost alone.

A carrier's operating costs are composed of terminal costs and line-haul costs, with elements of fixed and variable costs in each. Terminal costs, in addition to fixed costs, may include expenses of such operations as receiving, billing, and loadout. Usually terminal costs are the same for a given shipment regardless of long or short distance movement. Line-haul costs, made up of a higher proportion of variable costs, will be more or less proportionate to the distance hauled. In combining terminal and line-haul costs, the difference between short and long hauls is frequently compensated in tapering rate structures. Agencies with relatively low terminal costs and high line-haul costs have an advantage for shorter hauls, whereas agencies involving high terminal, pickup, and delivery charges and low line-haul costs are in a position to compete more effectively for the long haul business. Such relationships can be seen in Figure 6 which compares the relative transfer costs via truck, rail, and barge as distance increases.

The common cost characteristics of carriers can be summarized so as to include: 1) the prevalence of joint and common costs; 2) the typical large proportion of charges which are constant and fixed; and 3) the tendency to decreasing costs as the volume of traffic increases.

Controversy has occurred over the cost-of-service principle versus the value-of-service principle in rate-making. The latter has sometimes been referred to as "charging what the traffic will bear". The value-of-service consideration arose because losses on low-demand traffic could easily be offset by higher rates on high-demand movements. The tendency of carriers to discriminate, that is, to differentiate rates other than on a cost-of-service basis to favor certain traffic, arises from several factors. First, the incentive to discriminate arises largely from the ever present fact or threat of underutilization of the carrier's facilities--at least of certain routes served or at certain seasons or in one direction of haul. A second force for rate discrimination usually emanates from the shipper who always wants a lower freight classification and a lower rate. The monopoly theory (imperfect competition) of rate discrimination holds that effective carrier competition would eliminate discrimination between commodities because the higher rated traffic is the most attractive to a competitor who would cut rates to get the traffic when, in fact, the most attractive traffic is that which has the greatest potential in revenue production above direct costs. Another factor pertinent to rate discrimination is that a cost-of-service basis

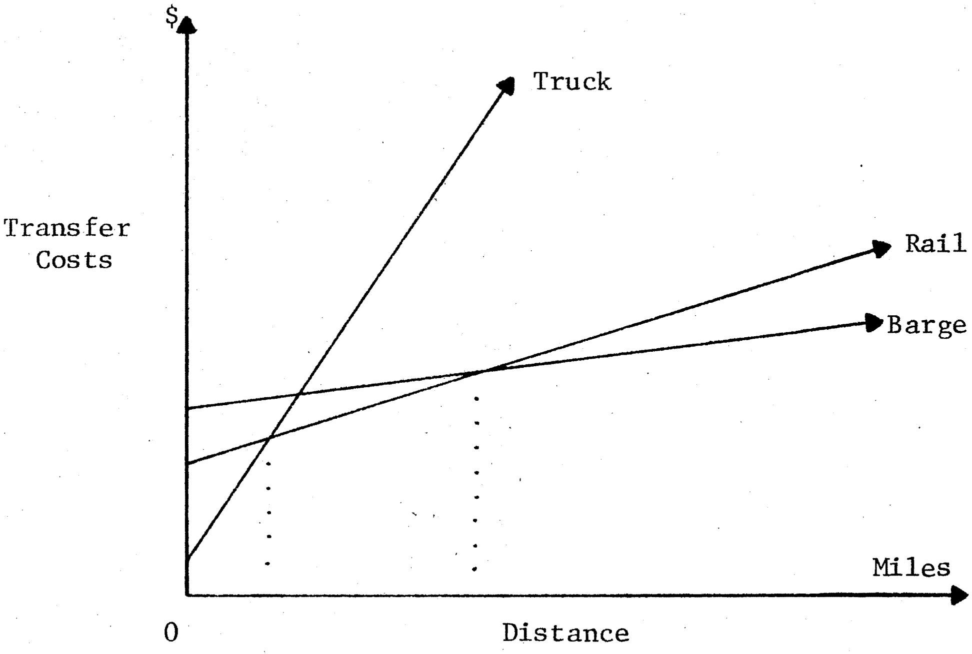


Figure 6. Relative Effect of Terminal and Line-Haul Costs on Modal Considerations

assumes an identity of the demand schedule as well as the supply schedule among commodities moved in the transportation service market.[21]

There are several considerations in determining the value of service. First is the difference in the market price of the commodity 1) at the point of origin and 2) at the point of destination. The degree of competition is another factor, as is the value of the commodity a factor. A fourth factor is the use of rates to develop a new area or industry where no carrier competition is involved.

As an example of modal considerations in the development of freight classifications, the principal cost-of-service classification factors of rail freight are: 1) space occupied in proportion to weight; 2) risks and hazards of handling incident to the nature and value of the commodity and the method of packing; 3) special services required; 4) handling costs incident to the packaging and unusual weight or size of the article; and 5) volume, regularity, and direction of traffic. The coincidental value-of-service factors include: 1) market value of the shipment; 2) market competition of shippers served by other carriers; 3) competition of other carriers; and 4) development of new production and markets.[22] Regardless of mode, whether rail, truck, or barge, the basic cost-of-service factors of rate structures are quantity shipped, distance, and operating conditions, and similar value-of-service factors are standardization of services and competition.

The previous discussion on costs is related to the supply of transportation services. Likewise, the demand for these services is indicative of the value of service, which has been alluded to briefly. The demand for transportation is a derived demand dependent upon the demand for the product being transported. Freight does not move from place to place just for the sake of movement. For products available locally as well as those transported into the area, the demand for transportation may be more elastic than the demand for the product itself. In transportation, three types of demand are considered. First is the aggregate demand for transportation which arises from the demand for all products and is closely related to the general level of economic activity; and, as such, is relatively inelastic. The elasticity of modal demand is significantly affected by the availability and suitability of other transport modes. The last type, particular demand, is influenced by shipper and customer facilities and business arrangements and is the most elastic demand of the three.

Regardless of the type of demand, the demand for transportation is likely to be more inelastic if 1) the demand for the product itself is extremely inelastic; 2) the burden of increased rates can be passed back to earlier production stages; 3) the higher rates can be absorbed easily by the shipper's or receiver's profit situation; or 4) when freight rates are only a small part of the total delivered cost; or 5) when freight rates are very low.[23]

In identifying particular kinds of freight rates, they are categorized according to certain characteristics. Class rates, or exception rates, and commodity rates are rates based on the kinds of things shipped, as are all-commodity or all-freight rates in which the rate quoted is applicable to any kind of product. Additional categories are based on the quantities shipped, route or routing characteristics, previous or future shipments of the product, agreements between carriers and shippers, and a miscellaneous category.[24]

The inclusion of transfer costs in transportation economics aids in the analysis of trade and regional specialization in spatially separated markets and aids in the development of price equilibrium--a consideration necessary in the development of the model utilized later in this study. Commodity prices move toward equality, but equilibrium is attained when prices differ exactly by the transfer costs. The total volume of trade is reduced, the exact effect depending on 1) the shape of the demand and supply curves; 2) the price difference existing in the absence of trade; and 3) the magnitude of the transfer cost. Trade will remain possible and profitable as long as the original difference in price is greater than the transfer costs.

The equilibrium analysis with transfer costs illustrated by a back-to-back diagram is reflected in Figure 7, in which excess supply curves are constructed.[25] Their intersection at $j'$ defines the equilibrium prices with trade, equal to $oc'$ at X and $o'c'$ at Y which differ by $oo'$ or $t$. The distance $c'j'$ represents the volume traded, which equals the quantity $f'g'$ shipped by U and $e'd'$ received by X.

The economic advantages of geographic specialization and large-scale production, as observed in grain marketing, can not be obtained without much long distance movement of bulk freight. The bulk freight service is a concomitant of extensive production, a large scale enterprise concentrating on the movement of traffic in relatively homogeneous flows of large volume at stable low cost. Adequacy and economy are the paramount and universal requirements for bulk freight. Adequacy involves 1) the availability to serve all of the desired areas of the market; 2) the capacity of route and industry to accommodate peak movements; and 3) the regularity of operation.[26] Adequacy is the quantitative aspect

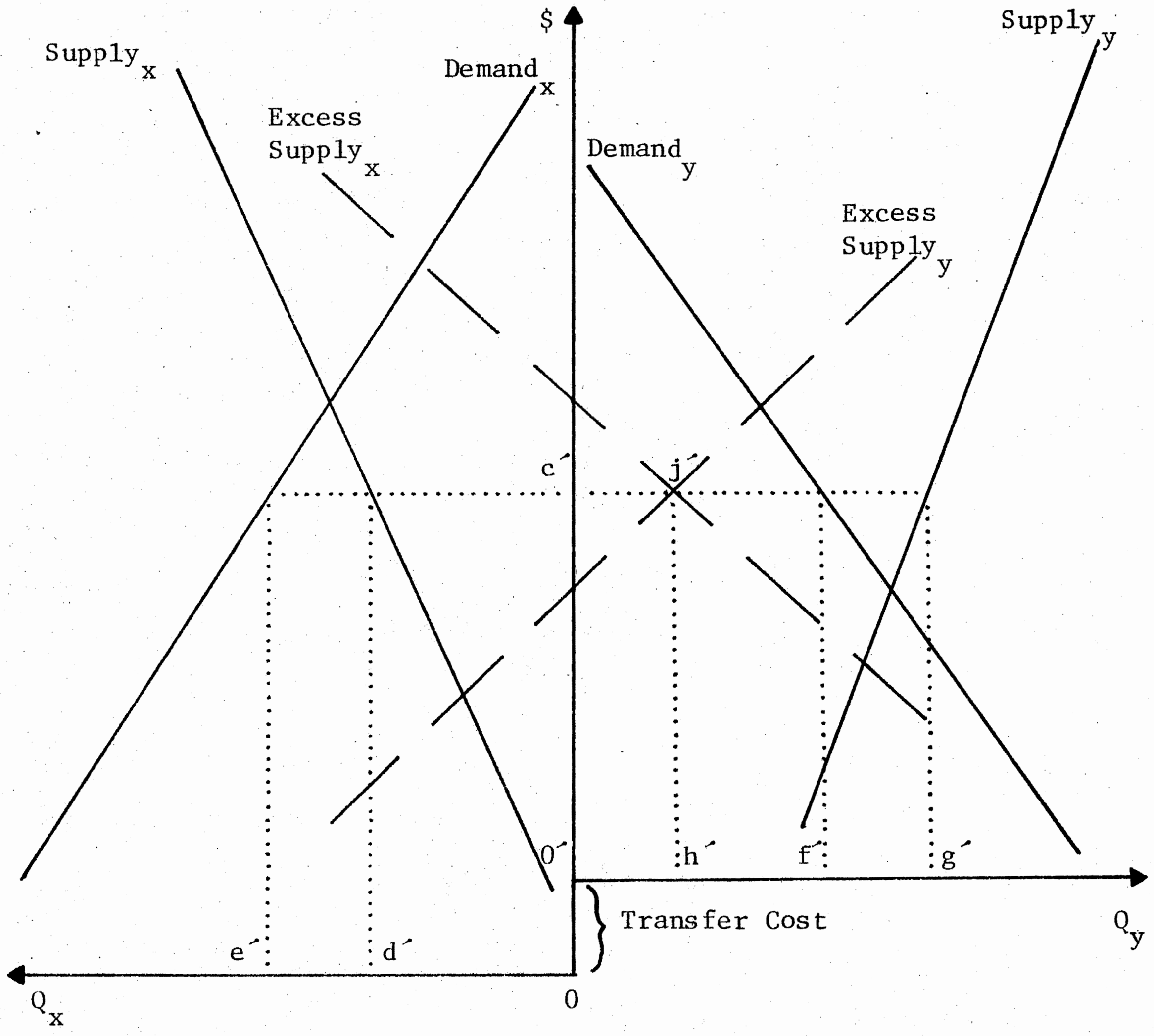


Figure 7. Effect of Transfer Costs on Trade Flow and Price

of transportation service. Under the caption of quality of service requirement, dependability, safety, and sometimes speed are considerations. Should several modal routes be available and adequate, a shipper is likely to base his choice of carrier on cost, as alluded to earlier in this section.

High transportation costs, no matter how large relative to total production costs, are not necessarily an evidence of waste. So long as the total costs of production are no higher because of transportation, no social loss is incurred.

The economic consequences of major improvements in transportation which both reduce the cost of transport and enhance the speed of movement are: 1) the expansion of market areas; 2) the development of cross penetration of markets causing a breakdown of local monopolies in the sale and production of goods; 3) the enhancement of the possibilities for economies of scale in manufacture and distribution; 4) the accessibility to raw material sources even though remote from points of prospective use; 5) the promotion of territorial specialization in production of all kinds; and 6) the increase of the rent value of land, including the reduction or elimination of the restraints upon urban growth and land use.[27]

## Network Analysis

Transportation problems are generally concerned with the distribution of a certain product from several sources of supply to numerous localities of demand. Many of the transportation network flow problems can be formulated as linear programs and their solutions may be obtained by the simplex method. However, a number of special network flow techniques have been developed which are generally more efficient than the simplex method. This section of Chapter II presents a brief historical development of network theory, a linear programming formulation of transportation problems, and a discussion of some of the special agricultural network flow problems and, in general, their solution techniques.

According to the theory of graphs (network theory), a graph consists of a set of junction points with certain pairs of the points being joined by lines; so in its simplest reference, a network is a system of lines or channels connecting different points.

Launhardt, in the late 1800's, gave formal mathematical treatment to the feeder route-main route problem, which is a basic network problem.[28] The same treatment can be applied to the problem of combined modes of transportation and the least-cost transport route as illustrated in Figure 8.

Assume a localized product, such as wheat, is located at point A and is to be hauled to the market at point B with the main-line, low-cost transport route annotated by the line CB, equal to the distance "b". Let "a" represent the most direct route distance (AC) from farm to main-line, and let "d" equal the most direct route possible from A to B (from farm to market).

Assume two modes of transportation available, truck and rail, at rates $r_1$ and $r_2$ dollars per ton mile, respectively with line CB being the low-cost rail line. With $r_1$ being the transport rate per mile from A to any point on CB, the total cost of shipping directly (truck mode only) from A to B is stated as:

$$TC_t = r_1 d = r_1 \sqrt{a^2 + b^2} \ . \qquad (2.1)$$

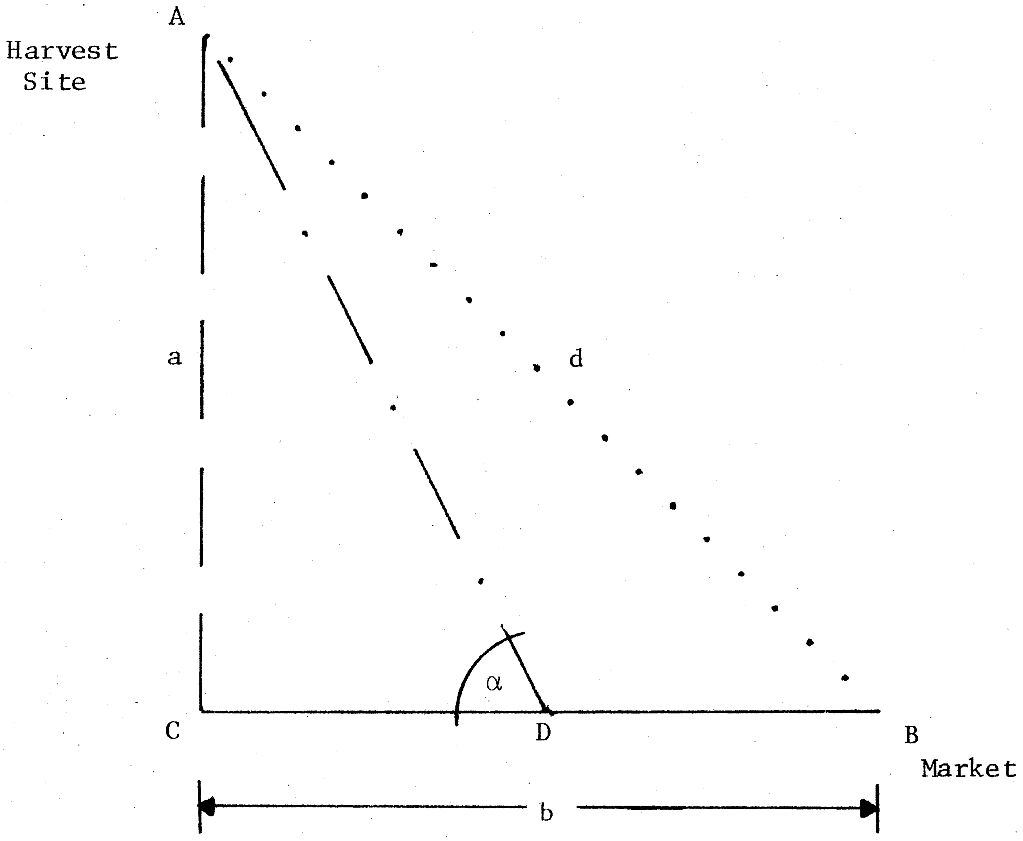


Figure 8. Launhardt's Formulation

The combined mode total cost can be written as:

$$TC_t = r_1 y + r_2 z + C \tag{2.2}$$

where y is the distance traveled by truck, z is the distance traveled by rail equal to b minus x, and C is the special cost of transfering cargo at the transshipment point. Substituting for y and z, Equation 2.2 can be rewritten as:

$$TC_c = r_1 \sqrt{a^2 + x^2} + r_2 b - r_2 x + C \, . \tag{2.3}$$

Since all terms in $TC_c$ above are fixed except x, the value of x that minimizes total cost can be found by taking the derivative of $TC_c$ with respect to x and setting equal to zero, as:

$$\frac{dTC_c}{dx} = r_1 \frac{x}{\sqrt{a^2 + x^2}} - r_2 = 0 \tag{2.4}$$

$$= r_1 \cos \alpha - r_2 = 0 \tag{2.5}$$

or

$$\cos \alpha = \frac{r_2}{r_1} \tag{2.6}$$

The cost minimizing location for transshipment is at point D where $\cos \alpha$ equals the ratio of the transport rates.

By defining $\frac{x}{y} = \frac{r_2}{r_1}$ or $x = y \frac{r_2}{r_1}$ and since $\sin \alpha = \frac{a}{y}$ or $y = \frac{a}{\sin \alpha}$, Equation 2.3 can be rewritten as:

$$TC_c = r_1 \frac{a}{\sin \alpha} + r_2 \left[ b - \frac{r_2}{r_1} \frac{a}{\sin \alpha} \right] + C \, . \tag{2.7}$$

Therefore the equation for the curve representing locations where the cost of the combined modes is equal to the cost of the single mode may be written as:

$$r_1 \sqrt{a^2 + b^2} = r_1 \frac{a}{\sin \alpha} + r_2 b - \frac{r_2}{r_1} \frac{a}{\sin \alpha} + C \; . \tag{2.8}$$

To find the point on CB where single and combined modes are equally costly, let $a = 0$, then:

$$r_1 b = r_2 b + C \tag{2.9}$$

or

$$b = \frac{C}{r_1 - r_2} \tag{2.10}$$

If the special cost $C = 0$, the equal cost boundary is the straight line through B forming angle $\alpha$ with CB. If $C \neq 0$, the boundary is not a straight line but arcs of circles as indicated by $TC_t$.

Just as Launhardt's treatment is an optimization procedure, so are the various network analyses, including linear programming. Linear programming is a computational technique to determine the best plan or course of action, among many which are possible when there are many alternatives for the plan, a specific numerical objective exists, and the means or resources available for attaining it are limited.[29]

There are three basic components to linear programming: an objective function, alternative methods or processes of attaining the objective, and the resources or other restrictions. These components are evidenced in the general format for the linear programming problem:

$$\begin{aligned} \text{Maximize:}\quad & Z = c_1x_1 + c_2x_2 + \dots + c_nx_n \\ \text{Subject to:}\quad & a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \leq b_1 \\ & a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \leq b_2 \\ & \vdots \qquad\qquad\qquad\qquad\qquad\quad \vdots \\ & a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \leq b_m \end{aligned}$$

where $x_1, x_2, \ldots, x_n \geq 0$,

$b_i$ = amount of $i^{th}$ resource available,

$x_j$ = level of $j^{th}$ activity,

$a_{ij}$ = amount of $i^{th}$ resource required per unit of $j^{th}$ activity, and

$C_j$ = return per unit of $x_j$ to unpaid resource.

Or, in matrix notation:

$$\text{Maximize } Z = C'X$$

$$\text{Subject to: } AX \overset{<}{\underset{>}{=}} B$$

$$X \geq 0$$

where A = mxn matrix of technical coefficients,

C = nxl vector of returns, prices, or other weights for the objective function,

X = nxl vector of activities, and

B = mxl vector of resource restrictions or other restraints.

The basic assumptions of the linear programming model include: 1) additivity of resources and activities; 2) linearity of objective function; 3) nonnegativity of decision variables; 4) divisibility of activities and resources; 5) finiteness of resources and activities; 6) proportionality of activity levels to resources; and 7) single-valued expectations.

The simplex method of solutions is an iterative solution technique that introduces slacks to make equalities out of inequalities. The procedure 1) reduces inequality constraints to equalities; 2) defines an initial feasible solution; 3) moves from the initial feasible solution to a "better" solution in an iterative fashion; and 4) finally determines the solution that optimizes the objective function.

Numerous optimization articles by applied economists have been published in which linear programming is the research tool utilized in solving the problem addressed. The nature of the problems has been diverse with recent attention being placed on transportation economics. Examples of these articles include those relating to location theory, i.e., Doeksen and Oehrtman,[30] and King and Logan,[31] as well as transportation models.

* The objective of linear programming transportation models is to meet a set of restraints at minimum cost. The transportation models seek to supply the product deficit locations from surplus quantities available in other locations at minimum cost, such as addressed by Leath and Blakley.[32] ✓

The transshipment model in linear programming is similar in structure to the transportation model with the exception of the introduction of intermediate destinations from which the commodities are transported to final destinations via shipping activities. The objective is to define the mix of shipment routes that will minimize the cost of transporting the merchandise typically from the producing regions to the destination points in the quantities required, as performed by Fedeler and Heady.[33]

Variations to the linear programming methods and problems just described include assignment problems and least-cost transportation problems. Examples of assignment type problems addressed by management and agricultural economists are assigning the jobs to the machines so as to minimize the total cost of machining, or finding that ship-berth assignment at an export grain terminal which will minimize the total ship-days of loading time.

The least-time transportation problem is concerned with meeting the demands at the markets in the least possible time. The transportation cost is not of primary importance. Such problems arise when perishable goods have to be transported without spoilage, as is the case for most livestock products and fresh produce.

Various models and computer algorithms have been publicized which use procedures that are, in essence, extensions of the basic linear programming transportation model. The simplex procedure accredited to Dantzig has been presented earlier in this section.

John Stollsteimer's working model for plant numbers and locations permits the simultaneous determination of the number, size, and location of plants that minimize the combined transportation and processing costs involved in assembling and processing any given quantity of raw materials produced in varying amounts at scattered production points.[34] Four economic cases are considered: economies of scale in plant operations with plant costs independent of plant locations, economies of scale in plant operations with plant costs varying with location, no economies of scale in plant operations and plant costs idependent of plant location, and no economies of scale in plant operations with plant costs dependent upon plant location. The relaxation of the assumptions pertaining to plant numbers and locations permits analysis of long-run problems involving changes in the entire system.

A modification of the Stollsteimer location model has been applied to the Florida orange industry. Rather than assuming a continuous plant cost function, Chern and Polopolus substituted a discontinuous plant cost function, as well as explicitly distinguishing between plant numbers and plant locations through the use of the concept of maximum plant size, and incorporating a measurement of excess plant capacity in optimal solutions.[35] These changes to Stollsteimer's original model were done so as to improve upon the construction of his model and to enhance its empirical realism.

Warrack and Fletcher suggest an iterative algorithm that enlarges the scope of the problem addressed by Stollsteimer's basic computational model.[36] As such, a large number of plants may enter the optimal solution (the objective is minimizing the total combined transfer plus manufacturing costs) in solving for the number of plant locations that should be used, the locational configuration for the plant locations, and the size of plant at each location chosen.

Another procedure for the modified Stollsteimer model advanced by Chern and Polopolus is that of Fuller and Seilken.[37] This is an efficient solution procedure that may yield a lower total cost solution than does the method developed by Chern and Polopolus, which introduced a discontinuous plant cost function.

Concurrent to the Stollsteimer-type modeling studies are computerized methods of sequential programming which deal with the aspects of routing and scheduling. These pickup and delivery procedures are the forerunners of network analysis in agricultural economics.

The "lockset method" of sequential programming, as described and developed by Schruben and Clifton, provides a feasible-rational rather than a feasible-optimum solution, and, therefore, is a tool to aid a dispatcher in route selection.[38] This procedure enables a dispatcher to design delivery routes by selecting a set of stops to be included on a given route, finding a sequence on a given route, and finding a sequence for each set. In achieving the objective of minimizing the total distance traveled by all carriers, the minimum number of carriers tends to be used. Ex-post route comparisons with those actually considered by firms indicate the validity and relative worth of the lockset procedure.

A subsequent technique to the lockset method is an associated procedure developed by Hallberg and Kriebel entitled "ROUTE".[39] This heuristic program formulates efficient routes for delivery or assembling products (or people) to or from a centrally located facility. Issues addressed by the model include evaluating the impact of overtime, changing delivery conditions, increasing the number of stops (customers), and changing the frequency of delivery. The total number of feasible applications is virtually unlimited.

To facilitate a synopsis of network analysis, the following glossary of network terminology is presented.[40] As mentioned earlier, a network or graph consists of a set of junction points called nodes, with certain pairs of the nodes being joined by lines called arcs or branches. Figure 9 is an example of a graph, where the circles are the node designators and the lines connecting them are the arcs or branches. A network is a graph with a flow of some type in its branches. Table I suggests several examples of systems satisfying the definition of a network.

A chain between nodes i and j is a sequence of branches connecting these two nodes. One of the chains connecting nodes A and D in Figure 9 is the sequence of branches AB, BC, CD, or AC, CD, or other possibilities. When the direction of travel along the chain is also specified, it is called a path. A cycle is a chain connecting a node to itself, such as AC, CD, DB, and BA in Figure 9. A graph is a connected graph if there is a chain connecting every pair of nodes; therefore, Figure 9 is a connected graph. A tree is a connected graph containing no cycles, such as in Figure 10.

TABLE I

COMPONENTS OF TYPICAL NETWORKS

| Nodes | Branches | Flow |
|---|---|---|
| Intersections | Highways | Vehicles |
| Airports | Air ways | Aircraft |
| Switching points | Wires, channels | Electricity |
| Pumping stations | Pipes | Liquid |
| Work centers | Material-handling routes | .Finished Products |

A branch or arc of a graph is oriented or directed if there is a sense of direction attributed to the arc so that one node is considered the point of origin and the other node the point of destination. An oriented graph is one in which all the branches have direction. If an oriented graph is a network, the orientation of an arc is the feasible direction of flow along the arc. A network need not be oriented, however, as it may be feasible to have flow in either direction along an arc. The flow capacity of a branch in a specified direction is the upper limit to the feasible rate of flow in the arc in that direction. The flow capacity may be any nonnegative quantity, including infinity.

A node in a network is called a source if every one of the arcs has an orientation such that the flow moves away from that node. Similarly, a node is referred to as a sink if each of the network's arcs is directed toward that node. Thus, sources may be thought of an supply points or

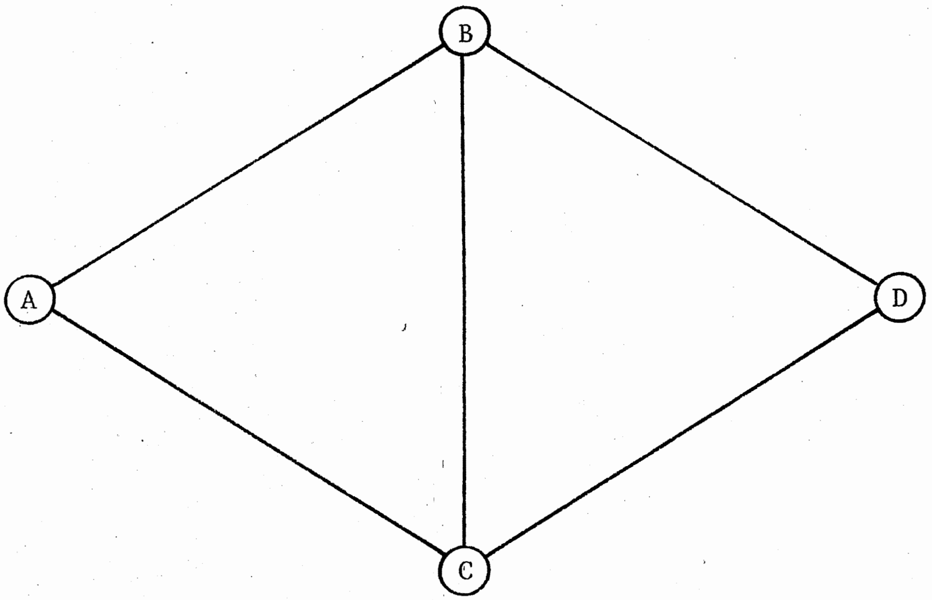


Figure 9. Network Graph Example

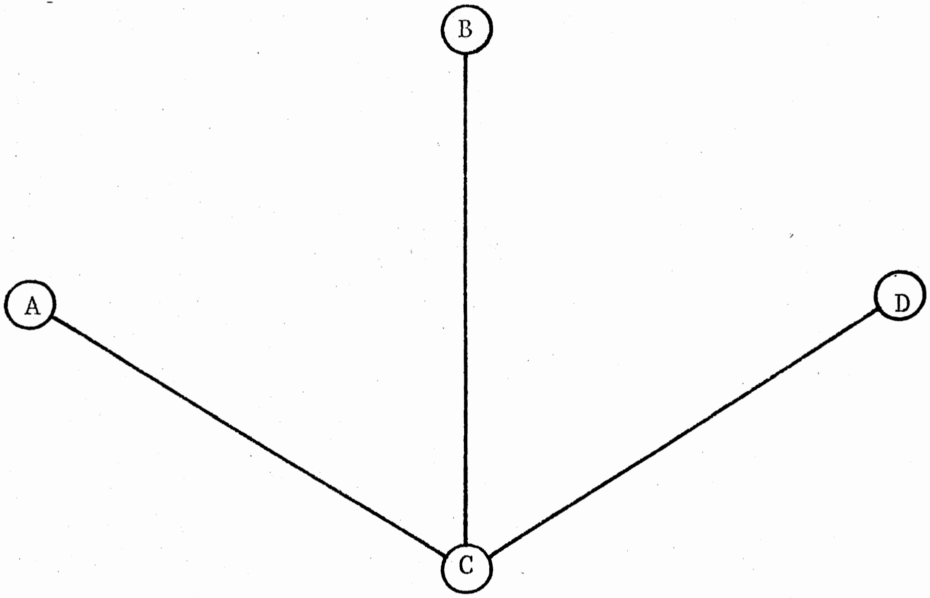


Figure 10. Network Tree Example

generators of flow and sinks as absorbers or demanders of that flow.

The rest of this section is devoted to a discussion of various network problems and their solution procedures or algorithms.

Not only is time critical in assignment and least-time transportation problems as mentioned earlier, but also in the careful planning, scheduling, and coordinating of interrelated activities by the management of large scale projects. Formal procedures to aid in these tasks were developed in the late 1950's based on network theory. The most prominent of these procedures have been PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method). The trend in recent years has been a merger of the two approaches into a PERT-type system.[41]

A PERT-type system is designed to aid in planning and control, so it may not involve much direct optimization. Sometimes one of the primary objectives is to determine the probability of meeting specified deadlines, in which case the three time estimates used by PERT are a most-likely estimate, an optimistic estimate, and a pessimistic estimate. PERT also identifies where the greatest effort should be made to stay on schedule. A third objective is to evaluate the effect of changes in the program as well as evaluate other resources and performance tradeoffs. A PERT-type system also evaluates the effect of deviations from schedule.

All PERT-type systems use a network to graphically portray the interrelationships among the elements of the project. This representation shows all the precedence relationships regarding the order in which tasks must be performed.

In PERT terminology, each arc or branch of the network represents an activity, which is one of the tasks required by the project. Each node represents an event, which is defined as the point when all activities leading into that node are completed.

In contrast to the original PERT, CPM assumes deterministic activity times which are reliably predicted without significant uncertainty, and CPM places equal emphasis on time and cost (rather than explicitly emphasizing time) by constructing for each activity a time-cost curve which plots the relationship between the budgeted direct cost for the activity and the resulting duration time. The plot is based on two points: the normal point giving the cost and time involved when the activity is performed in the normal way without any extra costs being expended to speed up the activity, and the crash point based on the activity being fully expedited with no cost spared to reduce the duration time.

The basic objective of CPM is to determine which time-cost trade off should be used for each activity to meet the scheduled project completion time at a minimum cost.

Although PERT-CPM analyses are not a managerial panacea, they do lay the basis for anticipatory management action against potential trouble spots based on the use of networks and network techniques.

One basic problem of network theory that commonly arises in the study of transportation systems is finding the shortest route through a network. The shortest-route problem is concerned with finding the shortest route from an origin to a destination through a connecting network given the nonnegative distance associated with the respective arcs of the network.

Although various solution procedures have been proposed, one of the most efficient algorithms is given by Dijkstra, as presented by Dreyfus.[42] The direct distance between any two nodes ($d_{ij}$) in the network of n nodes is assumed given, and all the distances are nonnegative. The algorithm assigns to all nodes a label which is either temporary or permanent. A temporary label represents an upper bound on the shortest distance from an initial node to a specified node, while a permanent label is the actual shortest distance from node 1 (the initial node) to that node.

Initially the source node 1 is given a permanent label of zero. All other nodes (2, 3, ..., n) are assigned temporary labels equal to the direct distance from node 1 to the node in question. Any node which can not be reached directly from node 1 is assigned a temporary label of $\infty$, while all the other nodes receive temporary labels equal to $d_{ij}$. Dijkstra's algorithm then makes tentative node labels permanent labels one at a time. As soon as the sink node (destination) receives a permanent label, the shortest distance from the source node to the sink node is immediately known.

To find the sequence of nodes in the shortest path from node 1 to node n, a label indicating the node from which each permanently labeled node was labeled is available, so by retracing the path backwards from the sink node to the source node, the minimal path is constructed. An alternative method is to determine which nodes have permanent labels that differ by exactly the length of the connecting arc, and by retracing the path backwards from n to 1, the shortest path may be found.

The major dynamic programming procedures proposed for solving shortest-route or least-cost route problems when only one node of transportation is possible are those of Dijkstra, Bellman and Ford, Floyd, and Dantzig. Of these, the Dijkstra and Bellman-Ford procedures solve the problem for a given pair of nodes whereas the Floyd and Dantzig procedures solve the problem for all pairs of nodes simultaneously.[43]

The essence of one of the shortest and simplest shortest-route procedures is that it fans out from the origin, successively identifying the shortest route to each of the nodes of the network in the ascending order of the shortest distances from the origin, thereby solving the problem when the destination node is reached.[44] For each of the original nodes connected by a branch to a new node not yet reached the technique computes the sum of 1) the known shortest distance from the origin to that node and 2) the distance from that node to the nearest new node along a single arc or branch. Each sum must be the distance along the corresponding route from the origin to this new node. Thus, the new node corresponding to the smallest sum must be the new node that is closest to the origin and the shortest route must be the route whose distance yields this smallest sum.

Therefore, to find the shortest route from origin to destination, repeat the above process of finding the nth nearest node to the origin successively for n = 1, 2, and so on until the destination node is reached.

The minimal spanning tree problem is a variation of the shortest route problem.[45] As before, a set of nodes and the distances between pairs of these nodes are given; however, the branches between the nodes are not specified. So, rather than finding the shortest route through a fully defined network, the problem involves choosing the branches for the network that have the shortest total length while providing a route between each pair of nodes. The branches are chosen in such a way that the resulting network forms a tree that spans all the given nodes. Concisely, the problem is to find the spanning tree with the minimum total branch length.

This problem has a number of important practical applications in planning transportation networks. One key agricultural example is the bulk tank pickup of milk from dairy farmers by milk cooperatives in which the bulk truck driver services all the dairy farmers in a minimum total distance.

The minimal spanning tree problem can be solved in a straightforward manner. Beginning with any node, the shortest possible branch to another node is selected without worrying about the effect of this choice on subsequent decisions. In the next stage of the process, the unconnected node that is closest to either of these connected nodes is identified and the corresponding branch is added to the network. The process is repeated until all the nodes have been connected. The resulting network is "guaranteed" to be a minimal spanning tree.

A number of seemingly different problems can be formulated as shortest route problems. Examples include 1) the problem of equipment replacement so as to minimize the total costs to management, which include capital cost, cost of maintenance, and running costs, and 2) the problem of storage of dissimilar sized objects.

Another fundamental problem that arises in the study of transportation systems involves allocating flows to maximize the flow through a network connecting a source and a destination. The flow network will generally consist of some intermediate nodes, known as transshipment points, through which the flows are rerouted. The network also consists of a number of arcs, associated with each of which is a maximum flow capacity in each direction.

A formal description of the maximal flow problem assumes a connected network having a single source and a single sink or destination and further assumes conservation of flow (flow into the node equals flow out of the node, i.e., supply equals demand) at each node other than the source and the sink. It is also assumed that the rate of flow along an arc from one node to another is any nonnegative quantity not exceeding the specified flow capacity of that arc. The objective is to determine the feasible steady-state pattern of flows through the network that maximizes the total flow from source to sink.[46]

The procedure is to repeatedly select any path from the source to the sink and assign the maximum feasible flow to that path, continuing the process until no more paths still have strictly positively flow capacity. Since this indiscriminate selection of paths for assigning flows may prevent the use of a better combination of flow assignments, a refinement to the process undoes a previous assignment to make room for a better one by permitting assignment of fictional flows in the wrong direction along an arc when the real effect of the assignment is to cancel out part or all of the previously assigned flow in the right direction. To permit this, whenever some amount of flow is assigned to a branch in one direction, the remaining flow capacity in the opposite direction for that arc is increased by the same amount.

The most difficult part of this procedure when large networks are involved is finding a path from source to sink with positive flow capacity. To simplify the task, all nodes are determined that can be reached from the source along a single arc with positive flow capacity. For each of these nodes reached all new nodes not yet reached that can be reached from this node along an arc with positive flow capacity, are determined. This process is repeated successively with the new nodes as they are reached. The result is the identification of a tree with all the nodes that can be reached from the source along a path with positive flow capacity. This fanning out procedure always identifies a path from source to sink with positive flow capacity, if one exists.

Although the above procedure is relatively straightforward, recognition of reaching optimality is desired to avoid an exhaustive search for a nonexistent path. This recognition is sometimes possible due to an important theorm in network theory known as the Max-Flow Min-Cut Theorem attributed to Ford and Fulkerson.[47] A cut is defined as any set of oriented arcs containing at least one arc from every path from source to sink. The cut value is the sum of the flow capacities of the arcs in the specified direction of the cut. The max-flow min-cut theorem states that, for any network with a single source and sink, the value of the maximal flow from source to sink is equal to the capacity of the minimal cut.

Using the max-flow min-cut theorem, the maximal flow in a network can be found by finding the capacities of all the cuts, and choosing the minimum capacity. Though this process gives the maximal value of the flow, the route of the flow through the various arcs is not specified, which leads to a procedure called the maximal flow algorithm whose validity is based on the max-flow min-cut theorem. The basic principle of the algorithm is to find a path through which a positive flow can be sent from the source to sink. This path is termed a flow augmenting path and is used to send as much flow as possible from source to sink. This iterative procedure is repeated until no such flow augmenting path can be found at which time the maximal flow is determined.

A variation to the basic maximal flow problem is the consideration of a network with several supply points and demand points. The problem is to maximize the flow from all the sources to all the destinations, which is an application of a transshipment problem with multiple sources and sinks.[48] The max-flow algorithm can be applied to solve this problem by converting to a single source-single sink situation. Creation of an imaginery super source and an imaginery super sink solves the dilemma. From the super source a directed arc is created to every one of the real sources such that the super source becomes the supplier to the real sources. Similarly, from each one of the real sinks, a directed arc to the super sink is created. By applying the max-flow algorithm, the flow from the super source to the super sink is maximized, which is equivalent to maximizing the flow from all the sources to all the sinks.

This transshipment problem is typical for agricultural commodity marketing in which there are numerous farmers producing goods over a diversified area and the markets are also many in number and occasionally diffused in concentration. The transshipment procedure discussed above is the foundation for the model developed in this study and is elaborated upon in the next chapter.

A most important problem to the economist in resource allocation involves the minimal cost flow in which costs have been associated with volume flows along each arc in the network. An assumption to the procedure is that the flows along all branches are symmetrical (the capacity and the cost to transfer a unit of quantity is the same in either direction along an arc). The problem is to find that flow assignment along each branch which will ship some specified (and feasible) amount from the source to sink via the cheapest combination of chains.

Busacker and Gowen developed an algorithm for solving this problem.[49] Initially flow capacity along an arc is designated as is the cost of shipping a unit along the same arc. A flow of zero is assigned to each and every arc. A "modified cost" associated with shipping a unit along the arc is established, subject to a specified relationship of the created flow to the flow capacity. The final step is to identify the minimal cost chain from source to sink, considering the shipping costs along the arcs in the chain. This is done by assigning the maximum allowable flow along the chain by adding, to the flow already assigned, the new flow assignment. If the flow from source to sink is the specified and feasible amount, terminate the procedure; otherwise, redesignate the "modified cost" according to the flow relationships developed by Busacker and Gowen.

The prior procedure has the disadvantage of forcing an exhaustive search for a complete chain from source to sink prior to labeling any nodes or making any flow assignments. A more general procedure, and one which is more attractive for large minimum cost flow problems, is a variation of the transshipment solution alluded to earlier in this section, and which is described in the next chapter of this study.

Rural and agricultural transportation economics problems have been successfully analyzed by applied economists using linear programming procedures. Recent literature has alluded to the superiority of network algorithms in comparison to linear programming with respect to computer efficiency, flexibility, realism, spatial and temporal dimensions, and the inclusion of finite details and data. Many of the linear programming articles relating to transportation and transshipment, i.e., Leath and Martin,[50] and Fedeler and Heady,[51] have a network structure but little comparative analysis has been performed to determine the relative superiority of linear programming or network analysis for certain types of problems. Fuller and Shanmugham have presented an article which demonstrates the potential use of network models in transportation research and compares the computer efficiency and flexibility of linear programming versus network flow models.[52] Their results show the network algorithm used is substantially faster (approximately 50 times) than linear programming and this indicates the network analysis is clearly more computer solution efficient for heavily constrained large models. They further conclude that network models are superior research tools to analyze transportation problems as long as the problems do not include concave costs nor require preservation of more than one commodity's identity throughout the network system.

## Grain Distribution

With a basic understanding of linear programming and its related models, and of network analysis, its terminology and procedures, a review of some of the major grain distribution studies of the past decade is presented. Four types of studies are presented: linear programming and Stollsteimer modifications, systems analysis, simulations, and network analysis. The various studies presented in each category are combinations of interregional or intraregional flows, and all grains or wheat only.

The first studies reviewed in this section are linear programming or Stollsteimer modifications analyzing interregional flows within the entire grain industry. Leath and Blakley (1971) developed a multiproduct linear programming transshipment model capable of determining simultaneously the geographical flows of wheat, feed grain, soybeans, and wheat flour that minimize the total cost of storage, assembly, milling, and distribution for the grain marketing industry.[53] The linear programming model contained five primary products, two processed products, 42 domestic regions with associated production, commercial storage, and flour-milling activities, and 13 export regions, and flour and grain demands associated with each region.

The total cost function for the grain marketing industry with the objective of minimizing total cost was presented via the mathematical definition of the transshipment model. The specified constraints included: 1) off-farm sales of a particular product in a given region plus carry-over from the previous period plus any transshipments into that region must equal all outshipments from that region plus the ending inventory in that time period; 2) shipments into a particular region must equal the requirements to satisfy the grain demand in that region; 3) storage and processing in a particular region is limited to the available capacities; 4) the quantity milled of a particular product in a given region equals the inshipments of wheat to that region and the outshipments of flour from that region; and 5) flour receipts in a region equal the flour demand of that region by type of flour.

The restrictive assumptions made by Leath and Blakley to simplify the model to a manageable size stated that 1) regional production and consumption takes place at particular points in each region, and quantities supplied and demanded are preassigned; 2) transfer charges between regions include loading and receiving costs, and the per unit transfer charge is independent of the quantity moved; 3) only that quantity of wheat needed to meet the domestic and export demands for flour is processed; 4) feed grains are perfect substitutes and requirements are met by the least-cost delivered grain; 5) feed milling is decentralized and occurs at points of consumption; 6) soybean-crushing plants are the final domestic demand for soybeans; and 7) the domestic demand for durum wheat for processing is specified at the durum-product mill site.

In analyzing their results and comparing the various models run, Leath and Blakley implied that incentives existed for shifts in the location of flour milling, especially hard wheat, as the key element affecting flour mill location had been the cost relationship of wheat and flour transportation whereas flour-mill location was becoming more transportation rate structure-oriented and more market-oriented with respect to hard wheat milling. Another conclusion attained was that the results of spatial models are very sensitive to the assumptions or restrictions involved in their formulation, causing significant changes in flow patterns of flour. The results of the time-staged model accentuated the importance of regional storage capacity restrictions.

The analyses performed by Leath and Blakley are a benchmark among grain marketing and transportation studies. Schnake and Franzmann reformulated the previous transshipment model utilizing the same elements and assumptions.[54] Their objective was to evaluate the interregional aspects and competitive structure of the grain marketing system through a transshipment model that incorporated cost-of-service transportation rates, rather than those rates published in the transportation rate structure.

The results obtained by Schnake and Franzmann, although closely related to those obtained by Leath and Blakley, indicate a relative savings in marketing costs using a cost-of-service transportation rate structure as compared with the existent published rate structure. Further implications show long run structural patterns being affected by changes in the rate structure to a cost-of-service orientation.

The general objective of the research done by Baumel, Drinka, Lifferth, and Miller was to determine a grain distribution system which would yield the maximum joint net revenue within a specified region of Iowa.[55] Net income was defined as the gross income from the sale of grain delivered to one or more markets, minus all transportation costs from farm to market, costs of non-farm storage, variable handling and facility investment costs, and rail line maintenance and upgrading costs.

The model utilized was a Stollsteimer-type two-stage, multi-period transshipment plant-location procedure which systematically compared alternative grain distribution systems and selected the optimal configuration based on the criteria of maximum joint net revenue from producers. The transportation alternatives considered included single and various multiple rail car shipments, truck, truck-barge, and rail-barge. The concept of subterminals for loading multiple car shipments was also considered.

From a transportation policy standpoint, the results showed the highest net revenue being obtained from a subterminal system using unit trains operating continuously between the Gulf ports and the specified subterminals within the study region. This conclusion reduced the investment in equipment and facilities and in capacity to move large quantities of grain with minimum congestion; although this modal system ignored the realities of modal and marketing services competition and of separate ownership (by the authors' own admission).

The overall objective of the study by Tyrchniewicz and Tosterud was to develop a framework within which rationalization of the grain transportation and handling system could be analyzed.[56] Rationalization, in grain marketing, usually refers to rail abandonment and the subsequent abandonment of country grain elevators located on the uneconomical branch rail-lines, although another interpretation of rationalization is the trading and consolidation of elevators by grain handling companies.

The Stollsteimer plant location model was the basis for the rationalization simulation model as the Stollsteimer model determines the number, size, and location of raw material processing plants that minimize the combined collection and processing costs, as described in the earlier section on network analysis. Modifications to the Stollsteimer model for applying the CHAD (collection, handling and distribution) simulation included: application to the grain marketing functions in Western Canada, introduction of a grain collection cost function, inclusion of a grain distribution activity, consideration of existing country elevators, and the introduction of institutional constraints.

By incorporating many simplifying assumptions, a basis (the current system) was developed from which to compare iterative simulations of branch line and elevator abandonment. The results of the CHAD simulation model presented by Tyrchniewicz and Tosterud, although naive in mathematical objectivity, reveal an attempt at measuring simultaneously the economic impact of branch line and elevator rationalization on farmers, railways, and grain elevator companies. Even though the model is based primarily on economic considerations, an inherent problem of evaluating the social and political costs and benefits of rationalization exists. The empirical results imply the farmer will bear the blunt of increased transportation and handling charges resulting from rationalization.

Ladd and Lifferth expanded the study by Tyrchniewicz and Tosterud to a two commodity, multiperiod, two-stage hierarchical transshipment problem with variable numbers, sizes, and locations of transshipment plants and variable rail networks to maximize incomes of grain producers.[57] The method utilized extends the Stollsteimer model to determine the heuristic optimal number, size, and location of processing plants when 1) transport costs from origins to plants and from plants to destinations are relevant; 2) multiple transshipment over time and space occur; 3) facilities exist at the beginning of the planning horizon; 4) a capacity constraint is imposed; and 5) economics of scale in rail transportation exist.

A number of solutions were obtained so as to analyze the effects of different rail abandonment plans, different rate structures, and different prices. The results by Ladd and Lifferth indicate a grain transportation system having fewer rail lines would increase joint net revenue, and country elevators incapable of loading multiple-car trains would be used as storage facilities and would transship much of their grain to market through inland terminals or subterminals.

Fedeler, Heady, and Koo utilized a regional linear programming model as a spatial transportation model in depicting the national grain transportation network.[58] They used a spatial model because spatial models can simultaneously answer questions about the transportation network and flow of goods as well as questions about the regional supplies and demands of commodities.

A regional linear programming model was used in the search for an efficient national and interregional grain transportation and production network obtained by minimizing the annual cost of grain production and transportation. The analysis consisted of four grains in the 48 contiguous states and included finding the least cost location for producing each of the grains, projecting domestic and export demands for each grain, and analyzing the transportation services required for the projected interregional grain transfers. The effectiveness of alternative modes and methods of grain transportation was determined to avoid an inefficient mix of transportation modes. This last analysis indicated how optimal transportation patterns are related to production and demand as well as how regional grain production is affected by transportation.

The model with its specified constraints was applied to ten alternative sets of interregional transportation costs and projected regional grain demands for 1980. These options were: the base model, a 50-car rail transport system, a 10 percent increase and a 20 percent increase in all rail costs, a 10 percent increase and a 20 percent increase in all barge costs, an alternative single-car transport system, a reassignment of 10 percent of the Gulf export demand for grains to Seattle as well as a 25 percent reassignment, and a 25 percent increase in grain exports.

Some of the more important findings of Fedeler, Heady, and Koo include: 1) alleviating the rail car equipment shortage by expanding the use of multiple rail car shipments which increase the supply of cars due to a faster turnaround; 2) generating a transportation cost savings and increasing the effective capacity of rail cars by using multiple rail car shipments; 3) rail cost changes producing larger impacts than equal percentage changes in barge costs even when the quantities carried by each mode are considered; 4) more trucking occurs when rail costs for short distances increase; 5) grain carried by rail to the waterways is a significant quantity of all grain that moves on the waterways; 6) the location of grain production is affected little by changes in transportation costs; and 7) changes in the level of exports cause large variations in needed transportation services.

Fedeler and Heady provided an alteration to the previous model they co-authored with Koo.[59] The same commodities and options were applied to the same linear programming model to jointly select the least cost locations of grain production and interregional grain transportation, with emphasis on choice of modes, grain movements, and production regions.

The model's solutions provided transportation costs and interregional shipments by grain and mode for each option and time period. The analysis utilized the cost of providing transportation rather than transportation rates.

The results suggest the choice of transportation mode and grain flows are sensitive to transportation cost changes and the distribution of exports among ports whereas the location of grain production is not.

The policy implications from the model's results include adoption of multicar rail systems, higher rail rates for financial strength of the railroads, and the implementation of fees for recouping the capital investments in inland waterways.

Rather than evaluating interregional flows of all grains, Rudel and Lamberton examined 1) the grain marketing system in South Dakota; 2) the distribution of South Dakota grain to the principle terminals; and 3) the costs of getting the grain from producers to elevators and from elevators to terminals.[60] They also considered a grain marketing system having fewer, more efficient elevators and a system of using larger elevators.

The particular model developed by Rudel and Lamberton was a linear programming transshipment model that determined the least-cost solution for the combined cost of assembling, handling, and distributing grain.

A few of the simplifying assumptions incorporated into the model were that the number and size of country elevators, their grain receipts and shipments, and their assembly and handling costs are constant, and the more efficient elevators in an area would draw producers' grain deliveries away from the less efficient elevators, given the licensed storage capacities of the elevators remained unchanged.

The results to the study were consistent with those obtained in the national interregional studies with the addition of a suggested substantial cost reduction through investment in large, high turnover elevators, particularly where a system of fewer, larger elevators would impose relatively small increases in assembly costs.

The models discussed thus far in this section on grain distribution have considered all grains and all transportation modes (without specific emphasis) on either a regional or national basis. The following study is commodity specific--winter wheat--and may be considered region specific in the sense that the supply points are from the relevant production area of winter wheat.

L. Orlo Sorenson evaluated the rail-barge competition in transporting winter wheat as the barge rates and the rail rates affected by truck-barge shipments had shifted the locational advantage of marketing and processing facilities of winter wheat and wheat flour.[61] Although the ton-mile cost differences between barge and rail favored the barge shipments, railroads could compete on point-to-point transfers because 1) the rail cost structure allowed a range of cost-based pricing; 2) point-to-point distances were typically greater by river than by rail; 3) additional costs associated with transfer from truck to barge may increase the total transportation charge; and 4) rail services may be preferred because of size or speed of shipment or because of receiving or loadout ability.

To evaluate the competitive transportation of winter wheat as a least-cost simulation for known supply and demand quantities, Sorenson used linear programming to depict the transportation network serving winter wheat movements from 220 supply (producing) points in Texas, Oklahoma, Kansas, Colcrado, and Nebraska to 50 destinations. Beside the least-cost evaluating, projections were made of transport demand quantities as well as supply quantities and demand distributions for 1990 and 2000 based on 1971 data.

The results indicated increased usage of truck-barge modal combinations for winter wheat to the terminal elevators and expanded truck traffic to satisfy mill demands within and adjacent to the supply area. Of greater consequence that the results mentioned are those possible from introducing hypothetical changes in the transport structure, as was performed in the larger models discussed earlier.

The following studies being reviewed utilize modeling concepts other than linear programming. Thowsen and McInnis utilized an aggregated systems model to study the rail transportation of export grain from inland terminals to the export elevators at the Port of Houston.[62]

The solutions from a cost minimization problem and the dynamic system model were used to determine the system response and the anticipated stationary levels of important state variables for different export levels, as well as investigate the effects of the existing rate structures under different operating conditions. The state or endogenous variables of primary interest in the grain export system include the number of loaded cars in transit, those at the yards in Houston, and the export elevator grain inventory.

The analysis by Thowsen and McInnis was divided into three cases distinguished by the amount of export elevator storage available at the port--virtually none, virtually unlimited, and finite storage. Besides providing detailed information about the expected state variables in the system under different operating conditions, the systems model revealed the existence of significant multiplier effects relative to rail yard traffic congestion and the demand for elevator storage. Further analysis revealed an extensive use of the inspection rerouting delay as a means of low cost intermediate storage. Policy implications stemming from the results indicate improvements toward more efficient utilization of the grain export railroad system will arise from greater employment of unit trains, changes in rate structures, and reciprocal demurrage laws.

Johnson and Mennem, utilizing a systems procedure, developed the concept of market area sensitivity in order to distinguish competitive from noncompetitive rate structures, especially as inherent in the Oklahoma-Kansas wheat transportation market.[63] Market area sensitivity arises when the boundary between two transport model service centers is very sensitive to slight changes in the relative transportation charges.

Site prices received for wheat shipments are the basis for modal considerations at the country elevators. Since transportation rates for winter wheat are primarily distance oriented, grain elevator locations where the site prices with barge transport are equal to or greater than those site prices with rail transport represent the market area in which water transport has the competitive pricing advantage. In their results, Johnson and Mennem determined the region (by county) in Kansas and Oklahoma which might ship wheat through the Port of Catoosa at various price spreads between Catoosa and the Gulf elevators. With changing

Interstate Commerce Commission regulations toward flexible rate making, the relative competitive edge appears to lean in favor of the railroads for capturing export wheat traffic.

The Railroad Revitalization and Regulatory Reform Act of 1976 proposed utilization of demand-sensitive rates by railroads so the railroads might respond to fluctuations in market conditions by smoothing out the railroad traffic and increasing the railroad revenues through seasonal rate surcharges. Shouse and Johnson evaluated the anticipated consequences of these seasonal or peak-load surcharges in the Oklahoma wheat transportation market during two time references--the harvest period during June and the nonharvest period by using a systems approach.[64] In doing so, they derived the handling and storage volumes feasible under various transfer modal combinations.

Following the analysis of Shouse and Johnson, applying the seasonal surcharges in Oklahoma would neither smooth the railroad traffic nor increase railroad revenues. The results indicate seasonal rates do not provide significant incentives to smooth traffic as the surcharge is viewed only as a market price differential between time periods, especially since alternative modes are available substitutes for rail at slightly higher rates. Additional implications are that due to the relatively constant wheat marketing pattern just described, railroad traffic will only be smoothed by decreased railroad traffic during harvest and, subsequently, reduced railroad revenues.

With the advancement of increased computer efficiency comes a shift in modeling techniques for the grain marketing system to computerized simulations and network analysis. Hammond and Salvador applied a simulation modeling technique to the export grain market at the Gulf ports.[65]

The model used was developed for use by the Office of Commercial Development of the Maritime Administration. The overall purpose of the Bulk Commodities Simulation Model was to provide a means of analyzing the capacity and other constraining design characteristics of the port facilities and, if necessary, allocate the facilities on a cost effective basis.

Results of the analyses reveal adequate capacity for increased exports of grain and soybeans through the Gulf ports. Although congestion increases with increased grain flow, congestion decreases with longer elevator operating hours thereby implying a tradeoff between new investment, added operating costs, and congestion costs.

In order to include additional realism into locational analysis, applied economists and those individuals doing related work, have turned progressively toward network analysis. Fuller, Randolph, and Klingman used a network analysis approach to determine marketing least-cost organizational adjustments in the cotton ginning industry.[66] The objective of the model was to minimize the aggregated costs of storage, assembly, and processing in such a manner as to designate which processing plants to operate, how much seed cotton to be field stored, how much seed cotton to be assembled, and the quantity of cotton to be processed at specific gins per time period.

The specific model used can be likened to a large scale mixed-integer plant-location model. Although the model was not specifically grain-oriented, the techniques and abstractions from historic network analysis indicate the feasibility and efficiency attributed to using network algorithms in agricultural economics.

Larson and Kane utilized a constrained network flow analysis in evaluating the impact of rail-line abandonment on grain marketing and transportation costs in Ohio.[67] Included in the study was the impact of abandonment on the total costs of transportation, handling, and storage, the grain shipping patterns and transport modes, the location of individual elevator operations, and the farm storage activities.

The specific technique applied was the Out-of-Kilter Algorithm in solving the objective of estimating a set of flows through specified channels that minimize the total costs of transportation and handling which satisfies all demands without violating the capacity limitations of the network. The algorithm was applied to a cost minimizing, multi-modal, multi-period, transshipment model entitled the Ohio Grain Rail Abandonment Model which consisted of four submodels functioning in three time periods. Four unique activities and three transportation modes were also included in the model.

The conclusions reached by Larson and Kane indicate rail line abandonment has little impact on the total grain transfer costs in Ohio, although changes in grain flows, storage, and transport modes do occur. Elevators losing rail service show reduced grain receipts from the producing farms and an increase in transport costs from increase intrastate trucking. Rail abandonment benefits those firms with viable rail service having multiple car shipping capabilities but does not favor grain movement through unit train facilities. The apparent increase in demand for on-farm storage is another result of the study by Larson and Kane.

The studies discussed in this section of Chapter II covered a variety of issues and objectives relating to grain marketing and transportation, but even more noteworthy were the methods and techniques utilized in solving the objectives. The articles were presented in a representative chronological sequence which accentuates the movement toward network analysis in evaluating problems and issues associated with grain marketing and transportation.

# FOOTNOTES

[1] R. O. Been, "A Reconstruction of the Classical Theory of Location" (unpublished Ph.D. dissertation, University of California, 1965), pp. 5-6.

[2] Ibid.

[3] J. H. von Thunen, The Isolated State (Chicago, 1960).

[4] Roy J. Sampson and Martin T. Farris, Domestic Transportation: Practice, Theory, and Policy (Boston, 1966), p. 221.

[5] Been, p. 40.

[6] Alfred Weber, Theory of the Location of Industries, tr. Carl J. Friedrich (Chicago, 1929), pp. 18-21.

[7] Ibid., p. 25.

[8] Ibid., p. 37.

[9] Sampson, p. 224.

[10] Weber, p. 103.

[11] August Losch, The Economics of Location (New Haven, 1954), p. 28.

[12] Ibid., p. 105.

[13] Sampson, p. 230.

[14] Walter Isard, Location and Space Economy (Cambridge, 1956), p. viii.

[15] Ibid., p. 95.

[16] Edgar M. Hoover, The Location of Economic Activity (New York, 1948), p. 28.

[17] Ibid., p. 49.

[18] Hugh O. Nourse, Regional Economics (New York, 1968), p. 30.

[19] Sampson, p. 234.

[20] Weber, p. 41.

[21] Marvin L. Fair and Ernest W. Williams, Economics of Transportation (New York, 1959), p. 363.

[22] Ibid., p. 375.

[23] Sampson, p. 148.

[24] Ibid., p. 171.

[25] Raymond G. Bressler, Jr. and Richard A. King, Markets, Prices, and Interregional Trade (New York, 1970), p. 90.

[26] Fair, p. 191.

[27] Ibid., p. 26.

[28] Bressler, pp. 116-9.

[29] R. C. Agrawal and Earl O. Heady, Operations Research Methods for Agricultural Decisions (Ames, 1972), p. 29.

[30] Gerald A. Doeksen and Robert L. Oehrtman, "Optimum Locations for a Rural Fire System: A Study of Major County, Oklahoma," Southern Journal of Agricultural Economics, VIII (1976), pp. 121-7.

[31] Gordon A. King and Samuel H. Logan, "Optimum Location, Number and Size of Processing Plants with Raw Product and Final Product Shipments," Journal of Farm Economics, XLVI (1964), pp. 94-108.

[32] Mack N. Leath and Leo V. Blakley, An Interregional Analysis of the U. S. Grain-Marketing Industry, 1966-67, USDA, ERS Technical Bulletin No. 1444.

[33] Jerry A. Fedeler and Earl O. Heady, "Grain Marketing and Transportation Interdependencies: A National Model," American Journal of Agricultural Economics, LVIII (1976), pp. 224-35.

[34] John F. Stollsteimer, "A Working Model for Plant Numbers and Locations," Journal of Farm Economics, XLV (1963), pp. 631-45.

[35] Wen-Shyong Chern and Leo Polopolus, "Discontinuous Plant Cost Function and a Modification of the Stollsteimer Location Model," American Journal of Agricultural Economics, LII (1970), pp. 581-6.

[36] Allan A. Warrack and Lehman B. Fletcher, "Plant Location Model Suboptimization for Large Problems," American Journal of Agricultural Economics, LII (1970), pp. 587-90.

[37] Stephen Fuller and Robert Sielken, A Solution Procedure for the Modified Stollsteimer Model, Texas A & M University, Department of Agricultural Economics Technical Paper No. TA 14420.

[38] Leonard W. Schruben and Ruth E. Clifton, "The Lockset Method of Sequential Programming Applied to Routing Delivery and Pickup Trucks," American Journal of Agricultural Economics, L (1968), pp. 854-67.

[39] Milton C. Hallberg and W. R. Kriebel, Designing Efficient Pickup and Delivery Route Systems by Computer, The Pennsylvania State University Agricultural Experiment Station Bulletin No. 782.

[40] Frederick S. Hillier and Gerald J. Lieberman, Operations Research (San Francisco, 1974), pp. 216-7.

[41] Joseph J. Moder and Cecil R. Phillips, Project Management with CPM and PERT (New York, 1970).

[42] Stuart E. Dreyfus, "An Appraisal of Some Shortest Path Algorithms," Operations Research, XVII (1969), pp. 395-412.

[43] Richard E. Just, Algorithms for Developing Least-Cost Transportation Systems with Multiple Transportation Modes, Oklahoma State University Agricultural Experiment Station Technical Bulletin T-138.

[44] Hillier, pp. 217-20.

[45] Ibid., pp. 220-4.

[46] Ibid., pp. 224-9.

[47] Ibid., p. 228.

[48] Don T. Phillips, A. Ravindran, and James J. Solberg, Operations Research (New York, 1976), pp. 94-5.

[49] D. R. Plane and C. McMillan, Jr., Discrete Optimization (New Jersey, 1971), pp. 128-30.

[50] Mack N. Leath and James E. Martin, "The Transshipment Problem with Inequality Restraints," Journal of Farm Economics, XLVIII (1966), pp. 894-908.

[51] Fedeler and Heady.

[52] Stephen Fuller and Chiyyarath Shanmugham, "Network Flow Models: Use in Rural Freight Transportation Analysis and a Comparison with Linear Programming," Southern Journal of Agricultural Economics, X (1978), pp. 183-8.

[53] Leath and Blakley.

[54] L. D. Schnake and John R. Franzmann, Analysis of the Effects of Cost-of-Service Transportation Rates on the U. S. Grain Marketing System. USDA, ERS Technical Bulletin No. 1484.

[55] P. C. Baumol, T. P. Drinka, D. R. Lifferth, and J. L. Miller, An Economic Analysis of Alternative Grain Transportation Systems: A Case Study, DOT, FRA-OE-7-3-4.

[56] Edward W. Tyrchniewicz and Robert J. Tosterud, "A Model for Rationalizing the Canadian Grain Transportation and Handling System on a Regional Basis," American Journal of Agricultural Economics, LV (1973), pp. 805-13.

[57] George W. Ladd and Dennis R. Lifferth, "An Analysis of Alternative Grain Distribution Systems," American Journal of Agricultural Economics, LVII (1975), pp. 420-30.

[58] Jerry A. Fedeler, Earl O. Heady, and Won W. Koo, "A National Grain Transportation Model," in Earl O. Heady and Uma K. Srivastava, Spatial Sector Programming Models in Agriculture (Ames, 1975), pp. 452-79.

[59] Fedeler and Heady.

[60] C. F. Lamberton and R. K. Rudel, A Pilot Study to Investigate Efficient Grain Transportation and Marketing Systems for South Dakota, Department of Transportation Report No. DOT-OS-50229.

[61] L. Orlo Sorenson, "Rail-Barge Competition in Transporting Winter Wheat," American Journal of Agricultural Economics, LV (1973), pp. 814-9.

[62] Arlid Thowsen and Bayliss C. McInnis, On Rail Transportation of Export Grain from Upcountry Elevators Through the Houston Rail System, University of Houston, November 1976.

[63] Marc A. Johnson and Gary M. Mennem, "Market Area Sensitivity as a Measure of Railroad-Barge Competition in the Oklahoma-Kansas Wheat Transportation Market," Southern Journal of Agricultural Economics, VIII (1976), pp. 115-20.

[64] James C. Shouse and Marc A. Johnson, Anticipated Consequences of Seasonal Railroad Rates in the Oklahoma Wheat Transportation Market, Oklahoma State University Agricultural Experiment Station Research Report No. P-773.

[65] Jerome J. Hammond and Michael S. Salvador, "Simulation Analysis of Export Grain Flows Through Gulf Ports," American Agricultural Economics Association Contributed Papers Session, Summer 1978.

[66] Stephen W. Fuller, Paul Randolph, and Darwin Klingman, "Optimizing Subindustry Marketing Organizations: A Network Analysis Approach," American Journal of Agricultural Economics, LVIII (1976), pp. 425-36.

[67] Donald W. Larson and Michael D. Kane, "An Economic Analysis of Rail Abandonment in Central and Southwestern Ohio Grain Producing Areas," American Agricultural Economics Association Contributed Papers Session, Summer 1978.

# CHAPTER III

# THE MODEL

The system to be modeled involves hard red winter wheat flows from farm harvest through country elevators and inland terminals to domestic and Gulf export terminal destinations. The modeled system is a typical representation of the hard winter wheat production area of the Southern High Plains, which includes counties in the states of Texas, Oklahoma, Kansas, Missouri, Nebraska, Wyoming, Colorado and New Mexico. Wheat harvest, in the most part, is during the month of June when, in a six-week period, nearly 90 percent of the study area's winter wheat is harvested. Most of the grain is transported to country elevators due to limited on-farm storage capacity. Country elevators have limited receiving, storage, and loadout facilities and capacities for wheat in some counties due to the competition for space by other grains such as milo in the south and soybeans and corn in the northeast part of the study area. Also, limited transportation services are usually associated with country elevators.

Winter wheat is transshipped from country elevators dispersed throughout the production area to inland terminals where transportation services typically are abundant, i.e., Ft. Worth, Amarillo, Enid, Hutchinson, Wichita, Kansas City, Omaha, and others, and the wheat is then transported to the Gulf port terminals in Texas and Louisiana via railroad and/or truck and/or barge. Available receiving, storage and loadout capacities of the inland terminals, the seasonally-dependent levels of congestion, and the capacity of the transportation network have impacts on the system's capacity and efficiency for wheat transshipment. Gulf ports are the primary destinations for the harvested wheat from the Southern High Plains. Export terminal capacities further constrain the system. Surge flows of various forms into the grain transportation system have impeded the system's performance.

## The Out-of-Kilter Network Model

The capacitated network model consists of a collection of points called nodes and a collection of arcs which connect the nodes. The nodes are denoted by single lower case letters and the arcs are identified by naming the nodes they connect. Some homogeneous commodity, such as hard red winter wheat, can flow over the arcs and the amount of the commodity flowing on arc (i,j) from node i to node j is denoted as $x_{ij}$. For any arc, the first subscript is the source of flow and the second is its sink, or destination. Generally, some cost is incurred to move a unit of commodity from node i to node j and these unit movement costs are denoted by $c_{ij}$. Frequently flow is limited by upper bounds or capacities on the arcs. These maximum arc capacities are identified by $u_{ij}$, and may be any nonnegative value including infinity. There may also be a requirement for a minimum amount of flow along any arc, and this is denoted by $l_{ij}$.

To summarize, a capacitated network is characterized by nodes, i; arcs between the nodes, (i,j); flow across the arcs, $x_{ij}$; unit costs of flow across the arcs, $c_{ij}$; upper bounds on flow across the arcs, $u_{ij}$; and lower bounds on flow across the arcs, $l_{ij}$. These characteristics can completely characterize steady state flow in a network.[1]

A general network problem is finding a minimum cost circulation in a network with arc capacities. The problem requires finding the flows, $x_{ij}$, that minimize the total cost:

$$\text{Minimize} \sum_{ij} c_{ij} x_{ij}, \text{ for all i and j,} \tag{3.1}$$

while satisfying the constraining conditions:

$$l_{ij} \leq x_{ij} \leq u_{ij} \text{ for all i and j,} \tag{3.2}$$

and show that in a circulation what goes into a node must come out of the node, which is represented by:

$$\sum_j x_{ji} - \sum_j x_{ij} = 0 \text{ for all i.} \tag{3.3}$$

A set of flows, $x_{ij}$, that satisfies the flow constraints of Equation (3.2) and the conservation of flow Equation (3.3) is called feasible. In attempting to find a minimal cost feasible circulation, the Out-of-Kilter Algorithm (also denoted as OKA) operates with both arc costs, $c_{ij}$, and node prices, $p_i$. The underlying concept of the OKA is to achieve an economic system which indicates whether a given set of flows has achieved the minimum-cost flow through the network. If the set is not optimal, either the node prices, $p_i$, or the flows, $x_{ij}$, are changed and the algorithm is tested again for optimality.

A heuristic explanation of the algorithm pictures a distributor making systematic decisions under the watchful eye of a Distribution Commission. At each step, the distributor considers "Which route shall be used to minimize total distribution costs, taking account not only transportation charges, but also the commodity prices at the various markets?" If no profitable route exists at some step, the distributor informs the Commission "You must not allow increased commodity prices at certain sites so that it is financially feasible for me to continue constructing a distribution route." The Commission concurs but replies "Find the route which requires the minimum price increase."

To comply with the fanciful request above, a variable, $P_i$, is associated with each node, i. $P_i$ can be considered the price of a unit of the flow commodity at the node. A net arc cost, $\bar{c}_{ij}$, is defined as:

$$\bar{c}_{ij} = c_{ij} + P_i - P_j \tag{3.4}$$

This new cost, $\bar{c}_{ij}$, represents the total cost to the system (consumer and distributor) of transporting one unit of flow from node i to node j by comparing the cost of retaining a unit at node i versus the cost of moving it to node j. In moving a unit of flow from node i to node j, the commodity price at i, $P_i$, is foregone, and an actual transportation cost, $c_{ij}$, is incurred. If the sum of these costs is greater than the commodity price at j, $P_j$, then it does not pay to ship a unit from i to j. On the other hand, if a unit at j costs more than at i plus the transportation cost, $\bar{c}_{ij}$ will be negative and shipment from i to j is profitable and the system benefits from the move. Additionally, if the value at j, $P_j$, is balanced exactly by the value at i plus the transportation cost, $P_i + c_{ij}$, than $\bar{c}_{ij} = 0$, and the system is indifferent to an additional unit flowing from i to j.

Limitations on permissable flow levels in Equation (3.2) together with possible levels of total system cost per Equation (3.4) yield the following conditions that are satisfied by an optimal solution to the minimal cost circulation problem addressed in Equations (3.1), (3.2), and (3.3).[2]

$$\text{If } \bar{c}_{ij} < 0, \text{ then } x_{ij} = u_{ij}. \tag{3.5}$$

$$\text{If } \bar{c}_{ij} = 0, \text{ then } l_{ij} \leq x_{ij} \leq u_{ij}. \tag{3.6}$$

$$\text{If } \bar{c}_{ij} > 0, \text{ then } x_{ij} = l_{ij}. \tag{3.7}$$

Equation (3.5) states that when the net arc cost is negative, flow on the arc should be as large as possible. Equation (3.6) states that when the net arc cost is zero, the value of the flow level does not matter as long as it meets the constraints. Equation (3.7) states that when the net arc cost is positive, flow on the arc should be at the minimum level permitted.

Any arc that fits the optimality conditions in either Equation (3.5), (3.6), or (3.7) is defined by "in-kilter". Arcs that do not satisfy these conditions are denoted "out-of-kilter", hence the algorithm's name.

Out-of-kilter arcs are grouped into two categories:

1) Those that are feasible but not optimal, having flow that satisfies (3.2), but prices and flow do not satisfy (3.5), (3.6), or (3.7).
2) Those that are infeasible in which flow is either below the lower bound or above the upper bound so that (3.2) is not satisfied.

Arcs that are feasible but not optimal must fit one of the following states or conditions:

I. $\bar{c}_{ij} < 0$ and $x_{ij} < u_{ij}$.
II. $\bar{c}_{ij} > 0$ and $x_{ij} > l_{ij}$.

Infeasible arcs fit one of the following states:

III. $\bar{c}_{ij} > 0$ and $x_{ij} < l_{ij}$.
IV. $\bar{c}_{ij} = 0$ and $x_{ij} < l_{ij}$.
V. $\bar{c}_{ij} = 0$ and $x_{ij} > u_{ij}$.
VI. $\bar{c}_{ij} < 0$ and $x_{ij} > u_{ij}$.

To summarize, the arcs are in one or another of several different states, as shown in Table II.[3] The first letter is either a K (for a branch in-kilter) or an N (for a branch not in kilter). The remaining letters are eighter F, R, or both. The letter F indicates added forward flow to increase the flow assignment, $x_{ij}$, is possible and R indicates added reverse flow to reduce an existing flow assignment is possible. Both F and R indicate added flow is permitted in either direction. When all arcs are in-kilter (K, KF, KR, KFR), the minimum cost circulation (flow) assignment has been found.

The overall flow scheme of the complete Out-of-Kilter algorithm can roughly be diagrammed as seen in Figure 11.[4] The OKA operates by arbitrarily selecting an out-of-kilter arc and rearranging the flows in an attempt to reduce the kilter number associated with the arc to zero. During this process the kilter numbers of other arcs either stay the same or decrease, but do not increase. The algorithm strives to bring into kilter an arc that was previously out-of-kilter, while never making an in-kilter arc out of kilter. The algorithm terminates with an optimal solution when the kilter numbers of all arcs are zero. The "kilter number" described above, that is associated with each arc, is defined according to the following states:

| States of Arc Condition | Kilter Number |
|---|---|
| I | $\bar{c}_{ij}\ (x_{ij} - u_{ij})$ |
| II | $\bar{c}_{ij}\ (x_{ij} - l_{ij})$ |
| III, IV | $(l_{ij} - x_{ij})$ |
| V, VI | $(x_{ij} - u_{ij})$.[5] |

In all cases, the Kilter number is positive. For the feasible states (I, II), the kilter number is a measure of non-optimality, whereas the

## TABLE II

## BRANCH STATES, IN THE OUT-OF-KILTER ALGORITHM, AND THEIR CONSEQUENCES

| | $X_{ij} < L_{ij}$ | $X_{ij} = L_{ij}$ | $L_{ij} < X_{ij} < U_{ij}$ | $X_{ij} = U_{ij}$ | $X_{ij} > U_{ij}$ |
|---|---|---|---|---|---|
| $\overline{C}_{ij} < 0$ | NF* | NF | NF | K | NR |
| $\overline{C}_{ij} = 0$ | NF | KF** | KFR | KR | NR |
| $\overline{C}_{ij} > 0$ | NF | K | NR*** | NR | NR |

*NF, KR, KRF: Added forward flow possible.

**KF, K, KFR, KR: In Kilter.

***NR, KR, KFR: Added reverse flow possible.

Note: If X = L = U, the branch is in state K.

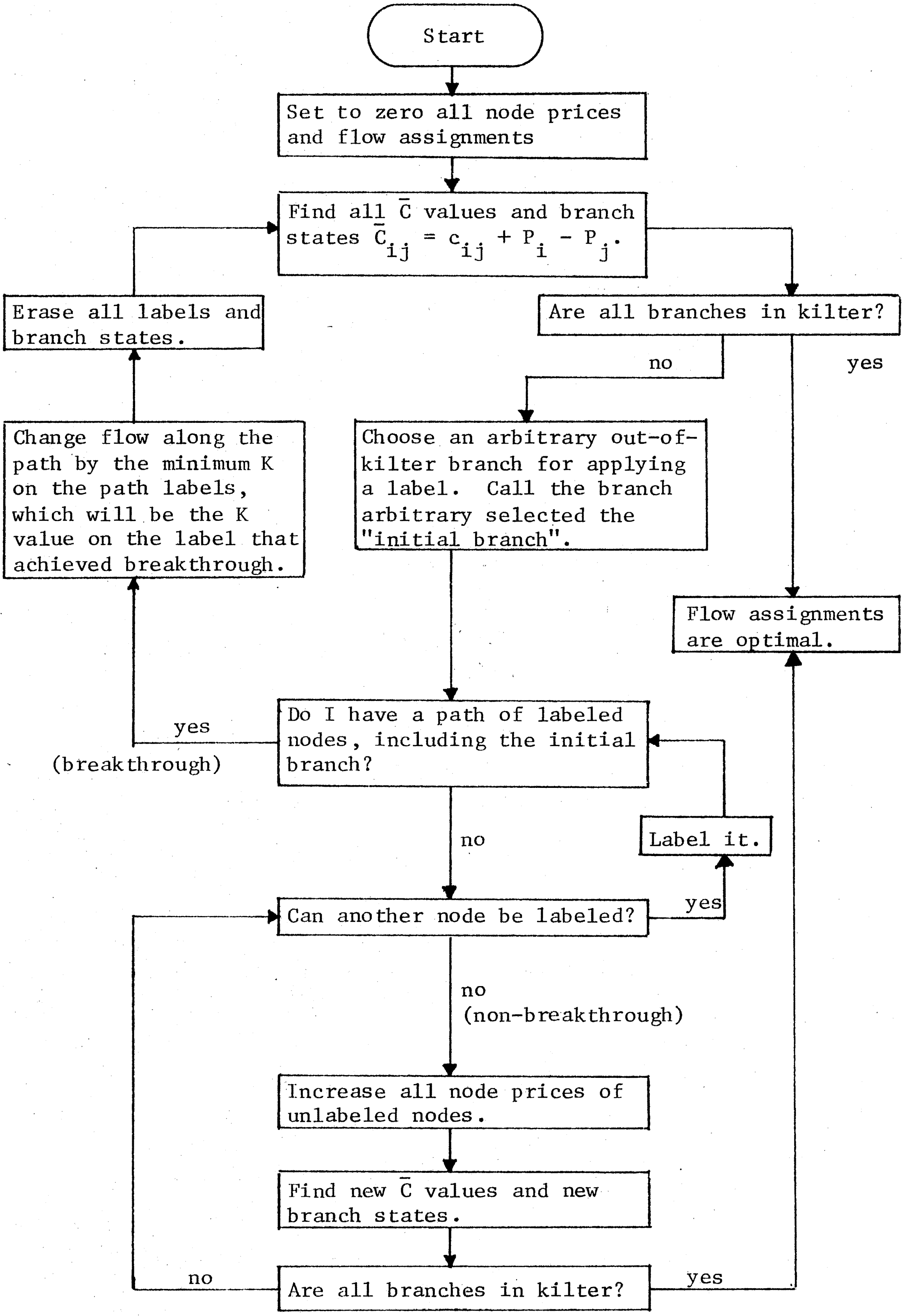


Figure 11. Out-of-Kilter Algorithm Flow Diagram

kilter number for states III through VI indicates the degree of arc infeasibility. In-kilter arcs satisfy the conditions of Equations (3.5), (3.6), or (3.7) and, as a result, have a kilter number of zero.

Optimality of a solution is verified by recalling the definition of $\bar{c}_{ij}$ and that a kilter number of zero implies Equations (3.5), (3.6), and (3.7) hold.

Once the minimum cost flow problem of Equation (3.2) has been formulated, the OKA can be started with any set of node prices, $P_i$, and any flow which satisfies the conservation of flow, Equation (3.3). These prices and flow can initially be zero, as in the flow diagram, although an existing price system and a feasible flow are excellent starting points for the algorithm. In arbitratily selecting an out-of-kilter arc, say (s,t), the fact that the arc is out of kilter indicates either profitability or necessity, or both, to ship an additional unit from t to s or s to it; regardless, flow change is always desired for an out-of-kilter arc.

In order to change the flow on the arc and yet keep flow in the network balanced in accordance with Equation (3.3), another path through the network from t to s must be found through which the flow values can be changed. In constructing this path, two pieces of information called a "label" must be retained at each node. The first component at a given node j indicates the previous node in the path and whether present flow moves from i to j, denoted (i+), or from j to i, denoted (i-). The second piece of the label is the amount by which flow on arc (i,j) is to be changed, $K_j$. A complete label at node j is $[i \pm , K_j]$. The search proceeds from node t through the network seeking a path to s. The labels indicate the direction and magnitude of necessary flow change along the path.

If a new path connecting nodes t and s is not found, resulting in a condition called non-breakthrough, the OKA determines new node prices, $P_i$, in such a manner that either a) another node is labeled in the partial (t,s) path; b) one less arc is considered for inclusion in the (t,s) path; or c) if no arcs remain and the path is incomplete, the problem is deemed infeasible.

The rules for labeling are summarized as follows:

Rule 1: For a node to be susceptible to being labeled,

- a) it must be connected to a labeled node, and
- b) it must be either
    - 1) the sink of an arc with added forward flow possible, or
    - 2) the source of an arc with added reverse flow possible.

Rule 1a: To start the labeling process when there are no labeled nodes, an out-of-kilter arc is arbitrarily selected, and then either:

- 1) the sink of this arc is labeled if added forward flow is possible, or
- 2) the source of this arc is labeled if added reverse flow is possible.

Rule 2: The smallest $|\bar{C}|$ (absolute value of $\bar{c}$) is found among all arcs which:

- a) connect a labeled node to an unlabeled node, and
- b) either
    - 1) $\bar{c} > 0$, the source is labeled, and $x \leq u$, or
    - 2) $\bar{c} \leq 0$, the source is not labeled, and $x \geq 1$.

This smallest $|\bar{c}|$ is called some quantity I, and all node prices associated with unlabeled nodes are increased by the quantity I without changing the prices of the labeled nodes. If no arc satisfies a) and b) above, there is no feasible flow meeting the limits for all arcs.

Rule 3: If node s is labeled and connected to node t, and if node t is susceptible to being labeled according to Rule 1, a label is applied to node t of the form [s ± , $K_t$], where:

t is the added flow capacity for node t, as determined below,

\+ indicates added forward flow capacity in arc (s,t)

\- indicates added reverse flow capacity in arc (s,t)

s is applied by virtue of its connection to labeled node s.

The value of $K_t$ is set equal to the smaller of:

a) $K_s$, from the label on node s, and

b) either $x_{ij} - l_{ij}$ or $u_{ij} - x_{ij}$, according to whether an l or u follows the state description in Table II.

Rule 3a: If the labeling process is just beginning, node t is not connected to a labeled node, since all nodes are unlabeled. The label in this case becomes [h ± , $K_t$], where:

$K_t$ as the added flow capacity is either $x_{ij} - l_{ij}$ or $u_{ij} - x_{ij}$, according to whether an l or u follows the state description in Table II

h is the arbitratily selected out-of-kilter arc connecting nodes h and t.[6]

A formal proof of the validity of the Out-of-Kilter algorithm is considerably more sophisticated, utilizing concepts of dynamic linear programming and duality.[7] The Out-of-Kilter Theorem as presented by Ford and Fulkerson, states:

> The Out-of-Kilter Algorithm either 1) solves the problem $\sum_j x_{ij} - \sum_j x_{ij} = 0$, $l_{ij} \le x_{ij} \le u_{ij}$, and minimize $\sum_{ij} c_{ij} x_{ij}$ in finitely many applications of the labeling process or 2) terminates with the conclusion that no feasible circulation exists. All arc kilter numbers are monotone, non-increasing throughout the computation. In addition, if the algorithm is initiated with a feasible circulation, at least one arc kilter number decreases with each labeling.[8]

This description of the algorithm is meant to present a "feel" for the operation of the Out-of-Kilter Algorithm (OKA).

A number of problems, other than minimum cost flow, which do not seem susceptible to solution via the OKA can indeed be so formulated and solved. Examples for consideration include the assignment problem, the shortest route problem, the maximum flow problem, and the PERT-type problem, all of which are discussed in Chapter II in the section on network analysis.

## The Model Developed in This Study

In the capacitated network model developed in this study, the nodes, representing the elements comprising the grain transportation system, constitute the production (harvest) locations, on-farm storage, country elevators, inland terminals, port terminals, and hard red winter wheat supplies and demands. The arcs connecting the nodes provide information on required wheat flows ($l_{ij}$), maximum wheat flows ($u_{ij}$), and grain assembly, handling, storage, or transportation rates or costs ($c_{ij}$).

The principal objective of this model, as inherently emphasized in the minimum cost circulation description of the Out-of-Kilter Algorithm, is: given a directed network with unit grain assembly, handling, storage, or transportation costs or rates with maximum and minimum flow constraints assigned to each arc, supplies of hard winter wheat at specified supply nodes, and the demand for winter wheat at demand nodes, the objective is to specify flows through the network system which satisfies the demands from the supplies at a minimum cost.

Application of the Out-of-Kilter Algorithm to the hard red winter wheat marketing and distribution system's network model resolves the grain movement which minimizes the aggregated costs of grain assembly, handling, storage, and transportation. Specifically, the algorithm determines per time period: 1) the quantity of wheat transported to the country elevators from harvest areas; 2) the quantity of wheat stored on farms; 3) the quantity and source of wheat handled and stored at each country elevator, inland terminal, and port terminal; and 4) the quantity of wheat transported between these facilities via alternative transport modes.

In order to evaluate any modifications to the system in terms of capacities or costs, a base model solution is obtained to serve as a benchmark for comparison. Then by altering respective arc parameters, it is possible to evaluate the effect of the modifications. These modifications include changes in the quantity of wheat harvested, elevator and/or transportation system capacities, transportation costs or rates, port demand for wheat per time period, and temporal pricing of transportation services. New facilities can be added into the network by including appropriate arcs and nodes, and the removal of facilities, resulting from elevator grain dust explosions or rail line abandonment, can be considered by eliminating the appropriate arcs. After modifying the parameters and optimizing the system, the resulting costs and flows are contrasted with the base solution to evaluate any gains or losses within the wheat distribution system.

The model developed in this study contains the following:

1) One homogeneous cash grain--hard red winter wheat;
2) 240 production areas whose average annual production of hard red winter wheat exceeds 750,000 bushels;
3) On-farm storage, commercial storage, grain processing, and

livestock feeding activities associated with each of the production regions;

4) Three export facility regions;
5) Truck, rail, and barge modal possibilities; and
6) Two time periods based on temporal shipping patterns.

The following restrictive assumptions were made to reduce the model to a manageable size, as any economic model must, of necessity, simplify the real world:

1) Regional production and consumption take place at particular points in each region, and the quantites supplied and demanded are preassigned;
2) Transfer charges between modes and transfer charges at transshipping facilities include the receiving costs and loadout costs of the mode and the facility;
3) Per bushel transportation rates are independent of the number of units moved;
4) Domestic demands for feed and flour milling and for feed lot activities are decentralized and, as such, are satisfied from the supplies within the production region;
5) Only export grain transportation rates are considered; and
6) Licensed grain facility storage and any modal constraints (mechanical or institutional) are preassigned.

Mathematically, the Out-of-Kilter Algorithm applied in this study yields the flow that minimizes total cost ($\min \sum_i \sum_j C_{ij}X_{ij}$) subject to a circulation principle which states that what flows into a node must also flow out ($\sum_j X_{ji} - \sum_j X_{ij} = 0$) and subject to the lower and upper constraints constraints of the arcs ($L_{ij} \leq X_{ij} \leq U_{ij}$).

The structure of the cost-flow network for hard red winter wheat, as addressed in the study, is formulated in Figure 12. The application is a cost-minimizing, multi-modal, multi-period, transshipment model.

The major activities are harvest, on-farm storage, country elevator and inland terminal storage, domestic demand for hard red winter wheat by grain processors and cattle feeding activities, and export transportation by truck, rail, and truck-barge modes. Beginning and ending hard winter wheat stocks are incorporated into the model as well.

Although unit-train options are available in the study area, only single-car rail shipping activities are represented. Multi-car and unit-train options decrease the total cost result, but these options are not adhered to nor utilized in the Plains States to any great extent on a round-turn basis.

Grain flows are possible from on-farm storage direct to either inland terminals, river port elevators, or export terminals; however, the volume transferred along these channels by producer-owned trucks has historically been minimal and is therefore not included in the model structure. Wheat transfer from inland terminals to grain processors does occur and, in doing so, is subject to domestic transportation rates. The focus of this study, however, is on the export transportation flows and rates; domestic rates and transfers are thereby excluded from the analysis.

The model developed in this study uses the political entity of the "county" as the basic geographic area for data collection. The county seat in each county is considered the location of harvested wheat accumulation and the point of origin for transfer to the Gulf port terminals. At the cellular level of the county, transportation rates and mileage

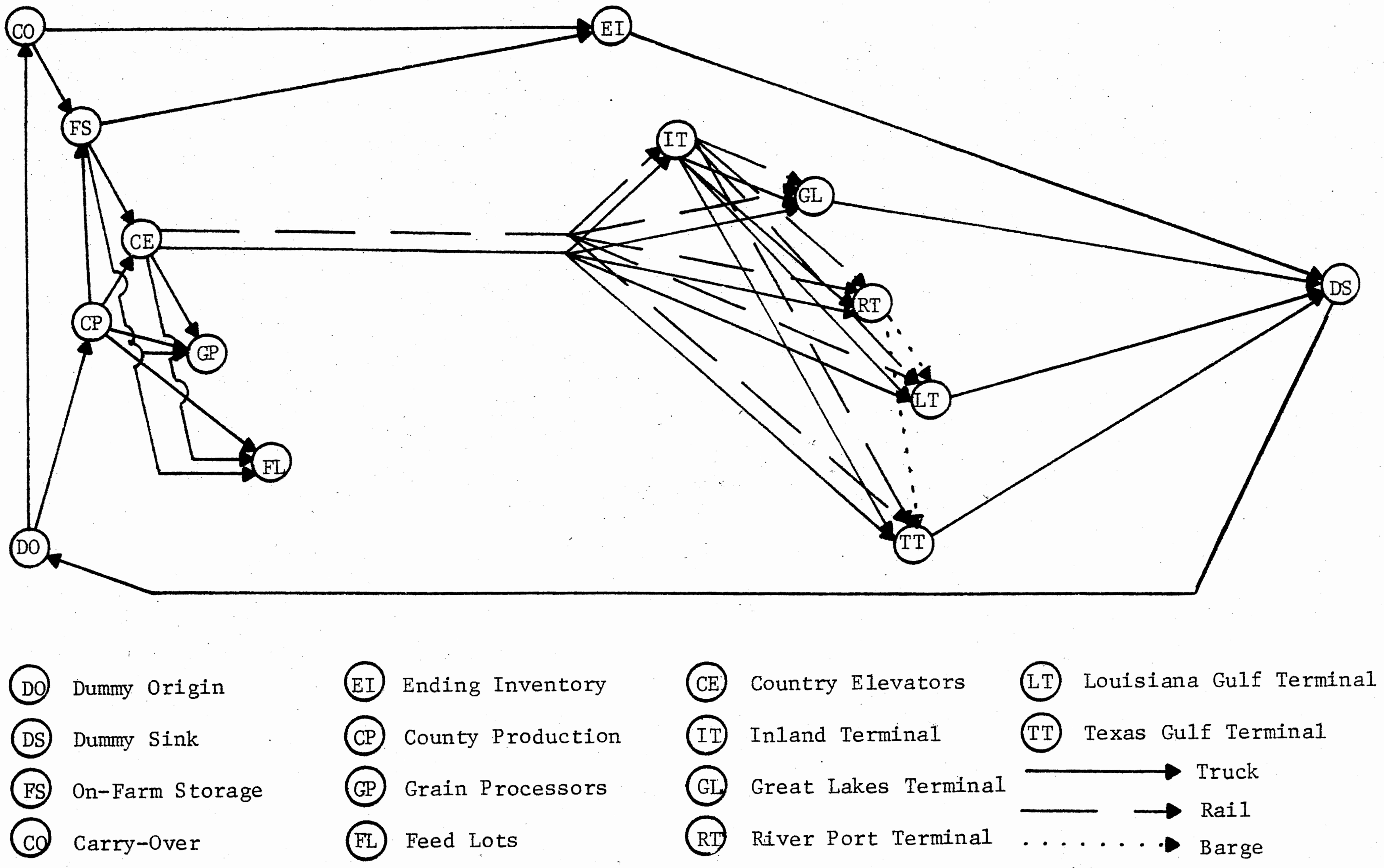


Figure 12. The Model

transfers are not included in the model. However, a discussion of the logistics at the cellular level reveals the development of the network model into the size and scope addressed in Chapter IV.

Hard red winter wheat harvest is typically dispersed throughout the county and the grain is accumulated at either on-farm storage or country elevators within the county. One of these commercial sites is usually at the county seat, as depicted in Figure 13a. These towns have been designated county seats, for the most part, because of early transportation services available and as a center of population growth, and these entities of social and economic growth may still hold true today. Because the county seat became the focus of attention at the cellular level, a pattern of commodity flow into and through the community developed. Frequently the vehicular traffic is unregulated producer-owned trucks and grain wagons which causes the application of transportation rates, charges, and costs to be practically impossible to administer or assess.

Inclusion and generation of all probable inter-county transfer is prohibiting due to the computer costs incurred if the study area included all commercial and private storage sites in the 240 counties. Inter-county grain transfers from county seat to county seat are, however, included in the model for those county seats which do not have multiple transportation mode capabilities. As a result, the cellular level of the model developed in this study is composed of a fewer number of origins relative to the possible number of grain shipment origins (see Figure 13 for the delineation depiction) and, consequently, a decreased number of network arcs to be evaluated in the model.

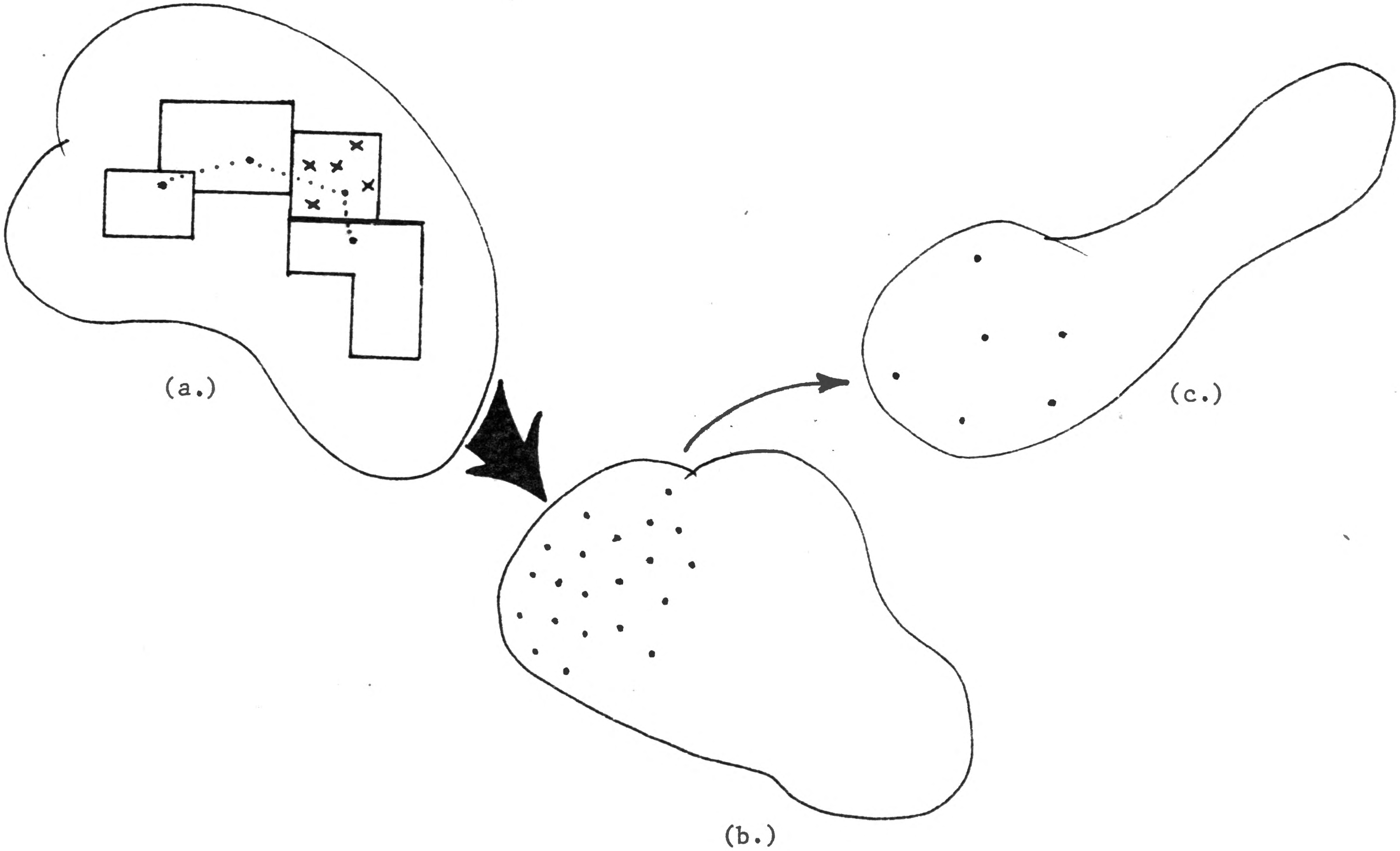


Figure 13. Cellular Level of Network Model

# FOOTNOTES

[1] E. P. Durbin and D. M. Kroenke, The Out-of-Kilter Algorithm: A Primer, The RAND Corporation Memorandum RM-5472-PR (December, 1972), p. 2.

[2] Ibid., p. 6.

[3] D. R. Plane and C. McMillan, Jr., Discrete Optimization (New Jersey, 1971), p. 133.

[4] Ibid., p. 134.

[5] Durbin, p. 7.

[6] Plane, pp. 133-6.

[7] L. R. Ford, Jr. and D. R. Fulkerson, Flows in Networks (New Jersey, 1962).

[8] Ibid., p. 132.

## CHAPTER IV

## REGIONAL DEMARCATION AND BASIC DATA

The basic data in this study are obtained primarily from various secondary sources. Although no surveys, per se, were conducted for the purposes of data collection, survey results may be the basis for data from some of the sources. Secondary data are used for two reasons. First, the data needed for the requirements of the model are not consistently available in the same format throughout the study area as supplied by the numerous activity centers. However, personal contacts within the grain marketing profession are utilized in evaluating the model's depiction of reality. Second, a major objective of the study is the methodology in utilizing network flows for economic analysis.

### Regional Demarcation

The area evaluated is the principal hard red winter wheat producing region in the Southern and Central High Plains States. Subjective considerations, the availability of disaggregated data, and the transportation rate structure are all given consideration in partitioning and establishing territorial boundaries for the study's regional demarcation.

Counties are the smallest geographic area for which much of the required data are available. Consequently, the hard red winter wheat producing counties are the basic geographic unit considered in the study.

In this study, the region is divided into 240 producing counties. The production region investigated comprises those counties whose individual average annual production for crop years 1975, 1976, and 1977 exceeded 750,000 bushels of hard red winter wheat.[1] These 240 counties are depicted in Figure 14 and listed by state and code in Table III. This demarcation follows closely the approximate distribution of wheat acreage, by predominant class of wheat, as indicated in Figure 15.[2]

The designation of 750,000 bushels of harvested wheat as a minimum for evaluation is a subjective consideration. The magnitude of the volume of wheat being stored and transported within the temporal wheat marketing pattern has been the cause of stress on the existing transportation facilities and network. Therefore, those counties harvesting fewer bushels of wheat are not stressing the local storage and transportation facilities as heavily as are the high volume producing counties. A minimum base of 750,000 bushels of wheat, when applied to those counties harvesting hard red winter wheat, represents in excess of 90 percent of the total production of hard winter wheat recorded in the 8-state study area and over 70 percent of all hard winter wheat harvested.[3] Furthermore, production data among those counties harvesting less than 750,000 bushel are spotty--some counties report the data; some do not, especially if hard winter wheat is not a principal agricultural commodity of that county.

An additional subjective consideration is in the use of an average of bushels harvested for the crop years of 1975, 1976, and 1977. First, these are the most current years for which complete data are available, as provided by the various agricultural statistic bulletins published by the states in the study region, and are adequately indicative of the

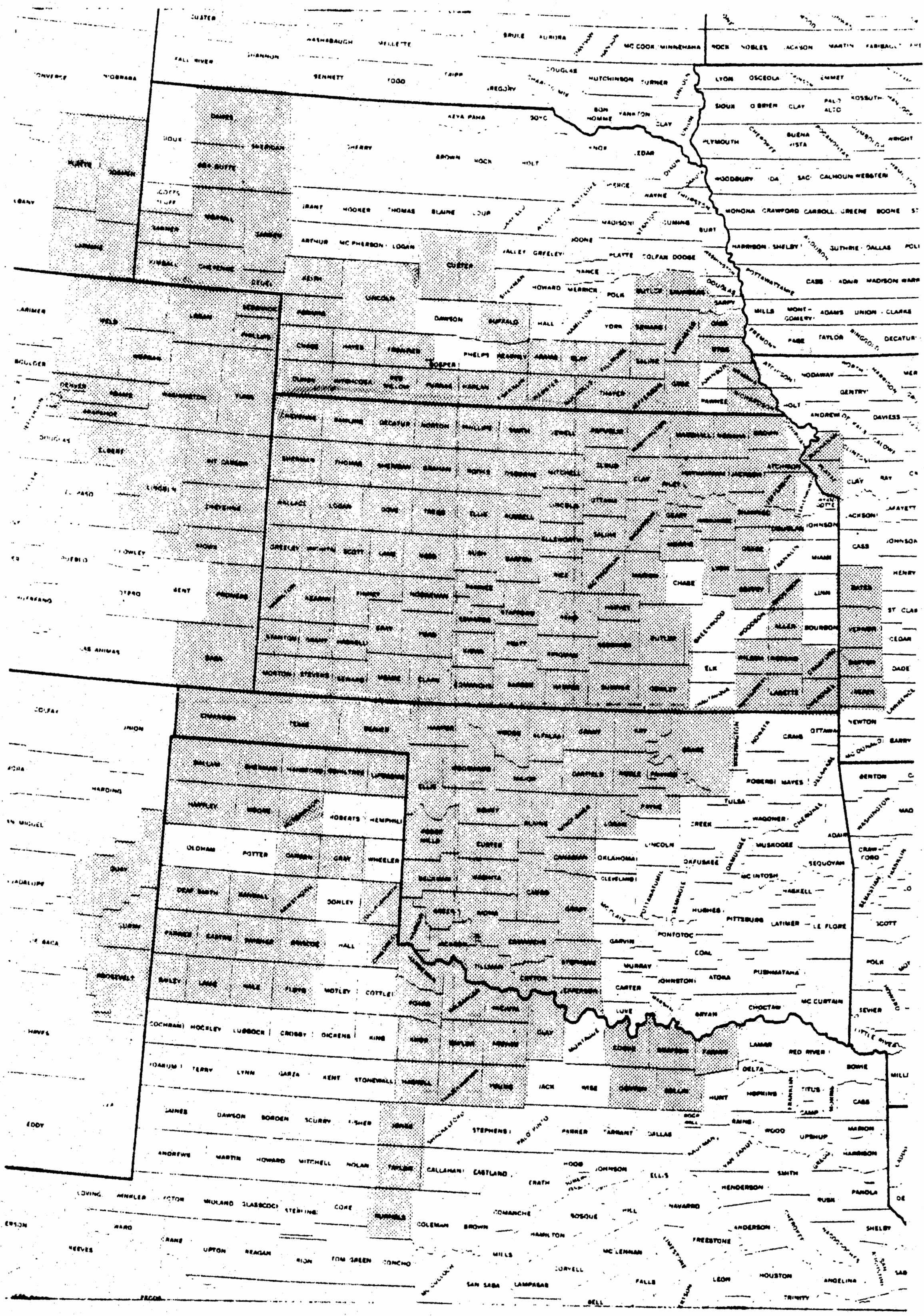


Figure 14. Regional Demarcation by County of Production Area

## TABLE III

## COUNTY CODES

| | | | |
|---|---|---|---|
| Texas | | | |
| Archer | 101 | Hansford | 125 |
| Armstrong | 102 | Hardeman | 126 |
| Bailey | 103 | Hartley | 127 |
| Baylor | 104 | Haskell | 128 |
| Briscoe | 105 | Hutchinson | 130 |
| Carson | 106 | Jones | 131 |
| Castro | 107 | Knox | 132 |
| Childress | 108 | Lamb | 133 |
| Clay | 109 | Lipscomb | 134 |
| Collin | 111 | Moore | 136 |
| Colingsworth | 112 | Ochiltree | 137 |
| Cooke | 114 | Parmer | 139 |
| Dallam | 115 | Randall | 140 |
| Deaf Smith | 116 | Runnels | 141 |
| Denton | 117 | Sherman | 142 |
| Fannin | 118 | Swisher | 143 |
| Floyd | 120 | Taylor | 144 |
| Foard | 121 | Throckmorton | 145 |
| Gray | 122 | Wichita | 146 |
| Grayson | 123 | Wilbarger | 147 |
| Hale | 124 | Young | 148 |
| Oklahoma | | | |
| Alfalfa | 201 | Jackson | 219 |
| Beaver | 202 | Jefferson | 220 |
| Beckman | 203 | Kay | 221 |
| Blaine | 204 | Kingfisher | 222 |
| Caddo | 205 | Kiowa | 223 |
| Canadian | 206 | Logan | 224 |
| Cimarron | 207 | Major | 225 |
| Comanche | 208 | Noble | 226 |
| Cotton | 209 | Osage | 227 |
| Custer | 210 | Pawnee | 228 |
| Dewey | 211 | Payne | 229 |
| Ellis | 212 | Roger Mills | 230 |
| Garfield | 213 | Stephens | 231 |
| Grady | 214 | Texas | 232 |
| Grant | 215 | Tillman | 233 |
| Greer | 216 | Washita | 234 |
| Harmon | 217 | Woods | 235 |
| Harper | 218 | Woodward | 236 |

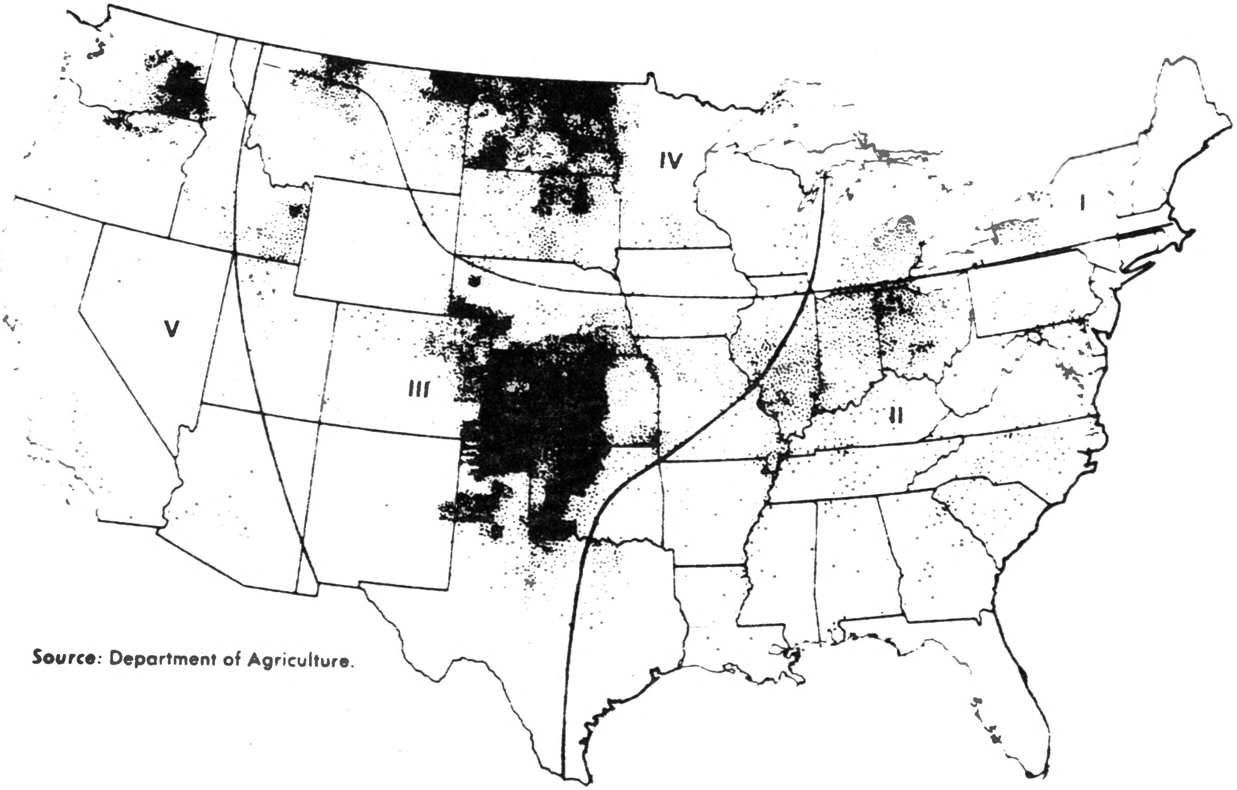
TABLE III (Continued)

Kansas

| | | | |
|---|---|---|---|
| Allen | 301 | McPherson | 347 |
| Anderson | 302 | Marion | 348 |
| Atchison | 303 | Marshall | 349 |
| Barber | 304 | Meade | 350 |
| Barton | 305 | Mitchell | 351 |
| Brown | 306 | Montgomery | 352 |
| Butler | 307 | Morris | 353 |
| Cherokee | 308 | Morton | 354 |
| Cheyenne | 309 | Nemaha | 355 |
| Clark | 310 | Neosho | 356 |
| Clay | 311 | Ness | 357 |
| Cloud | 312 | Norton | 358 |
| Coffey | 313 | Osage | 359 |
| Comanche | 314 | Osborne | 360 |
| Cowley | 315 | Ottawa | 361 |
| Crawford | 316 | Pawnee | 362 |
| Decatur | 317 | Phillips | 363 |
| Kickinson | 318 | Pottawatomie | 364 |
| Douglas | 319 | Pratt | 365 |
| Edwards | 320 | Rawlins | 366 |
| Ellis | 321 | Reno | 367 |
| Ellsworth | 322 | Republic | 368 |
| Finney | 323 | Rice | 369 |
| Ford | 324 | Riley | 370 |
| Geary | 325 | Rooks | 371 |
| Gove | 326 | Rush | 372 |
| Graham | 327 | Russell | 373 |
| Grant | 328 | Saline | 374 |
| Gray | 329 | Scott | 375 |
| Greeley | 330 | Sedgwick | 376 |
| Hamilton | 331 | Seward | 377 |
| Harper | 332 | Shawnee | 378 |
| Harvey | 333 | Sheridan | 379 |
| Haskell | 334 | Sherman | 380 |
| Hodgeman | 335 | Smith | 381 |
| Jackson | 336 | Stafford | 382 |
| Jefferson | 337 | Stanton | 383 |
| Jewell | 338 | Stevens | 384 |
| Kearney | 339 | Sumner | 385 |
| Kingman | 340 | Thomas | 386 |
| Kiowa | 341 | Trego | 387 |
| Labette | 342 | Wabaunsee | 388 |
| Lane | 343 | Wallace | 389 |
| Lincoln | 344 | Washington | 390 |
| Logan | 345 | Wichita | 391 |
| Lyon | 346 | Wilson | 392 |

## TABLE III (Continued)

| | | | |
|---|---|---|---|
| Nebraska | | | |
| Adams | 141 | Hayes | 422 |
| Banner | 402 | Hitchcock | 423 |
| Box Butte | 403 | Jefferson | 424 |
| Buffalo | 404 | Kearney | 425 |
| Butler | 405 | Keith | 426 |
| Cass | 406 | Kimball | 427 |
| Chase | 407 | Lancaster | 428 |
| Cheyenne | 408 | Lincoln | 429 |
| Clay | 409 | Morrill | 430 |
| Custer | 410 | Nemaha | 431 |
| Dawes | 411 | Nuckolls | 432 |
| Deuel | 412 | Otoe | 433 |
| Dundy | 413 | Perkins | 434 |
| Fillmore | 414 | Red Willow | 435 |
| Franklin | 415 | Richardson | 436 |
| Frontier | 416 | Saline | 437 |
| Furnas | 417 | Saunders | 438 |
| Gage | 418 | Seward | 439 |
| Garden | 419 | Sheridan | 440 |
| Gosper | 420 | Thayer | 441 |
| Harlan | 421 | Webster | 442 |
| Wyoming | | | |
| Goshen | 501 | Platte | 503 |
| Laramie | 502 | | |
| Colorado | | | |
| Adams | 601 | Logan | 609 |
| Arapahoe | 602 | Morgan | 610 |
| Baca | 603 | Phillips | 611 |
| Cheyenne | 604 | Prowers | 612 |
| Elbert | 605 | Sedgwick | 613 |
| Kiowa | 606 | Washington | 614 |
| Kit Carson | 607 | Weld | 615 |
| Lincoln | 608 | Yuma | 616 |
| New Mexico | | | |
| Curry | 701 | Roosevelt | 703 |
| Quay | 702 | | |
| Missouri | | | |
| Bates | 801 | Jasper | 804 |
| Barton | 802 | Platte | 805 |
| Buchanan | 803 | Vernon | 806 |



**Source:** Department of Agriculture.

• **Predominant Class of Wheat Grown in Region:**

**I – Soft White**
**II – Soft Red Winter**
**III – Hard Red Winter**
**IV – Hard Red Spring**
**V – Soft White**

Figure 15. Approximate Wheat Acreage Distribution, by Class

state of the arts in the production and harvesting of hard red winter wheat. Second, these crop years represent 1) boom years in which record harvests were recorded in some areas, 2) the impact of federal set-aside and acreage restraint programs on acres harvested, and 3) extreme weather conditions which affected the wheat harvest in some localized subregions. In other words, the crop years of 1975-77 are a representative sample of the bushels harvested and of the current production technology. Table IV presents the bushels harvested for the 1975-77 crop years for the counties and states in the study area.

The same county demarcation applies to on-farm and commercial storage, domestic grain and feed processing, and domestic consumption, as well as to the production of winter wheat.

In addition to the producing counties, three export demand subregions are designated as ports of exit for U. S. hard red winter wheat exports. Special export transportation rates are available for grain moving to the various export terminals. These rates are considerably lower than the domestic rates, and the export rates are the focus of the study. The three export subregions and the ports included in each are shown in Figure 16. Similarly, four river port subregions are designated in representing barge facilities for transshipping wheat from the producing counties to the export facilities on the Gulf of Mexico. The river subregions and the river ports included in each are shown in Figure 17.

The grain handling and transportation flow includes designated inland terminals which are typically established along the criterion lines of proximity to major transportation modes, i.e., main rail lines and the interstate highway network, and availability of large volume grain storage facilities. The inland terminals used in the study are annotated in Figure 18.

## TABLE IV

## HARD RED WINTER WHEAT PRODUCTION

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Texas | Northern High Plains | Armstrong | 1294 | 667 | 2111 | 1357 |
| | | Briscoe | 1280 | 478 | 863 | 874 |
| | | Carson | 4035 | 3523 | 2300 | 3286 |
| | | Castro | 3660 | 2172 | 3508 | 3113 |
| | | Dallam | 2925 | 2059 | 2529 | 2504 |
| | | Deaf Smith | 10210 | 3835 | 5357 | 6467 |
| | | Floyd | 3350 | 2967 | 2074 | 2797 |
| | | Gray | 2539 | 1698 | 1712 | 1983 |
| | | Hale | 2514 | 1772 | 1559 | 1948 |
| | | Hansford | 5901 | 4375 | 4904 | 5060 |
| | | Hartley | 2317 | 1900 | 2525 | 2247 |
| | | Hutchinson | 2201 | 1062 | 1078 | 1446 |
| | | Lipscomb | 2429 | 1487 | 831 | 1582 |
| | | Moore | 2286 | 3548 | 2479 | 2804 |
| | | Ochiltree | 5032 | 5282 | 2988 | 4434 |
| | | Parmer | 3568 | 3095 | 3093 | 3252 |
| | | Randall | 4439 | 1872 | 2839 | 3050 |
| | | Sherman | 4027 | 2265 | 3788 | 3360 |
| | | Swisher | 3427 | 2175 | 3575 | 3059 |
| Texas | Southern High Plains | Bailey | 1417 | 416 | 1521 | 1118 |
| | | Lamb | 1118 | 853 | 1162 | 1044 |
| Texas | Northern Low Plains | Childress | 1010 | 784 | 959 | 918 |
| | | Collingsworth | 949 | 860 | 606 | 805 |
| | | Foard | 2117 | 969 | 1340 | 1475 |
| | | Hardeman | 3400 | 2520 | 2250 | 2723 |
| | | Wichita | 2475 | 2320 | 2038 | 2278 |
| | | Wilbarger | 3339 | 3168 | 2433 | 2980 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Texas | Southern Low Plains | Baylor | 1959 | 1484 | 2240 | 1894 |
| | | Haskell | 1547 | 1525 | 1993 | 1688 |
| | | Jones | 2019 | 1979 | 2430 | 2143 |
| | | Knox | 2269 | 2488 | 3567 | 2775 |
| | | Runnels | 947 | 610 | 1234 | 930 |
| | | Taylor | 1129 | 970 | 1521 | 1207 |
| Texas | Cross Timbers | Archer | 1168 | 1020 | 1273 | 1154 |
| | | Clay | 1010 | 1231 | 3042 | 1428 |
| | | Throckmorton | 1047 | 888 | 787 | 907 |
| | | Young | 1242 | 914 | 1031 | 1062 |
| Texas | Blacklands | Collin | 1156 | 2005 | 1685 | 1615 |
| | | Cooke | 1091 | 1003 | 1154 | 1087 |
| | | Denton | 1010 | 1533 | 1971 | 1505 |
| | | Fannin | 452 | 1407 | 1090 | 983 |
| | | Grayson | 795 | 2238 | 1706 | 1580 |
| Texas | Study Area | | 102100 | 79417 | 88246 | 88941 |
| Texas | Total Population | | 131100 | 103400 | 117500 | 117333 |
| Oklahoma | Panhandle | Beaver | 3765 | 3959 | 3497 | 3740 |
| | | Cimarron | 2099 | 1805 | 5360 | 3088 |
| | | Ellis | 1669 | 2648 | 1410 | 1909 |
| | | Harper | 2990 | 2500 | 1963 | 2484 |
| | | Texas | 7021 | 4438 | 8680 | 6713 |
| Oklahoma | West Central | Beckham | 1795 | 2637 | 1742 | 2058 |
| | | Blaine | 5539 | 4803 | 5600 | 5314 |
| | | Custer | 7378 | 6600 | 5918 | 6632 |
| | | Dewey | 3570 | 2640 | 3105 | 3105 |
| | | Roger Mills | 1632 | 1920 | 1186 | 1579 |
| | | Washita | 4892 | 5630 | 6419 | 5647 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Oklahoma | Southwest | Caddo | 6216 | 5210 | 6752 | 6059 |
| | | Comanche | 1918 | 1730 | 2323 | 5971 |
| | | Cotton | 3270 | 4445 | 5712 | 4476 |
| | | Greer | 2214 | 2125 | 1910 | 2083 |
| | | Harmon | 1871 | 1230 | 1618 | 1573 |
| | | Jackson | 4841 | 4500 | 5019 | 4787 |
| | | Kiowa | 6895 | 6060 | 4996 | 5984 |
| | | Tillman | 5913 | 6600 | 7000 | 6504 |
| Oklahoma | North Central | Alfalfa | 8521 | 6460 | 8377 | 7786 |
| | | Garfield | 10648 | 9420 | 11004 | 10357 |
| | | Grant | 10804 | 9525 | 13971 | 11433 |
| | | Kay | 9235 | 8320 | 10584 | 9380 |
| | | Major | 4892 | 2910 | 4337 | 4046 |
| | | Noble | 3718 | 4740 | 5191 | 4550 |
| | | Woods | 5828 | 5990 | 7071 | 6296 |
| | | Woodward | 3295 | 2135 | 2665 | 2698 |
| Oklahoma | Central | Canadian | 7029 | 5540 | 6039 | 6203 |
| | | Grady | 2476 | 1825 | 2538 | 2280 |
| | | Kingfisher | 7374 | 7125 | 6110 | 6870 |
| | | Logan | 2591 | 3150 | 2777 | 2839 |
| | | Payne | 853 | 1110 | 1442 | 1135 |
| Oklahoma | South Central | Jefferson | 787 | 545 | 1245 | 859 |
| | | Stephens | 866 | 764 | 1884 | 1171 |
| Oklahoma | Northeast | Osage | 1070 | 1162 | 1149 | 1128 |
| | | Pawnee | 612 | 944 | 1115 | 890 |
| Oklahoma | Study Area | | 156089 | 143145 | 167719 | 155651 |
| Oklahoma | Total Production | | 160800 | 151200 | 175500 | 162500 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Kansas | Northwest | Cheyenne | 4568 | 4389 | 4022 | 4326 |
| | | Decatur | 4510 | 4229 | 4833 | 4524 |
| | | Graham | 3488 | 3709 | 3501 | 3566 |
| | | Norton | 3776 | 4508 | 4132 | 4139 |
| | | Rawlins | 5127 | 6161 | 5154 | 5481 |
| | | Sheridan | 4529 | 3968 | 3606 | 4034 |
| | | Thomas | 6962 | 8174 | 8302 | 7812 |
| Kansas | West Central | Gove | 4902 | 5048 | 4488 | 4813 |
| | | Greeley | 4490 | 3800 | 3472 | 3921 |
| | | Lane | 4410 | 2952 | 4511 | 3958 |
| | | Logan | 4541 | 4441 | 5461 | 4874 |
| | | Ness | 5782 | 5696 | 6045 | 5841 |
| | | Scott | 4970 | 3215 | 4644 | 4276 |
| | | Trego | 3802 | 4024 | 4044 | 3957 |
| | | Wallace | 2117 | 3785 | 3471 | 2791 |
| | | Wichita | 4270 | 2754 | 3188 | 3404 |
| Kansas | Southwest | Clark | 2574 | 1644 | 2138 | 2119 |
| | | Finney | 7210 | 4961 | 7148 | 6440 |
| | | Ford | 6537 | 5825 | 6559 | 6308 |
| | | Grant | 2364 | 1341 | 3133 | 2279 |
| | | Gray | 5457 | 3173 | 5851 | 4827 |
| | | Hamilton | 3027 | 1696 | 3288 | 2670 |
| | | Haskell | 4078 | 2661 | 3859 | 3533 |
| | | Hodgeman | 4200 | 3662 | 4381 | 4081 |
| | | Kearny | 3551 | 2176 | 4098 | 3275 |
| | | Meade | 3994 | 1425 | 3587 | 3002 |
| | | Morton | 1403 | 510 | 2150 | 1355 |
| | | Seward | 2323 | 1241 | 3224 | 2263 |
| | | Stanton | 2836 | 1879 | 3854 | 2856 |
| | | Stevens | 2434 | 1036 | 3012 | 2161 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Kansas | North Central | Clay | 3624 | 3277 | 2600 | 3167 |
| | | Cloud | 4132 | 5956 | 4242 | 4777 |
| | | Jewell | 3900 | 4700 | 3586 | 4062 |
| | | Mitchell | 5449 | 6682 | 6064 | 6065 |
| | | Osborne | 4351 | 4861 | 4804 | 4672 |
| | | Ottawa | 5075 | 6009 | 3121 | 4735 |
| | | Phillips | 3149 | 3827 | 3575 | 3517 |
| | | Republic | 3227 | 4663 | 2962 | 3517 |
| | | Rooks | 4176 | 4708 | 3448 | 4111 |
| | | Smith | 3658 | 4380 | 4763 | 4267 |
| | | Washington | 3264 | 4194 | 3359 | 3606 |
| Kansas | Central | Barton | 6679 | 6615 | 6559 | 6618 |
| | | Dickinson | 5660 | 5887 | 3021 | 4856 |
| | | Ellis | 3614 | 4153 | 4315 | 4027 |
| | | Ellsworth | 3980 | 3902 | 3781 | 3888 |
| | | Lincoln | 4177 | 5189 | 4089 | 4485 |
| | | McPherson | 7452 | 7264 | 5672 | 6796 |
| | | Marion | 4415 | 5082 | 3165 | 4221 |
| | | Rice | 6122 | 6409 | 4895 | 5809 |
| | | Rush | 5088 | 4642 | 4225 | 4652 |
| | | Russell | 3926 | 4746 | 4419 | 4364 |
| | | Saline | 4841 | 4724 | 2603 | 4056 |
| Kansas | South Central | Barber | 4586 | 4627 | 3983 | 4365 |
| | | Comanche | 2126 | 2237 | 1962 | 2109 |
| | | Edwards | 3809 | 3339 | 3553 | 3567 |
| | | Harper | 8084 | 7398 | 8071 | 7851 |
| | | Harvey | 3867 | 4031 | 3371 | 3756 |
| | | Kingman | 7390 | 5996 | 7782 | 7056 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Kansas | South Central (continued) | Kiowa | 2862 | 2678 | 2281 | 2607 |
| | | Pawnee | 5825 | 5036 | 5088 | 5136 |
| | | Pratt | 5609 | 5987 | 4496 | 5364 |
| | | Reno | 9915 | 10318 | 8779 | 9671 |
| | | Sedgwick | 6960 | 6933 | 7831 | 7241 |
| | | Stafford | 5728 | 5530 | 5420 | 5559 |
| | | Sumner | 13815 | 9412 | 14856 | 12694 |
| Kansas | Northeast | Atchison | 717 | 812 | 738 | 776 |
| | | Brown | 1343 | 1872 | 1689 | 1635 |
| | | Jackson | 864 | 1087 | 836 | 929 |
| | | Jefferson | 725 | 861 | 750 | 779 |
| | | Marshall | 3299 | 3609 | 2410 | 3106 |
| | | Nemaha | 1822 | 1639 | 1535 | 1665 |
| | | Pottawatomie | 1241 | 1344 | 926 | 1170 |
| | | Riley | 1202 | 1166 | 1081 | 1150 |
| Kansas | East Central | Anderson | 866 | 896 | 1085 | 949 |
| | | Coffey | 990 | 1468 | 896 | 1118 |
| | | Douglas | 810 | 819 | 860 | 830 |
| | | Geary | 990 | 950 | 525 | 822 |
| | | Lyon | 1272 | 1746 | 1192 | 1403 |
| | | Morris | 1821 | 1791 | 1047 | 1553 |
| | | Osage | 1172 | 1468 | 842 | 1161 |
| | | Shawnee | 993 | 1101 | 694 | 929 |
| | | Wabaunsee | 903 | 857 | 709 | 823 |
| Kansas | Southeast | Allen | 638 | 1109 | 1079 | 942 |
| | | Butler | 2436 | 2690 | 2296 | 2474 |
| | | Cherokee | 1014 | 2335 | 2458 | 1936 |
| | | Cowley | 3946 | 2924 | 3563 | 3478 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Kansas | Southeast (continued) | Crawford | 548 | 1132 | 978 | 886 |
| | | Labette | 1207 | 2115 | 2533 | 1952 |
| | | Montgomery | 1468 | 1547 | 1800 | 1605 |
| | | Neosho | 741 | 1030 | 1390 | 1054 |
| | | Wilson | 1200 | 1096 | 1234 | 1210 |
| Kansas | Study Area | | 344742 | 333201 | 338181 | 338708 |
| Kansas | Total Production | | 350900 | 339000 | 344850 | 344917 |
| Nebraska | Northwest | Banner | 2587 | 2664 | 2510 | 2587 |
| | | Box Butte | 3270 | 3919 | 4192 | 3794 |
| | | Cheyenne | 8055 | 7365 | 7579 | 7666 |
| | | Dawes | 1492 | 1748 | 1783 | 1674 |
| | | Deuel | 3363 | 3292 | 3442 | 3366 |
| | | Garden | 2657 | 2217 | 2192 | 2355 |
| | | Kimball | 4997 | 4342 | 4210 | 4516 |
| | | Morrill | 1162 | 1001 | 1187 | 1117 |
| | | Sheridan | 1851 | 1926 | 2369 | 1407 |
| Nebraska | Central | Buffalo | 579 | 781 | 1023 | 794 |
| | | Custer | 1356 | 1144 | 1253 | 1251 |
| Nebraska | East | Butler | 1376 | 830 | 1048 | 1985 |
| | | Cass | 1483 | 1271 | 894 | 1216 |
| | | Lancaster | 3023 | 2482 | 2067 | 2524 |
| | | Saunders | 1438 | 964 | 821 | 1074 |
| | | Seward | 1685 | 719 | 1180 | 1195 |
| Nebraska | Southwest | Chase | 2125 | 1615 | 2014 | 1918 |
| | | Dundy | 1699 | 1262 | 1272 | 1411 |
| | | Frontier | 2031 | 1936 | 2483 | 2150 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| Nebraska | Southwest (continued) | Hayes | 2031 | 1499 | 2153 | 1894 |
| | | Hitchcock | 3308 | 2569 | 3434 | 3104 |
| | | Keith | 2758 | 2417 | 2800 | 2658 |
| | | Lincoln | 1645 | 1364 | 1850 | 1620 |
| | | Perkins | 5986 | 4280 | 6323 | 5531 |
| | | Red Willow | 2730 | 3064 | 3525 | 3106 |
| Nebraska | South | Adams | 1439 | 1300 | 2272 | 1670 |
| | | Franklin | 809 | 878 | 1257 | 981 |
| | | Furnas | 2402 | 3210 | 3390 | 3001 |
| | | Gasper | 670 | 982 | 1003 | 885 |
| | | Harlan | 1314 | 1616 | 1661 | 1530 |
| | | Kearney | 858 | 1207 | 1473 | 1179 |
| | | Webster | 866 | 922 | 1864 | 1217 |
| Nebraska | Southeast | Clay | 963 | 1285 | 1204 | 1151 |
| | | Fillmore | 1975 | 2455 | 1999 | 2143 |
| | | Gage | 2294 | 3137 | 2604 | 2678 |
| | | Jefferson | 1587 | 2250 | 1979 | 5819 |
| | | Nemaha | 841 | 1107 | 952 | 967 |
| | | Nuckolls | 1152 | 1446 | 1713 | 1437 |
| | | Otoe | 1420 | 1248 | 1379 | 1349 |
| | | Richardson | 751 | 1092 | 989 | 944 |
| | | Saline | 2187 | 2585 | 2250 | 2341 |
| | | Thayer | 1752 | 2612 | 2515 | 2292 |
| Nebraska | Study Area | | 87967 | 86003 | 94078 | 89349 |
| Nebraska | Total Production | | 98240 | 94400 | 103250 | 98630 |

TABLE IV (Continued)

| State | Crop Reporting District | County | | Production | | Average |
|---|---|---|---|---|---|---|
| | | | 1975 | 1976 | 1977 | |
| Wyoming | Southeast | Goshen | 1335 | 1412 | 966 | 1237 |
| | | Laramie | 2552 | 2353 | 1706 | 2204 |
| | | Platte | 926 | 888 | 744 | 852 |
| Wyoming | Study Area | | 4813 | 4653 | 3416 | 4293 |
| Wyoming | Total Production | | 7725 | 7080 | 5200 | 6668 |
| Colorado | Northeast | Logan | 4222 | 3166 | 3394 | 3594 |
| | | Morgan | 1157 | 1260 | 1815 | 1411 |
| | | Sedgwick | 2669 | 2272 | 2394 | 2445 |
| | | Weld | 4166 | 3486 | 4117 | 3923 |
| Colorado | East Central | Adams | 4229 | 4005 | 4994 | 4426 |
| | | Arapahoe | 1380 | 1506 | 1151 | 1346 |
| | | Cheyenne | 1254 | 752 | 778 | 928 |
| | | Elbert | 1026 | 602 | 799 | 809 |
| | | Kiowa | 2641 | 942 | 1500 | 1694 |
| | | Kit Carson | 4192 | 3618 | 4151 | 3987 |
| | | Lincoln | 2193 | 2148 | 2194 | 2178 |
| | | Phillips | 3704 | 3246 | 3462 | 3471 |
| | | Washington | 6445 | 6586 | 6972 | 6668 |
| | | Yuma | 2977 | 2952 | 3410 | 3113 |
| Colorado | Southeast | Baca | 1598 | 2770 | 2783 | 2384 |
| | | Prowers | 1637 | 1969 | 2159 | 1922 |
| Colorado | Study Area | | 45540 | 41280 | 46073 | 44299 |
| Colorado | Total Production | | 50400 | 27300 | 51600 | 49767 |
| New Mexico | Northeast | Curry | 6438 | 2793 | 4315 | 4515 |
| | | Quay | 2018 | 448 | 1230 | 1232 |
| | | Roosevelt | 1288 | 868 | 1485 | 1214 |

TABLE IV (Continued)

| State | Crop Reporting District | County | Production (1,000 bu.) 1975 | 1976 | 1977 | Average |
|---|---|---|---|---|---|---|
| New Mexico | Study Area | | 9744 | 4109 | 7030 | 6961 |
| New Mexico | Total Production | | 11440 | 6825 | 9137 | 9134 |
| Missouri | Northwest | Buchanan | 1003 | 964 | 712 | 893 |
| | | Platte | 1174 | 1164 | 767 | 1035 |
| Missouri | West | Bates | 749 | | 1598 | 1049 |
| | | Vernon | 989 | 1366 | 1779 | 1378 |
| Missouri | Southwest | Barton | 1200 | 1976 | 1802 | 1659 |
| | | Jasper | 941 | 1354 | 1082 | 1126 |
| Missouri | Study Area | | 6056 | 7079 | 7740 | 6958 |
| Missouri | Total Production | | 6306 | 7624 | 7895 | 7275 |
| Total Study Area | | | 757051 | 697533 | 752483 | 735160 |
| Total Hard Red Winter Wheat Production (8 states) | | | 816911 | 756829 | 814896 | 796224 |
| Total Hard Red Winter Wheat Production | | | 1058000 | 976000 | 993000 | 1009000 |
| % Production in 8-State Study Area | | | 92.7% | 92.3% | 92.3% | 92.4% |
| % of Total HRW Wheat Production | | | 72.6% | 71.5% | 75.8% | 72.9% |

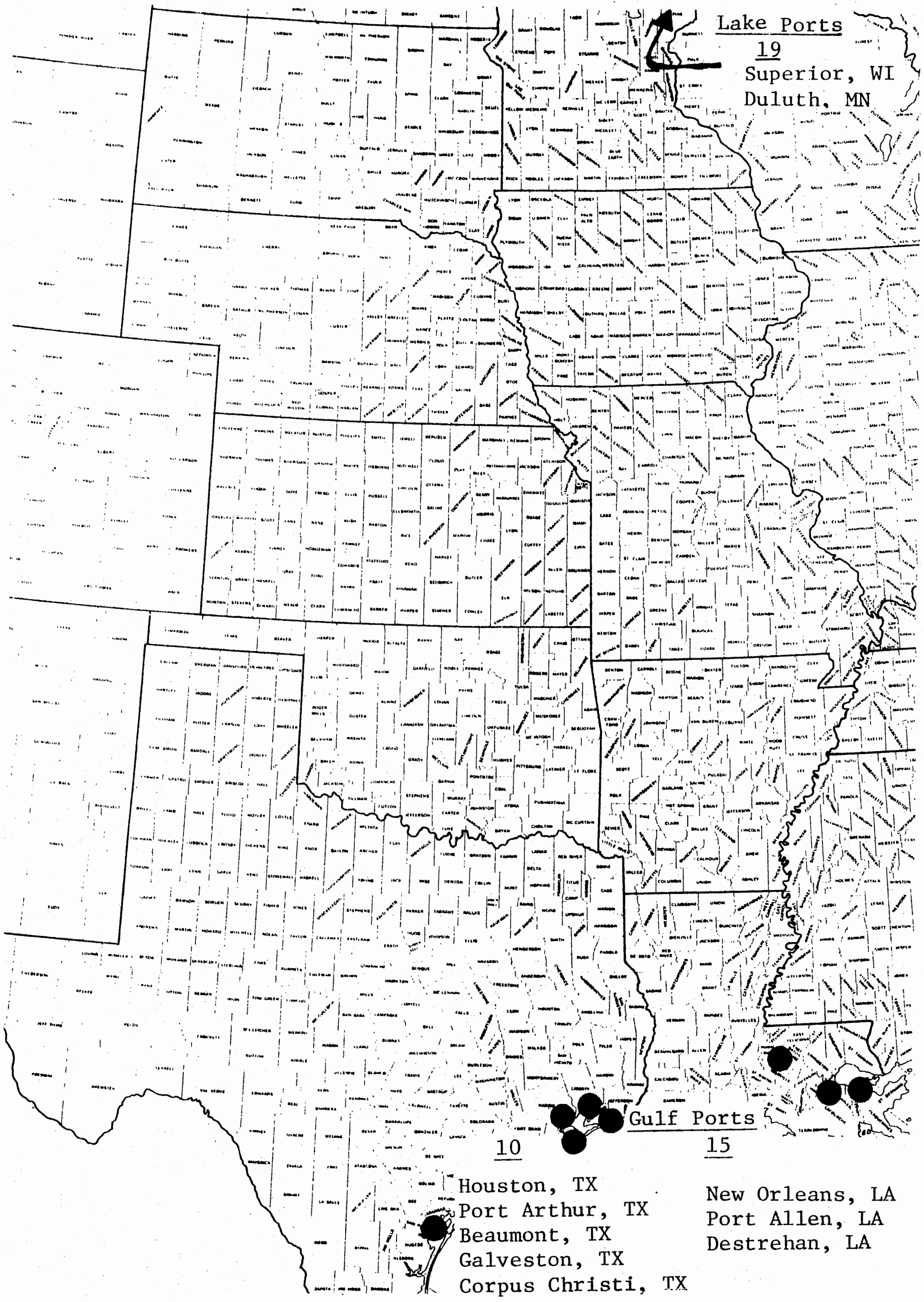


Figure 16. Export Terminals

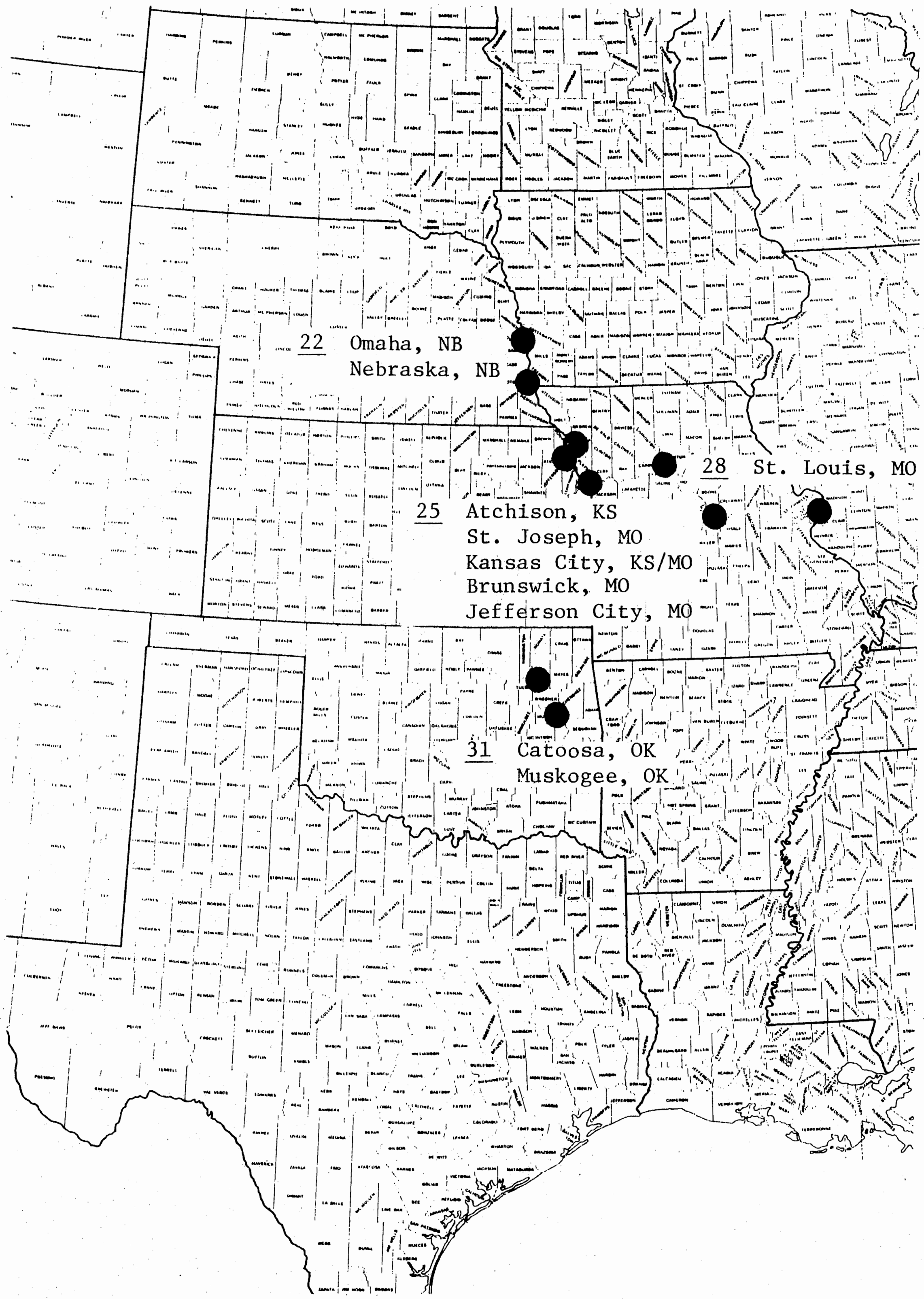


Figure 17. River Port Terminals

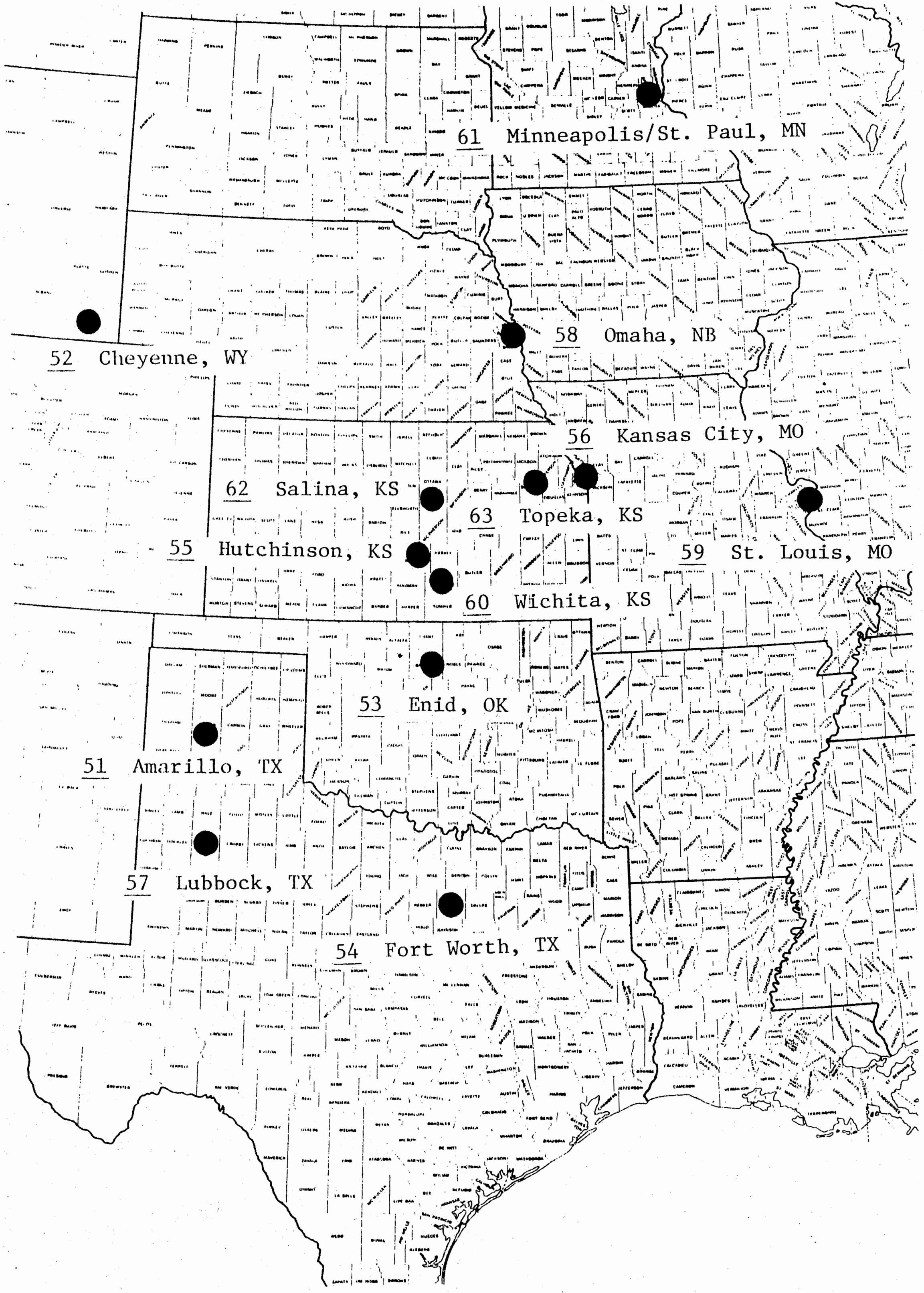


Figure 18. Inland Terminals

The code numbers presented in Figures 14, 16, 17, and 18 are used throughout the study to facilitate representation of the data inputs, the transportation and transshipment links and modes, and the results.

Production and consumption are assumed to take place at particular points in each region, and the quantity constraints are preassigned. Due to the geographic size of the counties relative to the size of the region being investigated, production is specified to have occurred at the county seat. This allows for a consistent point of departure for transporting wheat from each county. In most instances, the county seat approximates a central location within the county for production, consumption, and transportation. Domestic hard winter wheat consumption points are likewise designated at the county seat and are selected with reference to the county seat being a major population center and the site of grain processing facilities (feed and flour mills) and livestock feed lots. The relative locations of the county seats within the respective counties are depicted in Figure 19.

Once the regional demarcation is determined, the pertinent input data for the model implementation must either be collected or generated. As indicated earlier, secondary data are the sources of information and inputs for the model. The data requirements are similar to the typical transshipment models, as the data needs include: 1) regional supplies of hard red winter wheat by time period; 2) regional domestic consumption demands and export wheat demands by time period; 3) storage and transportation facility capacities; and 4) marketing, storage, distribution, and transportation charges and/or costs.

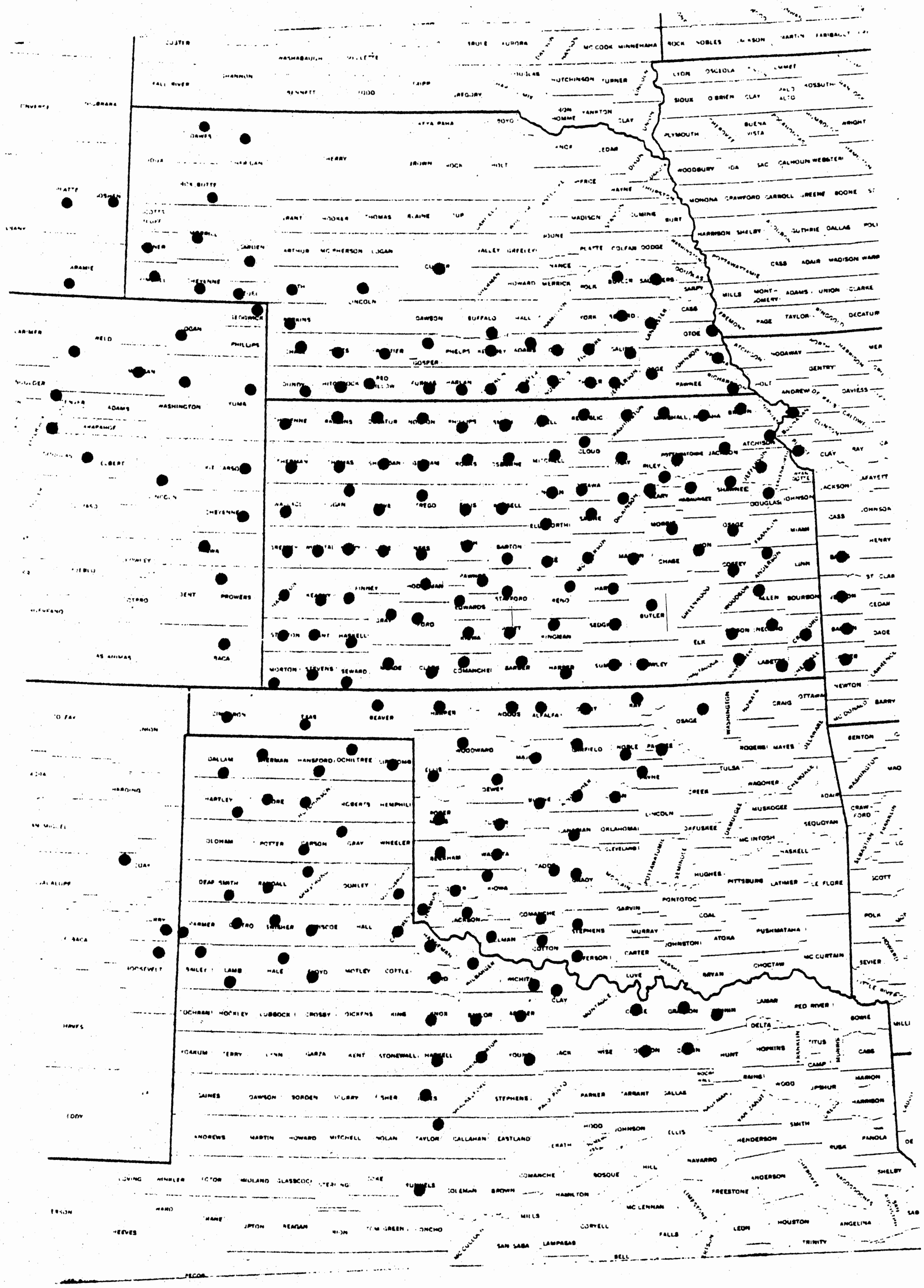


Figure 19. Relative Location of County Seats in Study Area

## Regional Supplies

The term "supply" simply refers to the respective quantities available in each region and is not to be confused with the term "supply" as used in economic theory. These supply quantities are preassigned for each county, the value depending upon the nature of the objective being addressed, and do not vary during any time period in question. For reasons of ease of discussion and data availability, the study incorporates hard red winter wheat on a bushel basis.

The supply components of production and inventories are typical for spatial equilibrium models. Since this study is investigating the export marketing system for hard red winter wheat and the optimum use of transportation and storage facilities involved in the system, only that portion of the total supply of hard red winter wheat that moved through the commercial export marketing channels and competed for the constraining capacities is considered. The relevant components of supply are therefore the off-farm or commercial stocks on hand May 31, commercial domestic sales for the crop year, and export sales for the crop year.[4]

Since a multi-period or time-staged model is employed, allocation of off-farm sales for export is necessary. The usual harvesting dates for hard red winter wheat in the eight-state producing region is a six-week period from late May through early July as the harvest progresses northward from the Southern High Plains of Texas and Oklahoma. An assumption is made that a disporportionate amount of harvested wheat, either from creating storage by shipping last year's crop or by shipping the current crop year's harvest, moves into the export marketing channel during June-July-August. Approximately one-third of the hard winter wheat export shipments to the Gulf of Mexico are delivered during this three month period, while the remaining two-thirds of the total shipments are transferred during the remaining three-fourths of the year. Flow is assumed stable within each of the two time periods.

In those states where the predominant type of wheat is more than just hard red winter, determining the specific counties to be included in the model presents a problem due to the aggregation of sales, stocks, and production among all classes of wheat. The problem is alleviated by considering the percentage of total wheat acreage in each state occupied by each class and using a like percentage for the state's production of each class of wheat.[5] In addition, comments made by the various state universities' agronomy departments and USDA offices aided in differentiating which counties produced hard red winter wheat in excess of 750,000 bushels. The estimated supplies are those volumes recorded in Table IV, excluding carryover.

Competition for commercial storage by feed grains grown in the study area is not a major problem as the corn, oats, barley, soybeans, and milo or grain sorghum harvest periods do not overlap nor closely approximate the harvest period of hard red winter wheat. In the counties where hard winter wheat is the major grain commodity, the feed grain production is of less volume, and vice-versa. Considerations of the feed grain-wheat competition for storage implementation into the model are discussed later in this chapter.

## Regional Demands

Contrary to the economic theory definition of "demand" referring to a schedule depicting price-quantity relationships, the term "demand" used throughout this study refers to the quantities of hard red winter wheat, storage, or transportation services a county or subregion must obtain through the marketing system so as to satisfy its requirements during the time period considered.

Domestic disappearance of hard red winter wheat in the United States involves the following uses: 1) processed for food, namely yeast breads and rolls; 2) seed wheat for sowing; 3) industrial in the form of distilled distilled spirit production (considered minimal for hard red winter wheat); and 4) livestock feeds. Exports of hard red winter wheat are greater in volume than is domestic disappearance.

State or county data are not available for quantities of hard winter wheat used in livestock feeding in excess of those quantities fed on farms where produced. Animal Science departments and USDA personnel provide typical least-cost feeding and maintenance rations for their particular state or region which indicate wheat is not used as a ration substitute for corn, milo, and soybean meal, based on the existing prices of these crops for 1977-78 crop years. Had wheat been an economical substitute, the recorded livestock numbers times the percent of wheat in the ration times the average consumption of ration per head provides an approximation of domestic winter wheat disappearance in livestock feed. However, since wheat is not an economical substitute in feed lot rations, these quantities are omitted from consideration. The domestic disappearance of hard red winter wheat as livestock feed is thereby underestimated by an average of 26 million bushels for the 1975-77 crop years.[6] The various varieties of winter wheat, including hard red winter wheat, are co-mingled at the feed mills and feed lots in developing the livestock rations, thereby making differentiation of wheat variety usage for feed a difficult task. The net effect on the results is an increase in average hard red winter wheat inventories recorded at 400 million bushels.[7] Inclusion of livestock feed in domestic disappearance merely decreases the quantity of wheat available for export, thereby decreasing the stress on the export wheat marketing system.

The processing of wheat into flour is by far the most important domestic use averaging 77 percent of total wheat domestic disappearance, approximating 540 million bushels from all classes of wheat.[8] Demands by flour millers for hard winter wheat based on 80 percent of average flour milling capacity, are assumed satisfied by hard winter wheat produced within the county where the mill is located and/or in adjoining counties thereby minimizing transportation. Reiterating, export flows are the focus of the study, so this assumption is made to eliminate inclusion of domestic transportation rates. The quantities demanded for domestic food use are, however, subtracted from the amount of harvested hard red winter wheat as a domestic disappearance to arrive at a quantity of hard winter wheat available for export.

The only significant industrial use of wheat is in the production of distilled spirits and this quantity is consistently less than 100,000 bushels, so is excluded from the model.[9]

Based on planting rates on a per acre basis, approximately six (6) percent of a prior year's harvest is retained as seed wheat either in on-farm storage or country elevators or by seed dealers. Therefore, six percent of a county's production is considered domestic disappearance for seed and deducted from the quantity of hard red winter wheat destined for export.

Domestic disappearance for the study area is summarized in Table V.

## TABLE V

## DOMESTIC DISAPPEARANCE OF WHEAT, ALL CLASSES AND HARD RED WINTER

| Year Beginning June 1 | Domestic Disappearance of Wheat (All Classes) Food | Industry | Seed | Feed | Total | Disappearance as Hard Red Winter Wheat |
|---|---|---|---|---|---|---|
| | -Million Bushels- | | | | | |
| 1975/76 | | | | | | |
| June-August | 140.0 | | 25.0 | 19.0 | 184.0 | 82.8 |
| September-May | 418.6 | | 74.0 | 45.0 | 537.7 | 242.0 |
| Market Year | 558.6 | .1 | 99.0 | 64.0 | 721.7 | 324.8 |
| 1976/77 | | | | | | |
| June-August | 141.0 | | 24.0 | .6 | 165.6 | 74.5 |
| September-May | 412.1 | | 68.0 | 102.7 | 583.0 | 262.4 |
| Market Year | 553.1 | .1 | 92.0 | 103.3 | 748.6 | 336.9 |
| 1977/78 | | | | | | |
| June-August | 137.0 | | 24.0 | 109.0 | 270.0 | 188.7 |
| September-May | 418.0 | | 56.0 | 91.0 | 565.0 | 288.2 |
| Market Year | 555.0 | | 80.0 | 200.0 | 835.0 | 476.9 |
| Average | | | | | | |
| June-August | 139.0 | | 24.3 | 42.9 | 206.5 | 115.3 |
| September-May | 416.2 | | 66.0 | 80.0 | 561.9 | 264.2 |
| Market Year | 555.2 | .1 | 90.3 | 122.9 | 768.4 | 379.5 |

Exports of wheat have been steadily increasing in recent years. Wheat exports accumulated to $3.9 billion in marketing year 1976-77.[10] The world demand for wheat is increasing approximately 11 million tons annually which necessitates approximately 60 percent of the United States annual harvest being used for export.[11] The average hard red winter wheat exports for the three crop years reviewed are 510 million bushels.[12] Exports are largely a function of worldwide production conditions, but total wheat exports, in all classes, of 1,200 million bushels is fairly representative for wheat exports.

Marketing year supply and disappearance for hard red winter wheat are recorded in Table VI and in Figure 20.

## Regional Storage Capacities

The grain handling and storage industry occupies a position of importance in the grain marketing system. The importance of storage arises from the seasonal nature of hard red winter wheat and other crop production. While hard winter wheat harvest is seasonal, primarily in June, processing and consumption takes place throughout the marketing year. The storage aspect performs the function of matching supplies and demands throughout the marketing year. As a result, the storage component of grain marketing adds a dynamic time element to the marketing system.

Country elevators and terminal elevators, either inland terminals, river port terminals, or export terminals, are the commercial storage facilities included in the model. On-farm storage estimates on a county-by-county basis are also included, but CCC binsite storage is excluded due to lack of substantiable information on location and storage capacity.

## TABLE VI

## MARKETING YEAR SUPPLY AND DISAPPEARANCE OF HARD RED WINTER WHEAT

| Year Beginning June 1 | Supply | | | Disappearance | | | Ending Stocks |
|---|---|---|---|---|---|---|---|
| | Beginning Stocks | Production | Total | Domestic Use | Exports | Total | |
| | | | | -Million Bushels- | | | |
| 1975/76 | | | | | | | |
| HRW | 225 | 1058 | 1283 | 325 | 581 | 906 | 377 |
| All Classes | 435 | 2122 | 2559 | 721 | 1173 | 1894 | 665 |
| 1976/77 | | | | | | | |
| HRW | 377 | 976 | 1353 | 334 | 418 | 752 | 601 |
| All Classes | 665 | 2142 | 2810 | 748 | 950 | 1698 | 1112 |
| 1977/78 | | | | | | | |
| HRW | 601 | 993 | 1594 | 430 | 525 | 955 | 639 |
| All Classes | 1112 | 2026 | 3140 | 835 | 1100 | 1935 | 1205 |
| Average | | | | | | | |
| HRW | 401 | 1009 | 1410 | 363 | 508 | 971 | 539 |
| All Classes | 737 | 2097 | 2836 | 768 | 1074 | 1842 | 994 |

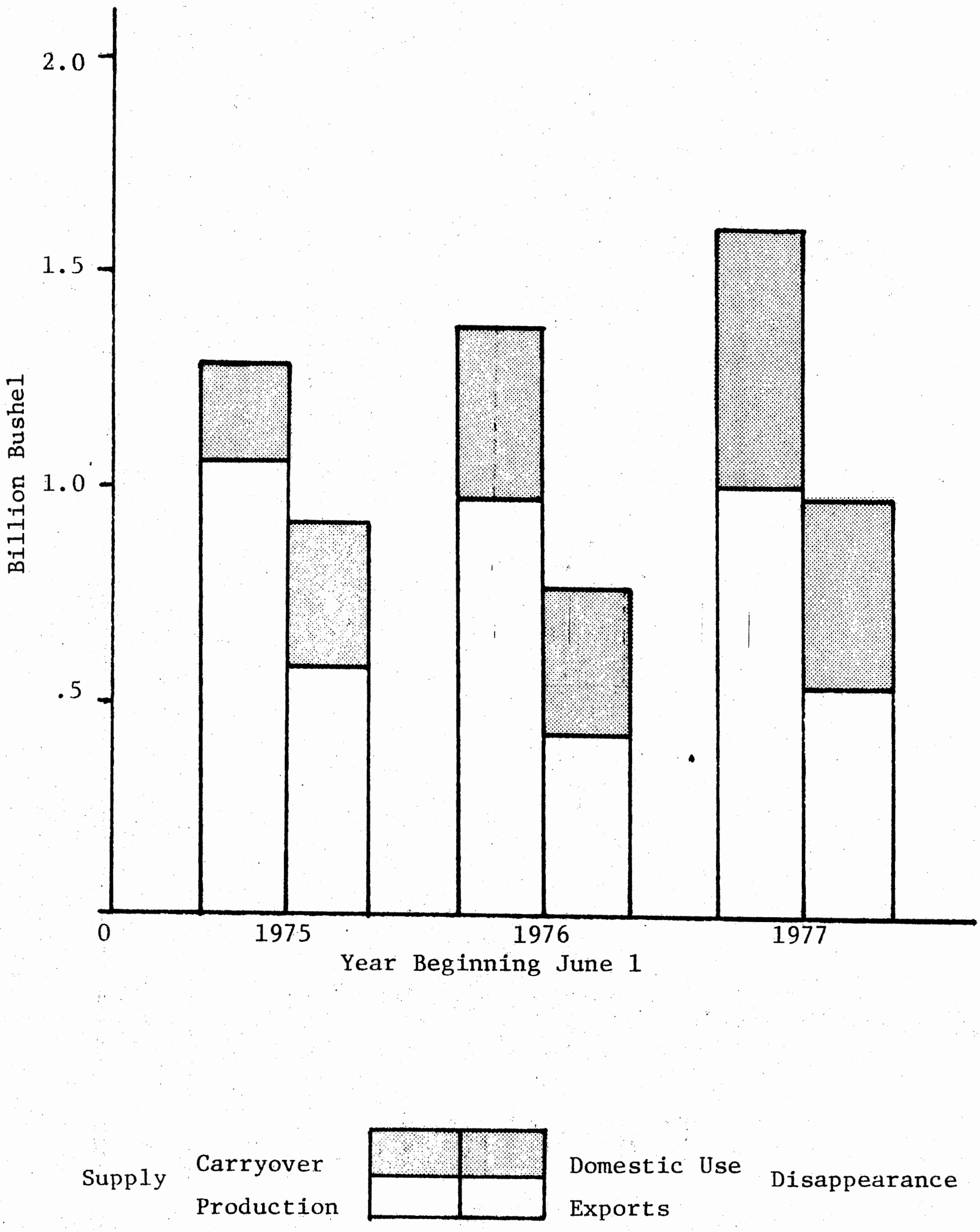


Figure 20. Marketing Year Supply and Disappearance of Hard Red Winter Wheat

Figure 12, as shown earlier, depicts the grain handling and storage components pertinent to hard red winter wheat and the grain marketing structure.

The country elevator has been the traditional first component in the grain flow; and even with increasing emphasis in the development of on-farm storage, the country elevator remains the first stage in the grain marketing system. The principal function of the country elevator is that of the primary assembler of whole grains for processors and terminals. The elevators serve as a market outlet for off-farm sales of whole grain, and, consequently, are found dispersed throughout the grain-producting regions of the United States.

The terminal aspect of commercial storage is comprised of 1) sub-terminals typically located in grain production regions, and 2) terminals located in grain producing regions and traditional grain marketing centers, such as Enid, Hutchinson, and Kansas City. The locations of these terminals are not restricted to either inland or river port locations. Storage and merchandising are the primary functions of terminal elevators, with storage being of longer duration and greater importance to the terminals than to subterminals.

Licensed storage capacities of grain elevators, warehouses, and terminals, as reported by the respective state feed and grain association directories, are the basis for developing commercial storage capacities required for the model.[13] The data is provided on a city-by-city basis and can therefore be aggregated to the county level. Commercial off-farm storage capacities are annotated in Table VII.

Personal elevator manager contacts randomly made throughout the study area indicate country elevators and inland terminals average 1.35

## TABLE VII

## LICENSED STORAGE CAPACITY, BY COUNTY (1000 BUSHEL)

| County Code | Licensed Storage | County Code | Licensed Storage | County Code | Licensed Storage |
|---|---|---|---|---|---|
| Texas | | | | | |
| 101 | 84 | 117 | 1283 | 133 | 9691 |
| 102 | 3624 | 118 | 564 | 134 | 0 |
| 103 | 5781 | 120 | 6610 | 136 | 1885 |
| 104 | 582 | 121 | 657 | 137 | 1857 |
| 105 | 1605 | 122 | 995 | 139 | 4720 |
| 106 | 5460 | 123 | 3949 | 140 | 9182 |
| 107 | 13945 | 124 | 52179 | 141 | 1372 |
| 108 | 185 | 125 | 6370 | 142 | 6010 |
| 109 | 68 | 126 | 2993 | 143 | 12694 |
| 111 | 3890 | 127 | 2444 | 144 | 568 |
| 112 | 825 | 128 | 532 | 145 | 362 |
| 114 | 649 | 130 | 0 | 146 | 3054 |
| 115 | 3621 | 131 | 1042 | 147 | 5887 |
| 116 | 14789 | 132 | 1873 | 148 | 1149 |
| Oklahoma | | | | | |
| 201 | 5347 | 213 | 2001 | 225 | 2810 |
| 202 | 2060 | 214 | 1561 | 226 | 2937 |
| 203 | 1309 | 215 | 5621 | 227 | 45 |
| 204 | 5615 | 216 | 250 | 228 | 154 |
| 205 | 3409 | 217 | 337 | 229 | 1398 |
| 206 | 8499 | 218 | 1005 | 230 | 355 |
| 207 | 3308 | 219 | 4353 | 231 | 390 |
| 208 | 2118 | 220 | 316 | 232 | 9734 |
| 209 | 1582 | 221 | 6645 | 233 | 4854 |
| 210 | 5726 | 222 | 4773 | 234 | 2292 |
| 211 | 1836 | 223 | 3015 | 235 | 2002 |
| 212 | 1310 | 224 | 1762 | 236 | 1927 |
| Wyoming | | | | | |
| 501 | 1829 | 502 | 2445 | 503 | 1589 |
| New Mexico | | | | | |
| 701 | 4119 | 702 | 1826 | 703 | 1815 |

## TABLE VII (Continued)

| County Code | Licensed Storage | County Code | Licensed Storage | County Code | Licensed Storage |
|---|---|---|---|---|---|
| Kansas | | | | | |
| 301 | 397 | 332 | 5349 | 363 | 3601 |
| 302 | 1866 | 333 | 4269 | 364 | 1319 |
| 303 | 5027 | 334 | 8745 | 365 | 5154 |
| 304 | 3220 | 335 | 2701 | 366 | 1619 |
| 305 | 7338 | 336 | 995 | 367 | 8073 |
| 306 | 4921 | 337 | 954 | 368 | 3244 |
| 307 | 1970 | 338 | 2308 | 369 | 7424 |
| 308 | 1378 | 339 | 1374 | 370 | 1818 |
| 309 | 2684 | 340 | 3576 | 371 | 3519 |
| 310 | 3197 | 341 | 3270 | 372 | 3226 |
| 311 | 3742 | 342 | 1541 | 373 | 3085 |
| 312 | 3411 | 343 | 5461 | 374 | 4961 |
| 313 | 854 | 344 | 2142 | 375 | 6014 |
| 314 | 2603 | 345 | 4459 | 376 | 7525 |
| 315 | 1711 | 346 | 1515 | 377 | 2339 |
| 316 | 1820 | 347 | 7970 | 378 | 2745 |
| 317 | 1785 | 348 | 4286 | 379 | 2074 |
| 318 | 5842 | 349 | 4860 | 380 | 6964 |
| 319 | 1690 | 350 | 5934 | 381 | 3124 |
| 320 | 3850 | 351 | 3421 | 382 | 6510 |
| 321 | 2837 | 352 | 606 | 383 | 5745 |
| 322 | 3396 | 353 | 1070 | 384 | 6368 |
| 323 | 7744 | 354 | 4652 | 385 | 18735 |
| 324 | 11585 | 355 | 2581 | 386 | 9155 |
| 325 | 1226 | 356 | 787 | 387 | 2359 |
| 326 | 4043 | 357 | 7086 | 388 | 306 |
| 327 | 1980 | 358 | 2415 | 389 | 3208 |
| 328 | 7594 | 359 | 1601 | 390 | 5021 |
| 329 | 9681 | 360 | 2167 | 391 | 5548 |
| 330 | 3261 | 361 | 4222 | 392 | 456 |
| 331 | 3435 | 362 | 5025 | | |
| Colorado | | | | | |
| 601 | 4049 | 607 | 3712 | 612 | 2260 |
| 602 | 1896 | 608 | 2428 | 613 | 2606 |
| 603 | 2565 | 609 | 3418 | 614 | 5936 |
| 604 | 1643 | 610 | 1936 | 615 | 3663 |
| 605 | 1573 | 611 | 3328 | 616 | 3070 |
| 606 | 2114 | | | | |

TABLE VII (Continued)

| County Code | Licensed Storage | County Code | Licensed Storage | County Code | Licensed Storage |
|---|---|---|---|---|---|
| Nebraska | | | | | |
| 401 | 2099 | 415 | 1675 | 429 | 2067 |
| 402 | 2203 | 416 | 2409 | 430 | 1756 |
| 403 | 3566 | 417 | 2990 | 431 | 1666 |
| 404 | 1564 | 418 | 2765 | 432 | 1953 |
| 405 | 1737 | 419 | 2546 | 433 | 1898 |
| 406 | 1816 | 420 | 1618 | 434 | 4946 |
| 407 | 2258 | 421 | 2011 | 435 | 3065 |
| 408 | 6862 | 422 | 2242 | 436 | 1653 |
| 409 | 1777 | 423 | 3063 | 437 | 2536 |
| 410 | 1838 | 424 | 5190 | 438 | 1730 |
| 411 | 2101 | 425 | 1794 | 439 | 1804 |
| 412 | 3251 | 426 | 2751 | 440 | 1934 |
| 413 | 1936 | 427 | 4167 | 441 | 3504 |
| 414 | 2405 | 428 | 2660 | 442 | 1817 |

turns of their normal operating storage capacity per annum. Approximately 15 percent of a facility's licensed storage capacity is retained for drying, airing or turning, and increased receiving or loadout leg requirements. This redefines available storage as normal operating storage, a quantity somewhat less than licensed capacity. A storage turn or rotation is a complete recycling of available storage, for instance--empty, filled with incoming grain, loaded out due to market orders for grain, and empty again.

Port terminals along the Gulf of Mexico and the Great Lakes use their storage capacity primarily for the accumulation of grain prior to the loading of ocean going ships rather than for long term storage. Accumulation of grain at port elevators is necessary on a short term basis because the vessel types employed in grain haulage, i.e., bulk carriers, general cargo ships, tankers, ore carriers, and container ships, have capacities averaging 730,000 bushels per vessel, with bulk carriers having the capability to carry the most grain per vessel (2,137,333 bushels).[14] Loading of ships directly from trucks or rail cars is impractical because to schedule the arrival of the necessary volume exactly when ships are ready for loading is practically impossible. Export terminals facilities average six (6) turns of their normal operating storage capacity, as compared with the 1.35 turns used by country elevators and inland terminals.[15]

The normal operating storage capacities, in relation to rotational storage turns, are depicted in Table VIII for the two time periods of June through August and September through May.

On-farm storage estimates by state are obtained from ESCS publications.[16] The available on-farm storage is assumed proportionate on a

## TABLE VIII

## NORMAL OPERATING STORAGE CAPACITIES

| County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] | County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] |
|---|---|---|---|---|---|
| | (1,000 bushel) | | | (1,000 bushel) | |
| 101 | 71 | 23 | 125 | 5414 | 1787 |
| 102 | 3089 | 1019 | 126 | 2544 | 840 |
| 103 | 4914 | 1622 | 127 | 2077 | 685 |
| 104 | 495 | 163 | 128 | 452 | 149 |
| 105 | 1364 | 450 | 130 | 0 | 0 |
| 106 | 4641 | 1532 | 131 | 886 | 292 |
| 107 | 11853 | 3911 | 132 | 1592 | 525 |
| 108 | 157 | 52 | 133 | 8237 | 2718 |
| 109 | 58 | 19 | 134 | 0 | 0 |
| 111 | 3306 | 1091 | 136 | 1602 | 529 |
| 112 | 701 | 321 | 137 | 1578 | 521 |
| 114 | 552 | 182 | 139 | 4012 | 1324 |
| 115 | 3078 | 1016 | 140 | 7805 | 3576 |
| 116 | 12571 | 4148 | 141 | 1166 | 385 |
| 117 | 1091 | 360 | 142 | 5108 | 1686 |
| 118 | 479 | 158 | 143 | 10790 | 3561 |
| 120 | 5618 | 1854 | 144 | 483 | 159 |
| 121 | 558 | 184 | 145 | 308 | 102 |
| 122 | 846 | 279 | 146 | 2596 | 857 |
| 123 | 3357 | 1108 | 147 | 5004 | 1651 |
| 124 | 44352 | 14636 | 148 | 977 | 322 |

TABLE VIII (Continued)

| County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] | County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] |
|---|---|---|---|---|---|
| | (1,000 bushel) | | | (1,000 bushel) | |
| 201 | 4545 | 1500 | 219 | 3700 | 1221 |
| 202 | 1751 | 578 | 220 | 269 | 89 |
| 203 | 1113 | 367 | 221 | 5684 | 1864 |
| 204 | 4773 | 1575 | 222 | 4057 | 1339 |
| 205 | 2898 | 956 | 223 | 2563 | 846 |
| 206 | 7224 | 2384 | 224 | 1498 | 494 |
| 207 | 2812 | 928 | 225 | 2388 | 788 |
| 208 | 1800 | 594 | 226 | 2396 | 824 |
| 209 | 1345 | 444 | 227 | 38 | 13 |
| 210 | 4867 | 1606 | 228 | 131 | 43 |
| 211 | 1561 | 515 | 229 | 1288 | 425 |
| 212 | 1113 | 367 | 230 | 302 | 100 |
| 213 | 5951 | 1964 | 231 | 331 | 109 |
| 214 | 1327 | 438 | 232 | 8274 | 2730 |
| 215 | 4778 | 1577 | 233 | 4126 | 1362 |
| 216 | 212 | 70 | 234 | 1948 | 643 |
| 217 | 286 | 94 | 235 | 5952 | 1964 |
| 218 | 854 | 282 | 236 | 1638 | 541 |
| 301 | 337 | 111 | 347 | 6774 | 2235 |
| 302 | 1586 | 523 | 348 | 3643 | 1202 |
| 303 | 4273 | 1410 | 349 | 4131 | 1363 |
| 304 | 2737 | 903 | 350 | 5044 | 1665 |
| 305 | 6237 | 2058 | 351 | 2908 | 960 |
| 306 | 4183 | 1380 | 352 | 515 | 170 |

## TABLE VIII (Continued)

| County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] | County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] |
|---|---|---|---|---|---|
| | (1,000 bushel) | | | (1,000 bushel) | |
| 307 | 1674 | 552 | 353 | 909 | 300 |
| 308 | 1171 | 386 | 354 | 3954 | 1305 |
| 309 | 2281 | 753 | 355 | 2194 | 724 |
| 310 | 2717 | 897 | 356 | 669 | 221 |
| 311 | 3181 | 1050 | 357 | 6023 | 1099 |
| 312 | 2899 | 957 | 358 | 2053 | 677 |
| 313 | 726 | 240 | 359 | 1361 | 449 |
| 314 | 2213 | 730 | 360 | 1842 | 608 |
| 315 | 1454 | 480 | 361 | 3589 | 1184 |
| 316 | 1547 | 511 | 362 | 4271 | 1409 |
| 317 | 1517 | 501 | 363 | 3061 | 1010 |
| 318 | 4966 | 1639 | 364 | 1121 | 370 |
| 319 | 1436 | 474 | 365 | 4881 | 1611 |
| 320 | 3272 | 1080 | 366 | 1376 | 454 |
| 321 | 2411 | 796 | 367 | 6862 | 2264 |
| 322 | 2887 | 953 | 368 | 2757 | 910 |
| 323 | 6582 | 2172 | 369 | 6353 | 2096 |
| 324 | 9847 | 3250 | 370 | 1545 | 510 |
| 325 | 1042 | 344 | 371 | 2991 | 987 |
| 326 | 3437 | 1134 | 372 | 2742 | 905 |
| 327 | 1683 | 555 | 373 | 2622 | 865 |
| 328 | 6455 | 2130 | 374 | 4217 | 1392 |
| 329 | 8229 | 2716 | 375 | 5112 | 1687 |
| 330 | 2772 | 915 | 376 | 6396 | 2122 |
| 331 | 2920 | 964 | 377 | 1988 | 656 |
| 332 | 4547 | 1501 | 378 | 2333 | 770 |

## TABLE VIII (Continued)

| County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] | County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] |
|---|---|---|---|---|---|
| | (1,000 bushel) | | | (1,000 bushel) | |
| 333 | 3629 | 1198 | 379 | 1763 | 582 |
| 334 | 7433 | 2453 | 380 | 5919 | 1953 |
| 335 | 2296 | 748 | 381 | 2655 | 896 |
| 336 | 846 | 279 | 382 | 5533 | 1826 |
| 337 | 811 | 268 | 383 | 4883 | 1611 |
| 338 | 1962 | 647 | 384 | 5413 | 1786 |
| 339 | 1168 | 385 | 385 | 15925 | 5255 |
| 340 | 3040 | 1003 | 386 | 7782 | 2568 |
| 341 | 2779 | 917 | 387 | 2005 | 662 |
| 342 | 2310 | 432 | 388 | 260 | 86 |
| 343 | 4642 | 1532 | 389 | 2727 | 900 |
| 344 | 1821 | 601 | 390 | 4268 | 1408 |
| 345 | 3790 | 1251 | 391 | 4716 | 1556 |
| 346 | 1288 | 425 | 392 | 388 | 128 |
| 401 | 1784 | 589 | 422 | 1906 | 629 |
| 402 | 1873 | 618 | 423 | 2604 | 859 |
| 403 | 3031 | 1000 | 424 | 4411 | 1456 |
| 404 | 1329 | 439 | 425 | 1525 | 503 |
| 405 | 1476 | 487 | 426 | 2338 | 772 |
| 406 | 1544 | 510 | 427 | 3542 | 1169 |
| 407 | 1919 | 633 | 428 | 2261 | 746 |
| 408 | 5833 | 1925 | 429 | 1757 | 580 |
| 409 | 1510 | 498 | 430 | 1493 | 493 |
| 410 | 1562 | 515 | 431 | 1416 | 467 |
| 411 | 1786 | 589 | 432 | 1660 | 548 |

TABLE VIII (Continued)

| County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] | County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] |
|---|---|---|---|---|---|
| | (1,000 bushel) | | | (1,000 bushel) | |
| 412 | 2763 | 912 | 433 | 1613 | 532 |
| 413 | 1646 | 543 | 434 | 4204 | 1387 |
| 414 | 2044 | 675 | 435 | 2605 | 860 |
| 415 | 2424 | 470 | 436 | 1405 | 464 |
| 416 | 3048 | 676 | 437 | 2156 | 711 |
| 417 | 2541 | 839 | 438 | 1470 | 485 |
| 418 | 2350 | 776 | 439 | 1533 | 506 |
| 419 | 2164 | 714 | 440 | 1644 | 543 |
| 420 | 1375 | 454 | 441 | 2128 | 702 |
| 421 | 1709 | 564 | 442 | 1544 | 510 |
| 501 | 1555 | 513 | 503 | 1358 | 448 |
| 502 | 2078 | 686 | | | |
| 601 | 3442 | 1135 | 609 | 2905 | 959 |
| 602 | 1612 | 532 | 610 | 1646 | 543 |
| 603 | 2180 | 719 | 611 | 2829 | 943 |
| 604 | 1397 | 461 | 612 | 1921 | 634 |
| 605 | 1337 | 441 | 613 | 2215 | 731 |
| 606 | 1797 | 593 | 614 | 5046 | 1665 |
| 607 | 3155 | 1041 | 615 | 3114 | 1028 |
| 608 | 2064 | 681 | 616 | 2609 | 861 |
| 701 | 3501 | 1155 | 703 | 1543 | 509 |
| 702 | 1552 | 512 | | | |

TABLE VIII (Continued)

| County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] | County Code | Licensed Storage -15% Rotation Working Space= 1.00 Turn [Sept. - May] | .33 Turn [June - Aug.] |
|---|---|---|---|---|---|
| 801 | 1535 | 507 | 804 | 1545 | 510 |
| 802 | 1903 | 628 | 805 | 1415 | 467 |
| 803 | 1351 | 446 | 806 | 1732 | 572 |

county basis to the relative percent of hard red winter wheat produced in the county to the total state grain production (wheat and feed grains). On-farm storage estimates are not fully indicative of the quantity of wheat retained by the producer as the facilities used may actually have been devised for other purposes but have been converted for temporary grain storage. Therefore, the on-farm storage figures are probably under-estimated; however, the statewide published data are used in the model. Table IX indicates the on-farm storage estimates used in the model.

## Transportation Availability

The seasonal availability of transportation facilities and services is more highly related to the transportation rates than to the quantity of grain commodity to be shipped. Given profitable transportation rates, no lack of transportation facilities would likely exist either in the form of covered rail hopper cars, five-axle semi-trailer grain hauling trucks, or nine-foot draft river barges. Constraining numbers of covered hopper cars, semi-trailer trucks, or river barges are not considered.

Modal constraints in terms of physical, institutional, or mechanical limitations are considered. River barge traffic is slower per mile than other modes due to navigational locks, river currents and other barge traffic. Also the dredged width and depth of the navigation channel is a factor. The average number of days for one-way barge shipment and the average speed for the various river sections investigated in the study are reported in Table X.[17]

## TABLE IX

## ON-FARM STORAGE CAPACITIES

| State Totals | On-Farm Storage Estimates for Wheat (1,000 bushel) |
|---|---|
| Colorado | 97,216 |
| Kansas | 340,892 |
| Missouri | 309,084 |
| Nebraska | 715,594 |
| New Mexico | 9,136 |
| Oklahoma | 76,688 |
| Texas | 238,472 |
| Wyoming | 19,519 |
| 8-State Total | 1,806,601 |
| 48 U. S. State Total Storage (for Shelled Corn, Other Grains, Oil Seeds) | 8,116,815 |

## TABLE X

## AVERAGE SPEED AND LOST DAYS FOR BARGE SHIPMENTS

| River Section* Encountered | Speed (mph) | | Days Lost |
|---|---|---|---|
| | Upstream | Downstream | |
| Mississippi River (below St. Louis) | 4.6 | 8.1 | |
| Arkansas River | 4.5 | 4.5 | 12 |
| Missouri River | 3.5 | 9.0 | 12 |
| St. Louis | | | 8 |
| New Orleans | | | 6 |

*Originating river section for Gulf bound shipments; junction applies if shipment originated above St. Louis on the Mississippi River.

Truck traffic is constrained by speed limits and weight limits. The national 55-mph speed limit on limited access interstate highways and state and U. S. highways has not severely incumbered the trucking of grain to either inland terminals or export terminals. The average speed of long-haul trucking to the Gulf port facilities, including food, fuel, and rest stops and weigh station and port of entry checks, is 47 mph.[18] Long haul grain trucking rates are typically bid on an overweight basis which further enhance the competitiveness of truck freight to rail and barge traffic. The constraining factor becomes the absence of back-hauls from the Gulf to the up-country elevators to encourage the trucking industry. The variable operating costs, especially labor and fuel, further constrain and limit the usage of long-haul trucks.

The availability of covered hopper cars and converted box cars at the inland terminals and country elevators appears to be a function of the supply of rail cars rather than the demand for rail services.[19] Peak load pricing, the pricing policy of charging proportionately more for rail services during the harvest season (the peak load period) than the remainder of the marketing year, has been investigated as a technique for smoothing the demand for rail services to match the available supply throughout the year. However, peak load pricing by the railroads is viewed by the grain shippers as a seasonal surcharge which more nearly equates all modal transportation rates during a period in which a more abundant supply of transportation services is needed. Traffic would not noticably be smoothed throughout the marketing year because of peak load pricing. Nor would extensive switching from one mode to another occur, even though the transportation rates are competitive.

The railroads have maintained the predominant share of grain haulage (consistently in excess of 70 percent) through the element of the railroad rate structure known as transit privilege.[20] Transit privilege permits grain to be moved from particular origins to a particular final destination on a single through rate, with intermediate stops for reconsignment, inspection, storage, or processing. Grain shippers gain from the transit privilege because typically a single long-haul rate is less than the sum of two or more short-haul rates. Export rates on commodities are considerably lower than domestic rates. Also, the potential for a greater car supply and a more rapid car service exists. The railroads gain from offering the transit privilege with a fixed through rate by remaining competitive with other modes, and by holding control of the largest part of the freight bill over the life of the transit bill, as well as improved equipment utilization. Not all railroad companies operating in an area offer the same privileges to grain shippers as the railroads hold the perogative of offering transit privileges from specific origins through specific intermediate locations to specific final destinations.

A recent development in the grain marketing system is the probable elimination of transit privileges on a fixed through rate which will have the net effect of increasing the railroad freight bill if an intermediate off-loading is incurred.

Truck allowance and truck substitution tariffs are gaining interest as lower cost alternatives to grain transport. These tariffs provide the country elevators an opportunity to move the grain by truck in lieu of rail to the terminal elevators served by the same railroad, and if the country elevator is located within a prescribed radius to the terminal. This allows the railroads to use equipment elsewhere rather than in collecting grain from the applicable country elevators.

The navigable rivers, the network of state, U. S., and Interstate highways, and the railroad network utilized in the study are shown in Figures 21, 22, and 23, respectively.

## Marketing Charges

The final data category necessary for the model, and perhaps the most relevant for economic accuracy, is the marketing charges and/or costs of performing various functions involved in grain marketing. Four types of data inputs are required for this study. These inputs are 1) transportation rates between the grain shipment origins and destinations, 2) handling costs for receiving grain, 3) handling costs for loadout of grain, and 4) storage charges. The costs associated with cleaning and drying of grain are excluded from the study since the need and extent of these activities are dependent upon the quality and condition of the grain as it departs the field of harvest, and the variable cost of fuel is increasing consistently. Furthermore, a basic assumption of the model is that the hard red winter wheat is of homogeneous quality.

### Transportation Rates

Spatial problems generally require a very large number of transportation rates between various locations. In grain transportation, the shipper typically has more than one mode of transportation available to him and, in some instances, a combination of modes may be considered, such as truck-barge or rail-barge.

Rail traditionally has been the most important carrier of grain. The rate structure for rail transportation of grain has developed over many years and is based on numerous factors, including distance and

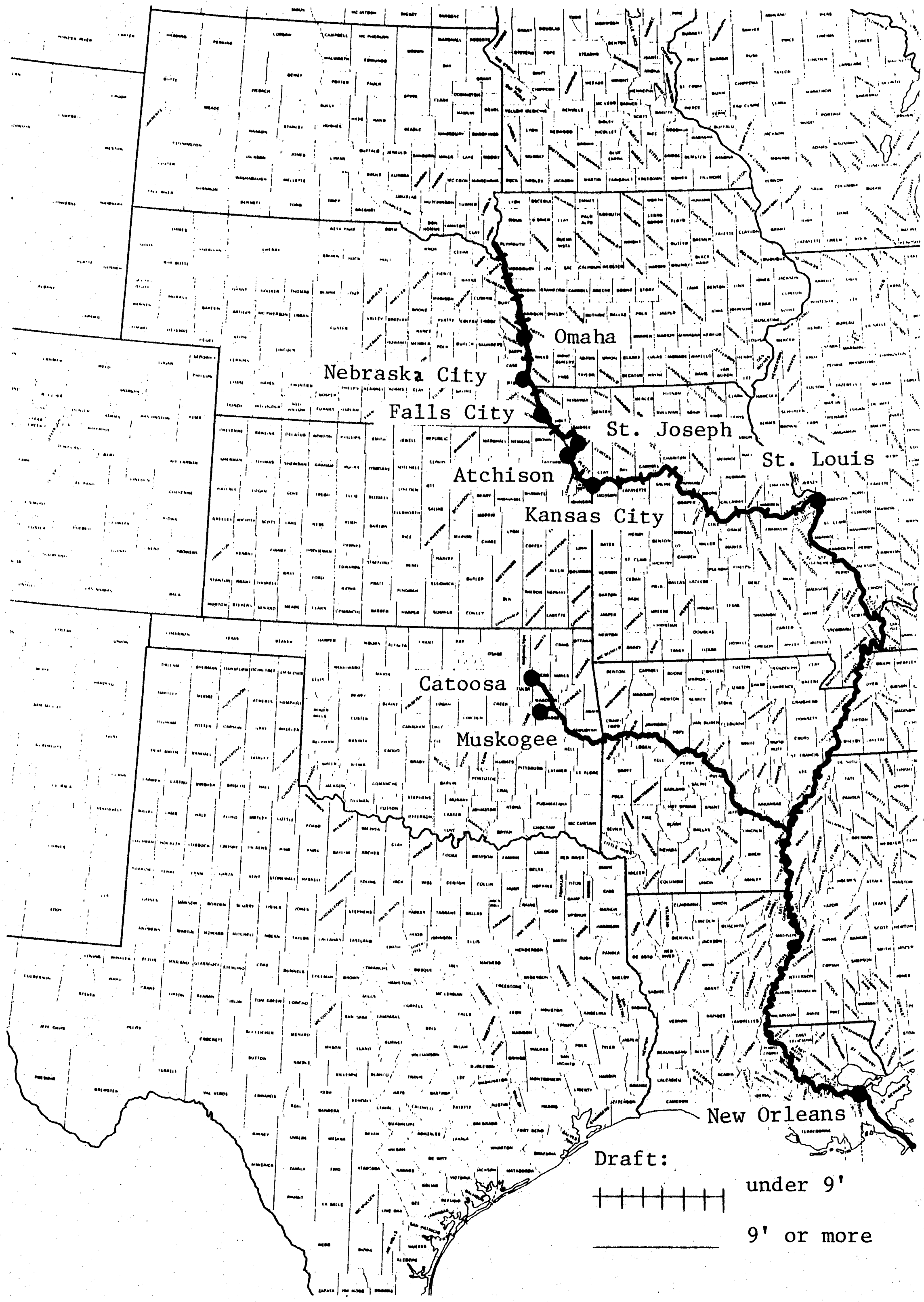


Figure 21. Navigable Rivers in the Study

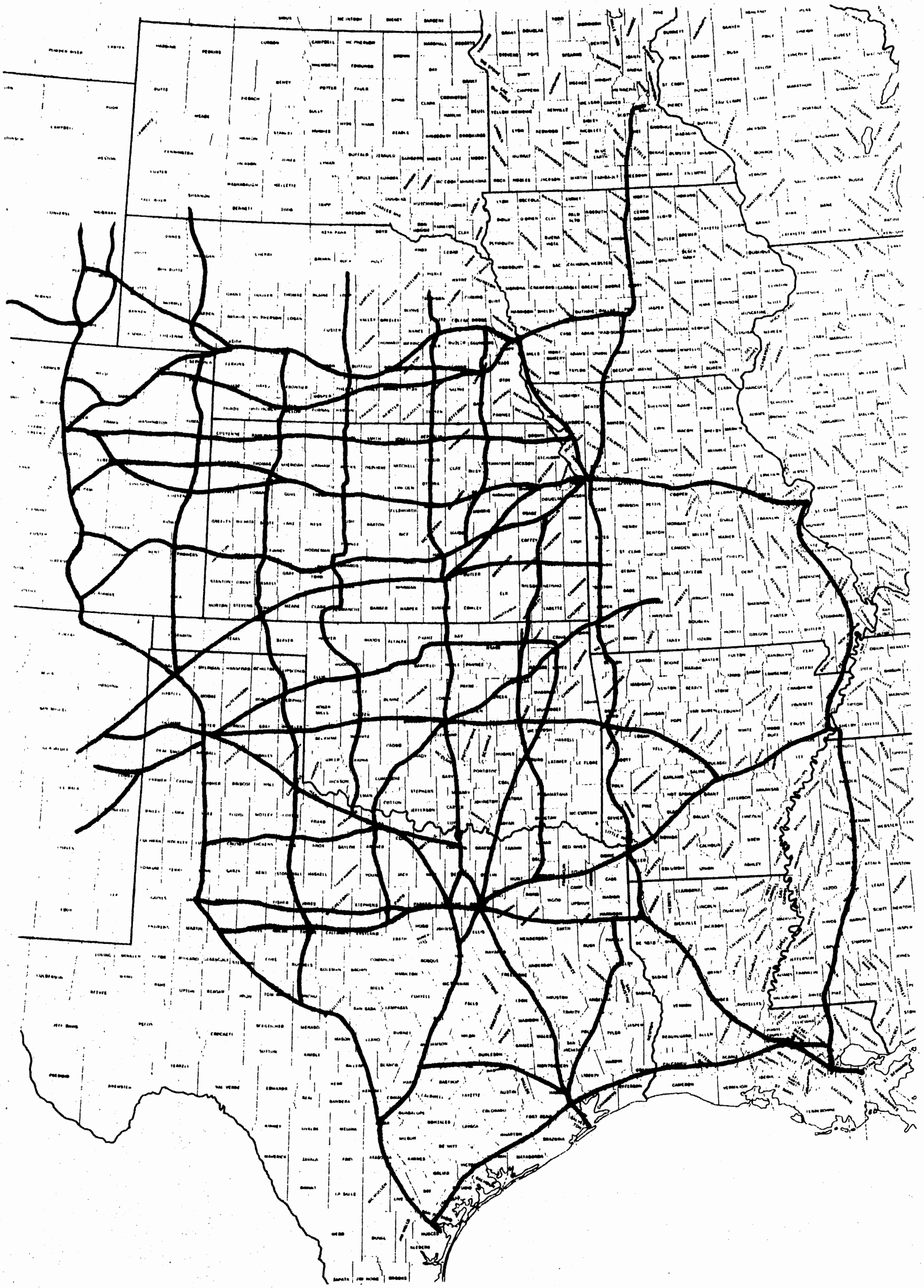


Figure 22. State, U. S., and Interstate Highways in the Study

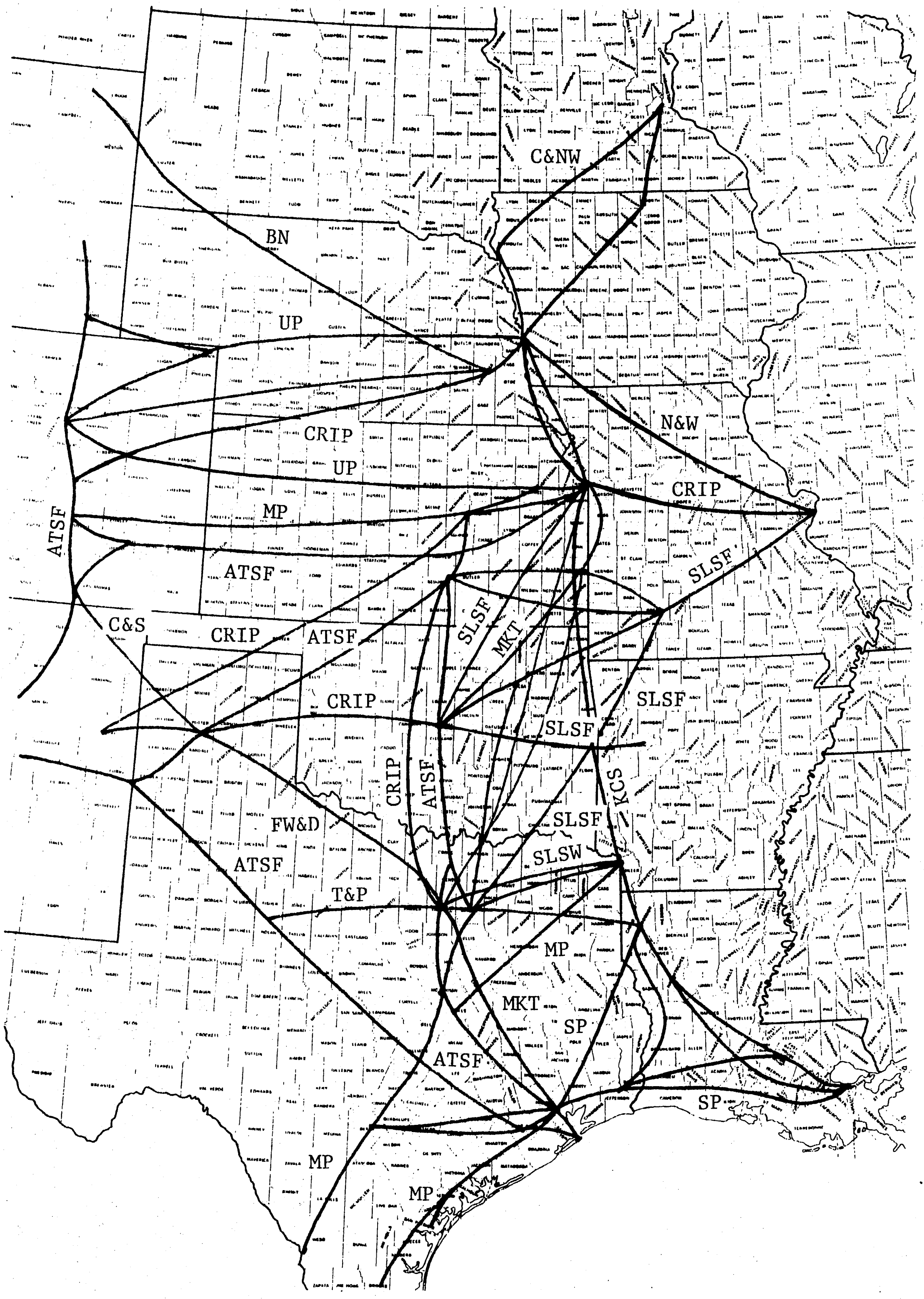


Figure 23. Railroad Network in the Study

volume. Consequently, mathematical regression equations relating distance or mileage to rates are not evaluated. Instead, single-car export wheat rates to Gulf ports for specified origins in the study area are used. The export rates, furnished by the Enid Board of Trade, are through the current X-357 level effective 15 December 1978.[21] Multi-car and unit train rates were not available in the study region so these options are not explored.

The prevailing barge rates used in this study are provided by the Arrow Transportation Company as extracted from its Guide to Published Barge Rates on Bulk Grain, Schedule No. 8, issued 1 October 1972 and updated with Supplement No. 3 to Schedule No. 8, dated 1 March 1975.[22] Seasonal variation ranges from 100 percent upward to 200 percent of the standard rate, as the comments provided by the Tulsa Port of Catoosa management reflect.[23] As a consequence to this seasonal variation in charges, most wheat barge movements occur in early spring to take advantage of the lower barge rates afforded when barges are not scarce nor being used for corn and soybeans, as in the late fall. One hundred seventy-five (175) percent of the standard rate is used in the model.

In most instances, particularly with hard red winter wheat, water transportation is not available for the complete movement between particular origins and port destinations. Therefore, point-to-point truck-barge combination rates are computed for appropriate hard winter wheat transfers.

Mileage is an important factor in the rate-making by trucking firms, enough so that mathematical equations expressing the relationship between rates and mileage are often employed. However, several secondary sources including published tariffs, truck brokers, independent grain haulers, and truck leasing firms are employed in the collection and derivation of representative long-haul grain trucking rates. Backhauls are excluded from the model as the variation in charges resulting from backhauls confounds the computer application and the influence of such factors is beyond the scope of this study. For the specific origins where "rates" could be obtained, these rates are used in the model. Elsewhere, regression equations for the particular originating states to the Gulf are used, as are regression equations for grain haulage from country elevator and inland terminal to river port terminal.

The data used as observations in deriving the regression equations were obtained from spot checks of grain haulers along the Interstate Highway System in the study area and from randomly selected truck brokers and contract haulers located throughout the study area. The data sought were trucking rates from selected origins to selected inland, river, or port terminals. The response values were used as received although many of these responses were based on overweight freight. The scattered and limited number of observations received from independent truckers were subjectively considered as these grain haulers generally charge "rates" dependent upon their individual indebtedness and cash flow situations in meeting their financial obligations. When approached, many of the independent truckers skirted the questions or declined to comment.

However, the data obtained from most of the observations were used in conducting an analysis of variance and obtaining regression equations for determining export trucking rates, and these mathematical equations are as follows:

Texas to Gulf:

$$\text{Rate } (¢/\text{bu.}) = .4704 - .000444\ (\text{Miles}) + .00000074\ (\text{Miles})^2$$

(3.6928) (-1.0092) (2.6351)

$R^2 = .808$ S.D. = .0243

New Mexico to Gulf:

$$\text{Rate } (¢/\text{bu.}) = .4303 - .000278\ (\text{Miles}) + .00000058\ (\text{Miles})^2$$

(5.2930) (-.9003) (2.0748)

$R^2 = .777$ S.D. = .0259

Oklahoma to Gulf:

$$\text{Rate } (¢/\text{bu.}) = -.0539 + .001162\ (\text{Miles}) - .00000048\ (\text{Miles})^2$$

(-.2695) (1.7527) (-.8745)

$R^2 = .781$ S.D. = .0255

Kansas and Missouri to Gulf:

$$\text{Rate } (¢/\text{bu.}) = 1.1655 - .002092\ (\text{Miles}) + .00000184\ (\text{Miles})^2$$

(3.4124) (-2.4017) (3.3341)

$R^2 = .772$ S.D. = .0351

Nebraska to Gulf:

$$\text{Rate } (¢/\text{bu.}) = -3.6031 + .007423\ (\text{Miles}) - .00000294\ (\text{Miles})^2$$

(3.3113) (3.5033) (-2.8741)

$R^2 = .839$ S.D. = .0561

Colorado and Wyoming to Gulf:

$$\text{Rate } (¢/\text{bu.}) = -3.0000 + .006766\ (\text{Miles}) - .00000283\ (\text{Miles})^2$$

(-3.6789) (4.2562) (-3.6812)

$R^2 = .889$ S.D. = .0417

Oklahoma to Fort Worth:

$$\text{Rate } (¢/\text{bu.}) = 6.4353 + .0794\ (\text{Miles}) - .00002248\ (\text{Miles})^2$$

(3.111) (5.4916) (-4.1871)

$R^2 = .970$ S.D. = .0147

Oklahoma to Enid and Catoosa; Nebraska to Omaha; and Kansas to Hutchinson, Salina, Kansas City, and Wichita:

$$\text{Rate } (¢/\text{bu.}) = 3.1486 + .1038\ (\text{Miles}) - .00008134\ (\text{Miles})^2$$

(2.7922) (3.5334) (-2.6137)

$R^2 = .983$ S.D. = .0270

Kansas and Missouri to Catoosa and Enid:

$$\text{Rate } (¢/\text{bu.}) = 3.54 + .094\ (\text{Miles}) - .000045\ (\text{Miles})^2$$

(3.0076) (4.1012) (-3.4679)

$R^2 = .799$ S.D. = .0399

The values in parentheses under the equation coefficients are the respective t-values. The R-squared values and the standard deviations of the equations are also annotated.

Although the trucking rates determined by the regression equations above are a function of mileage only, the regression coefficients and signs in some of the equations do not follow the results typically associated with transportation service rates. Intercepts are anticipated to be of a positive sign, representing terminal charges. The magnitude of the intercept is generally larger for shorter distances, i.e., Oklahoma to Fort Worth, than for long-hauls, such as Kansas and Missouri to the Gulf. This implies the long-haul trucking rates are more a function of the miles traversed and that any terminal costs incurred are increasingly absorbed by the mileage factor.

Nonetheless, these second-degree polynomial equations and their resulting rates were used as a proxy for export grain trucking rates from those county seats where published rates were not readily available.

## Handling Costs

The cost associated with receiving and loadout of hard red winter wheat varies depending upon the mode of transportation and the type of storage or elevator facility used. The cost figures used in the model are obtained from the sequence of bulletins or reports published by USDA-ERS on the Cost of Storing and Handling Grain in Commercial Elevators and then estimating the appropriate costs for the marketing year 1977-78 using least-squares regression.[24] The estimated costs, recorded as weighted average standardized book values, are presented in Table XI by mode and function.

## TABLE XI

## VARIABLE COST, IN CENTS PER BUSHEL, OF HANDLING GRAIN USING WEIGHTED AVERAGE STANDARDIZED BOOK VALUES

| Year Beginning June 1 | Received by Truck | Loadout by Truck | Received by Rail | Loadout by Rail | Received by Water | Loadout by Water |
|---|---|---|---|---|---|---|
| Country Elevators | | | | | | |
| 1975-76 | 1.942 | 2.016 | | 2.071 | | |
| 1976-77 | 1.968 | 2.040 | | 2.041 | | |
| 1977-78 | 1.994 | 2.065 | | 2.011 | | |
| Inland Terminals | | | | | | |
| 1975-76 | 1.564 | 1.192 | 1.890 | 1.521 | | .747 |
| 1976-77 | 1.607 | 1.125 | 1.946 | 1.518 | | .753 |
| 1977-78 | 1.650 | 1.058 | 2.002 | 1.514 | | .758 |
| Port Terminal | | | | | | |
| 1975-76 | 1.246 | | 1.309 | | 1.565 | |
| 1976-77 | 1.278 | | 1.313 | | 1.625 | |
| 1977-78 | 1.309 | | 1.317 | | 1.685 | |

The charges for grain storage present a dilemma. Estimated costs in cents per bushel of grain storage are available, but with no specific reference to duration of storage. Therefore, storage costs are not assessed in the model although the variable cost components of receiving and loadout by mode and facility function are included. These costs are combined with the transportation rates by the various modes of transportation to arrive at total export transfer charges.

## FOOTNOTES

[1] County production data based on selected states' Departments of Agriculture, Agricultural Statistics, 1975 (and subsequent issues), Crop and Livestock Reporting Services (Austin, Denver, Cheyenne, Topeka, Omaha, Jefferson City, Albuquerque, Oklahoma City, 1976).

[2] U. S. Department of Agriculture, Distribution of the Varieties and Classes of Wheat in the United States, Statistical Reporting Service Statistical Bulletin 369 (Washington, 1964), pp. 55-65.

[3] U. S. Department of Agriculture, Wheat Situation, Economics, Statistical, and Cooperative Service WS-244 (Washington, 1978), p. 20.

[4] Ibid.

[5] U. S. Department of Agriculture, Crop Production, 1975 Annual Summary, Acreage, Yield, Production, By States, Statistical Reporting Service Publication No. Cr Pr 2-1(75) (Washington, 1975), p. 51 (and subsequent reports).

[6] U. S. Department of Agriculture, Feed and Seed Crops, Production, Farm Use, Sales, Value, By States, 1975-76, Statistical Reporting Service Publication No. Cr Pr 1(77) (Washington, 1977), pp. 5-11.

[7] U. S. Department of Agriculture, WS-244, p. 20.

[8] Ibid., p. 2.

[9] Ibid., p. 19.

[10] Thomas Saylor, Associate Director, Foreign Agriculture Service, U. S. Department of Agriculture, Agricultural Policy Seminar, Oklahoma State University (Stillwater, March 9, 1979).

[11] Ibid.

[12] U. S. Department of Agriculture, WS-244, p. 20.

[13] Licensed storage capacity data based on selected states' Feed and Grain Dealers' Associations, Annual Directory, 1975, and subsequent issues (Austin, Denver, Cheyenne, Hutchinson, Omaha, Kansas City, Albuquerque, and Oklahoma City, 1975).

[14] Stephen W. Fuller, and Mechel S. Paggi, *Port of Houston: Intermodal Grain Transfer System and Market Area, 1976-77*, The Texas Agricultural Experiment Station Bulletin No. B-1190 (Austin, 1978), pp. 7-10.

[15] Ray Copeland, Fort Worth Operations, Personal Telephone Interview, Union Equity Cooperative Exchange, Fort Worth, Texas, August 22, 1978.

[16] "Six States Show More Than One Billion Bushels Storage Capacity," *Milling and Baking News* (August 22, 1978), p. 57.

[17] Jerry A. Fedeler, Earl O. Heady, and Won W. Koo, "A National Grain Transportation Model," *Spatial Sector Programming Models in Agriculture* (Ames, 1975), pp. 463-8.

[18] U. S. Department of Transportation, *Highway Statistics: 1977*, Bureau of Public Roads (Washington, 1978), p. 18.

[19] Erhardt O. Rupprecht, Jr., "Demand for Freight Cars in the Movement of Grains," American Agricultural Economics Association Contributed Papers Session (Pennsylvania State University, 1976), p. 3.

[20] Marc A. Johnson, Gary M. Mennem, and Robert L. Oehrtman, *Rail Wheat Transportation Efficiency Study (Problem Assessment)*, Oklahoma State University, Department of Agricultural Economics Paper No. AE 7708 (Stillwater, 1976), pp. 38-44.

[21] Enid Board of Trade, *Ex Parte X-357 Export Rates* (Enid, 1979).

[22] Arrow Transportation Company, *Guide to Published Barge Rates on Bulk Grain, Schedule No. 8, Supplement No. 3* (Sheffield, Alabama, 1976).

[23] Harry Coffel, OK Grain Company, Personal Interview, Catoosa, Oklahoma, February 26, 1979.

[24] U. S. Department of Agriculture, *Cost of Storing and Handling Grains in Commercial Elevators, 1964-65*, Economic Research Service ERS-288, and subseqent bulletins (Washington, 1966).

# CHAPTER V

## RESULTS

Aggregate models, rather than time-staged models, are useful in studying 1) optimum geographic grain flows, 2) regional domestic activities using hard red winter wheat, and 3) optimum export distribution patterns for hard red winter wheat. Useful information can be derived from the macro or "big picture" solutions of these models concerning regional price differentials, the locational advantages of various production regions and inland terminals and export grain facilities, and the utilization of various transportation services and modes. Model I incorporates the basic data in its annual form as the model was presented in the Out-of-Kilter description in Chapter IV. This model represents the total cost minimization of an operational transportation network for hard red winter wheat. Model II maximizes the flow of grain from harvest to export terminal using the export grain network as depicted in Model I. Model III incorporates the element of time, but not time-staged, to reflect the total time minimization for exporting grain when speed is of the essence as in a PERT-type analysis. The remaining models are time-staged so as to be multi-period, as discussed in Chapter IV. Model IV evaluates the temporal impact on distribution patterns of an alteration to the export grain transportation rates, specifically a five percent hike in the wheat export railroad rates. Such an impact is considered plausible with the elimination of the transit privileges for certain producing regions. A similar change in the competitive rate structure by barges increasing their waterway rates occurs during the peak barge demand periods in the fall corresponding to the sorghum and corn harvest in the Upper Mississippi River Valley. Model V examines the export modal distribution patterns to the Gulf of Mexico export facilities under an hypothesized barge rate on a theoretically completed Trinity River Waterway to Fort Worth, Texas, and an extension of the Arkansas River Waterway to Wichita, Kansas, evaluated during two time periods. Model VI indicates the relative impact on export distribution flows if the export grain handling facilities in the New Orleans-Baton Rouge area were no longer serviceable to hard winter wheat. A limited example of this effect occurred with the closing of Continental Grain in New Orleans due to a grain dust explosion.

## Model I: Total Cost Minimization

Model I was based on the regional demarcation in Figure 14 and the data on supplies, demands, storage and transportation service capacities, and marketing costs presented in Chapter IV. The least-cost distribution patterns were determined using the Out-of-Kilter network algorithm. The annual model largely ignores the requirements for commercial and on-farm storage since only the ending inventory requires storage. The time-staged model (Model IV) brings storage requirements and limited storage capacities into proper persepctive for the harvest and non-harvest periods.

The optimum spatial flow patterns and modal utilization subject to the cost minimization criteria for hard red winter wheat were derived. The export flow patterns should be interpreted as how the grain marketing system should function given the production levels and competitive transportation service conditions of 1977-78 in order to minimize the cost of supplying the estimated export requirements for hard red winter wheat from the available grain supplies. Given the basic data in Chapter IV, and assuming that input data are correct, no other flow patterns exist which will result in a lower total cost for the study area.

Reiterating the data development of Model I, export wheat flow for each county in the study area was determined by subtracting the domestic disappearance and ending inventory from the carryover plus production. Point-to-point export transportation rates were obtained for the various modes possible for the county and, in particular, its county seat to the export terminal facilities selected as viable destinations. If modal transshipment was considered, i.e., truck-barge or truck-rail, the variable costs of receiving and loadout for the appropriate intermediate facility and transportation modes involved were added onto the straight line transfer rates in determining the total transportation charge.

Neither the variable costs attributed to receiving by farm truck at the country elevator nor the variable receiving costs incurred by the export terminal are included in the transportation charge, so the total charge is underestimated by a few cents per bushel. The former costs vary divergently depending on the individual country elevator's truck unloading equipment, the nature of the grain delivery vehicle (producer owned grain truck, pickup truck, grain wagon, etc.), and the labor force's knowledge of and expertise with the equipment (untrained summer labor is frequently used during peak harvest periods). The variable receiving costs by node at the port terminals were also exlcuded. They could have been incorporated into the model had simplifying assumptions been made pertaining to the type of grain haulage instrument (covered hopper versus box car, five-axle semi-trailer versus pup trailer) used. By excluding both these costs throughout the model, the effect was to underestimate the total charge and cost by 3.303 cents per bushel for truck receiving at both the country elevator and at the port terminal or 3.311 cents per bushel for truck receiving at the country elevator and rail receiving at the port terminal.[1]

No constraints as to the availability of appropriate rail cars, trucks, or barges were imposed. Licensed storage capacity was used as a proxy variable for transportation service limitations. Therefore, the constraining bounds on the arcs for the implementation of the algorithm were the grain flows. The harvested production was forced into the model at the recorded volumes from the dummy origin, but the transfer flows were either constrained at the upper bound by the grain handling capacity or by infinity; zero flow was the lower bound. The branch flow costs were the transportation and handling charges on a cents per bushel basis attributed to that arc. The circulation principle of the algorithm requires that what enters a node must also exit that node; the use of a dummy sink facilitates the circulation and the success of the algorithm.

The solution by mode of transportation is shown in Figure 24 and the percentages of hard red winter wheat shipped by each are indicated in Table XII. All of the truck-barge shipments were destined for the Louisiana Gulf ports whereas the long-haul truck and the rail shipments were exported throuth the Texas port facilities of Port Arthur, Beaumont, Galveston, Houston, and Corpus Christi. Had domestic rates been included and had a national model been developed, a portion of the hard red winter wheat from the northern part of the study area would probably have been

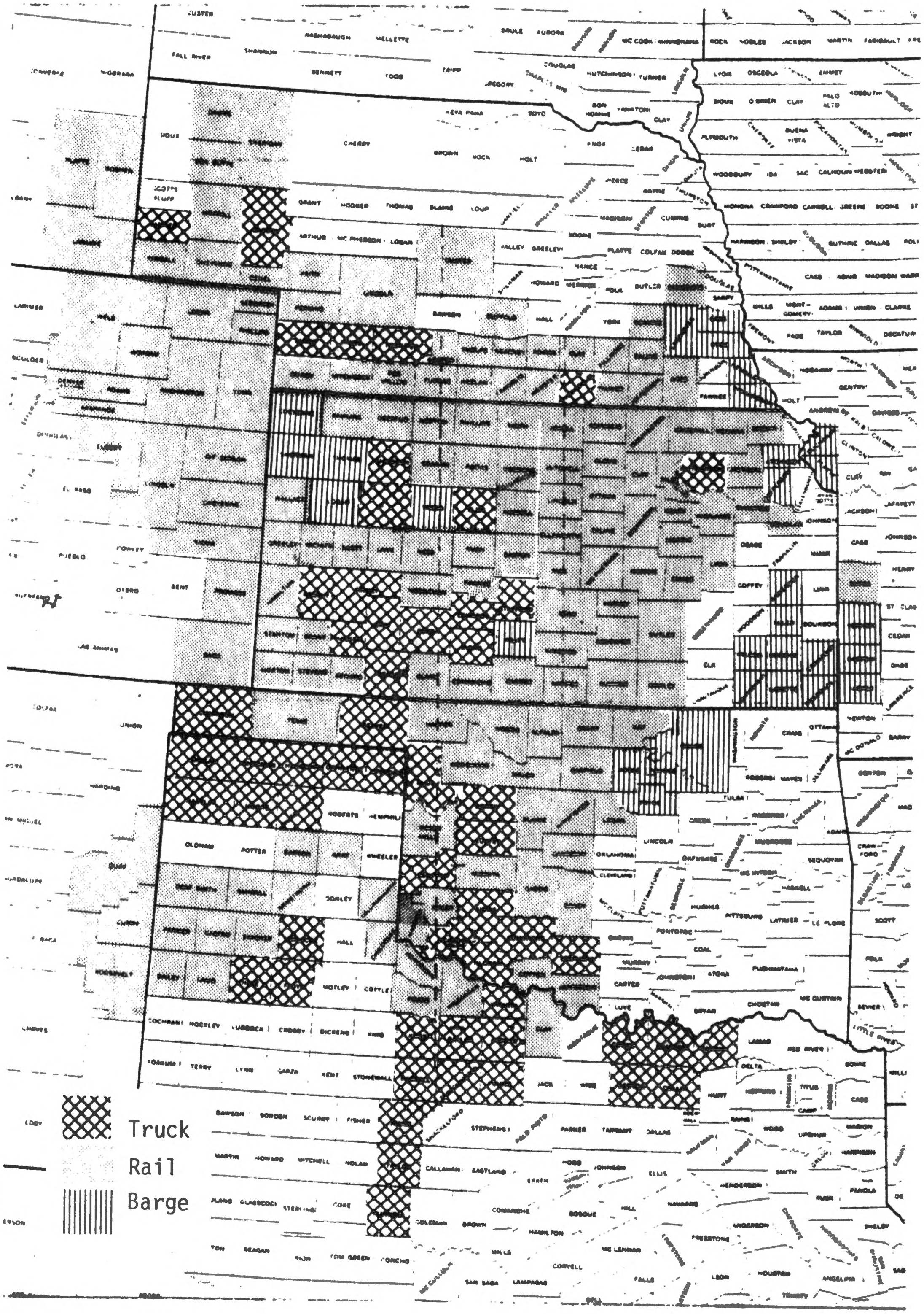


Figure 24. Modal Selection in Model I

## TABLE XII

## SOLUTION TO MODEL I: TOTAL COST MINIMIZATION

| Mode/Bushel | | Bushels Shipped (1000 bu.) | Percent of Total Exported |
|---|---|---|---|
| Truck/Direct to Texas Gulf | | 99,620 | 20.28 |
| Rail/Direct to Texas Gulf | | 348,179 | 70.90 |
| Barge to New Orleans | | | |
| Nebraska | 4,665 | | |
| Kansas, Missouri | 2,893 | | |
| Oklahoma | 35,758 | | |
| TOTAL | | 43,316 | 8.82 |
| Total Export Shipments | | 491,115 | 100.00 |
| Total Cost (Optimal Solution): | | $312,715,438 | |

transshipped to east coast and southeastern flour mills;[2] however, these possibilities were not addressed in this study. Seasonal shipments, rather than an annual model, might also reveal increased shipments to the Great Lakes ports.

The minimum dollar cost associated with Model I, given the input data, is $312,715,438 for 491,115,000 bushels of hard red winter wheat exported and/or transshipped from the study region.

The methodology of the Out-of-Kilter Algorithm and its implementation were instrumental in determining the solutions used in the study. The computer efficiency was alluded to in an article reviewed in Chapter II.[3] Granted more efficient versions of the Out-of-Kilter Algorithm may be operational elsewhere; however, less than 40 seconds of computer processing time on an IBM 370 was needed to solve Model I having 270 participating nodes and 1200 active arcs.

## Model II: Grain Flow Maximization

Model II maximized the flow of grain from harvest to export terminal using the same transportation network referenced in Model I. Unlike Model I, this model does not derive the cost associated with the solution. The algorithm maximizes the physical flow through the system by setting all branch flow costs (the $c_{ij}$'s) to zero rather than to an actual transportation rate, except for the cost or charge associated with the flow from the sink to the source which was assigned an arbitrary unit shipment cost of $c_{ij} = -1$. In reality, the algorithm maximizes the flow in reverse from the dummy sink to the dummy origin.

The lower bounds for the arcs are of no concern; the upper bounds are the critical issue. The upper bounds used were the normal operating commercial storage capacities of the elevators and terminals (1.35 storage turns and six rotational turns). As in Model I, no limitations on the availability of transportation services were imposed since Model II is an aggregate or annual depiction of the hard red winter wheat export market. Infinity was not a feasible upper bound constraint on any arc; only finite numbers were evaluated.

Subject to the restraints imposed, Model II indicates that 2,754,623,000 bushels of wheat could be exported from the study area in one marketing year without exceeding "normal" operating conditions. The breakdown of this total by state in the study is shown in Table XIII. This result indicates excess commercial and on-farm storage capacity exists in the study area for hard red winter wheat, given the historical harvest levels for the grain. Some counties or areas within a county may experience storage capacity constraints below the quantity of wheat harvested, but due to the aggregation of the data, such implications are not presented. Nor does the analysis allude to any transportation incumberances as a result of physical, mechanical, or institutional restraints in transporting such a volume of hard red winter wheat.

In order to obtain the total cost of this maximum flow, the individual volumes for each arc can be forced (lower bound equals upper bound) into the cost minimization format as described in Model I. The answer would then indicate which modes to use for the least-cost solution to Model II, given the maximum flows attained in Model II.

## Model III: Minimum Time Requirement

In the situation where minimum time for transporting wheat to the port terminals is the objective, the Out-of-Kilter Algorithm combines

## TABLE XIII

## SOLUTION TO MODEL II: GRAIN FLOW MAXIMIZATION

| State | Off-Farm Commercial Storage |  | Production |  |
|---|---|---|---|---|
|  | Total | Study Area* | Total | Study Area |
|  | -Thousand Bushels- |  |  |  |
| Colorado | 93,158 | 46,195 | 49,767 | 44,299 |
| Kansas | 830,602 | 364,719 | 344,917 | 338,708 |
| Missouri | 210,375 | 11,157 | 7,275 | 6,958 |
| Nebraska | 487,926 | 104,623 | 98,630 | 98,349 |
| New Mexico | 17,662 | 7,760 | 9,134 | 6,961 |
| Oklahoma | 205,009 | 112,656 | 162,500 | 155,651 |
| Texas | 837,775 | 195,040 | 117,333 | 88,941 |
| Wyoming | 6,331 | 5,972 | 6,668 | 4,293 |
| Total Comm. Stor. and Prod. | 2,688,838 | 848,022 | 796,224 | 735,160 |
| On-Farm Storage |  | 1,906,601 |  |  |
| Maximum Flow Subject to Storage Constraints |  | 2,754,623 |  |  |

*Excludes storage capacity of the inland terminals.

the PERT-CPM network analysis with the shortest-path formulation in arriving at a solution. Rather than using a monetary charge for the arc flow cost, "time" is set as the $c_{ij}$ value. The times associated with each branch or arc are given negative signs and are then considered to be the costs. The algorithm is then employed as in the minimum cost model. One additional modification needed is that of imposing a constraint on the arc between the dummy sink and the dummy origin such that the lower bound and the upper bound equal one ($l_{ij} = u_{ij} = 1$).

The minimum "time" derived by the algorithm is the same result as in the CPM or Critical Path Method. The path or arc requiring the longest duration is the constraining path, activity, or flow among all minimum transportation network paths to be included. The minimum time for the activity is then the maximum time among all the minimum transshipment times for transporting grain from county seats to the port terminals over the appropriate network arcs.

Due to the spatial diversity of the counties in the study area and varying distances of the counties from each of the three port regions in the model, simplifying assumptions were imposed for the methodology evaluation. Only the Gulf of Mexico port facilities (Louisiana and Texas port terminals) were included; the Great Lakes area of Duluth and Superior were omitted. This was done so as to permit three viable modal considerations--truck, rail, and barge--simultaneously for the harvested hard red winter wheat. Rather than determine individual times attributable to specific county seats, times for each mode were incremented according to distance zones from a centrally located point on the Gulf shore, as shown in Figure 25. County seats that were located in the same distance zone were assumed to have the same modal minimum time to the port terminal.

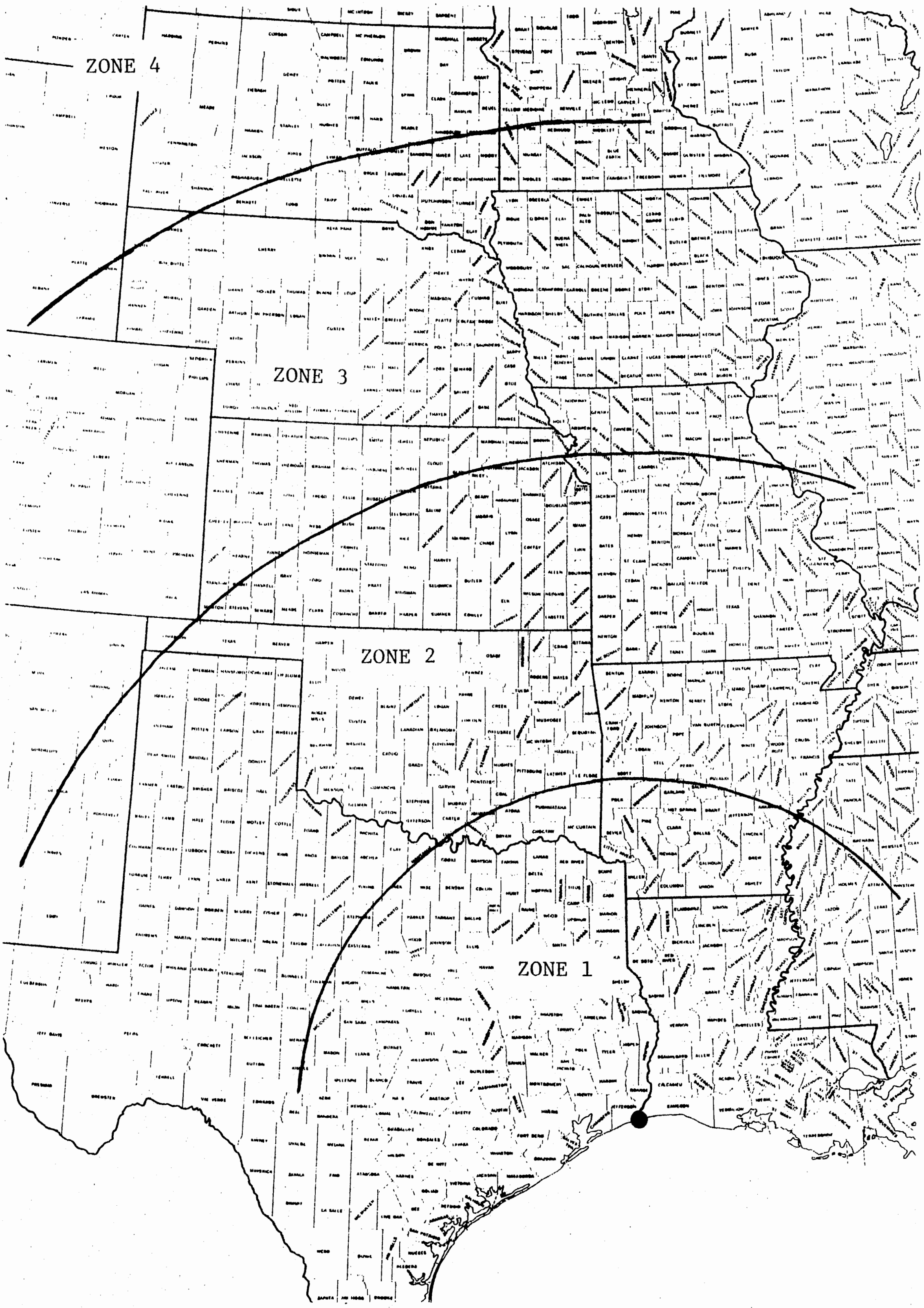


Figure 25. Distance Zones for Model III

The "times" developed for the grain trucks were based on single-driver, 5-axle rig, hopper or flat bottom trailer hauling an average of 1100 bushels of wheat, driving an average 400 miles per normal legal operating day. Increasing the over-the-road speeds on long hauls with the aid of radar detectors, citizen-band radios, and frequency scanners (all fairly common-place equipment on grain hauling trucks) and by driving extended hours, the total time can, of course, be eclipsed.

Railway "times" were more reliant on secondary data sources with cited past experience as the norm for time requirements; speed has never been the issue with the railroads. Transit privileges, rail siding grain inspections, and main-line switches, hub congestion, or rerouting delays for train make-up, all complicate the determination of time requirements for various distance zones on a single car basis. Each rail car was assumed to carry an average 3200 bushels of wheat.

The barge "times" were those used by Fedeler, Heady, and Koo in their national grain transportation model for days lost in barging on the Missouri, Askansas, and Mississippi River waterways.[4]

Representative times, by mode, for the distance zones are shown in Table XIV.

TABLE XIV

REPRESENTATIVE TIMES FOR DISTANCE ZONES, BY MODE

| | Production (1,000 bu.) | Days Lost, by Mode, at Zonal Boundary | | |
|---|---|---|---|---|
| | | Truck | Rail | Barge |
| Zone 1 | 6,770 | 1 | 2 | not applicable |
| Zone 2 | 423,070 | 2 | 5 | 12 |
| Zone 3 | 303,231 | 3 | 9 | 12 |
| Zone 4 | 2,089 | $\geq$ 4 | $\geq$ 10 | not applicable |

The results of Model III reveal, by coincidence, the opposite of typical cost-distance relationships in which trucks are primarily short distance haulers. No costs or charges were determined in this model; however, due to the decreased time requirements for trucks given no limitations on truck avilability, the trucking industry was the prominent haulage medium, regardless of distance. By constraining the number of available trucks, the modal distribution pattern showed trucks hauling from the distant sites whereas railroads acquired those counties nearest the port terminals. Barge traffic never entered the solution. Time, not economics in the monetary sense, was the issue of this model and the results should be interpreted as answering what if minimum transfer time to the ports is a critical objective, without consideration for minimum transportation costs nor transportation availability and queueing.

The implicit times and results to Model III are highlighted in Table XV.

TABLE XV

SOLUTION TO MODEL III: MINIMUM TIME REQUIREMENT

| | Solution | | |
|---|---|---|---|
| Constraints Available on Transportation* | Mode Selected (Number) | Volume Transported (1,000 bu.) | Minimum Time (days) |
| None | Trucks (668,327) | 735,160 | 4 |
| 40% Truck | Trucks (267,331) | 294,064 | 4 |
| | Rail Cars (137,843) | 441,096 | 5 |

[*] Assumes a one-way, one-time only shipment.

Models I, II, and III were aggregate depictions for the grain marketing year. Wheat harvest is a seasonal activity, occurring primarily in June, which stresses the grain handling facilities due to the tremendous production influx on the system during the summer months. Not only must the harvested wheat be stored but shipments from up country elevators must occur in order to create available storage for the fall crops, such as corn, milo, and soybeans. With competition for limited commercial storage, the temporal receipt and shipment patterns for hard winter wheat permit closer scrutiny of the grain marketing and transportation system and the observation of some of the historical wheat marketing issues. Models IV, V, and VI were time-staged models that addressed some of these problems and examined the methods in solving the issues.

## Model IV: Alteration of Transportation Rates

The existing transportation rate structure is very competitive as a few cents change in the per bushel rates charged by one mode can alter not only the choice of mode for transport but also the direction and composition of traffic. Model IV evaluated the changes in the export distribution patterns resulting from a five-percent increase in rail rates, compared with those patterns cited in Model I. With the termination of transit privileges, a grain marketing industry estimate was that the rail rates for export grain would increase about five percent as any intermediate off-loading or rerouting would be dutifully added to the freight bill instead of the weigh-bill being charged on a straight through basis, as is the case with transit privilege.

The distribution flows for Model IV are shown in Figure 26 and the net changes in modal flows are indicated in Table XVI.

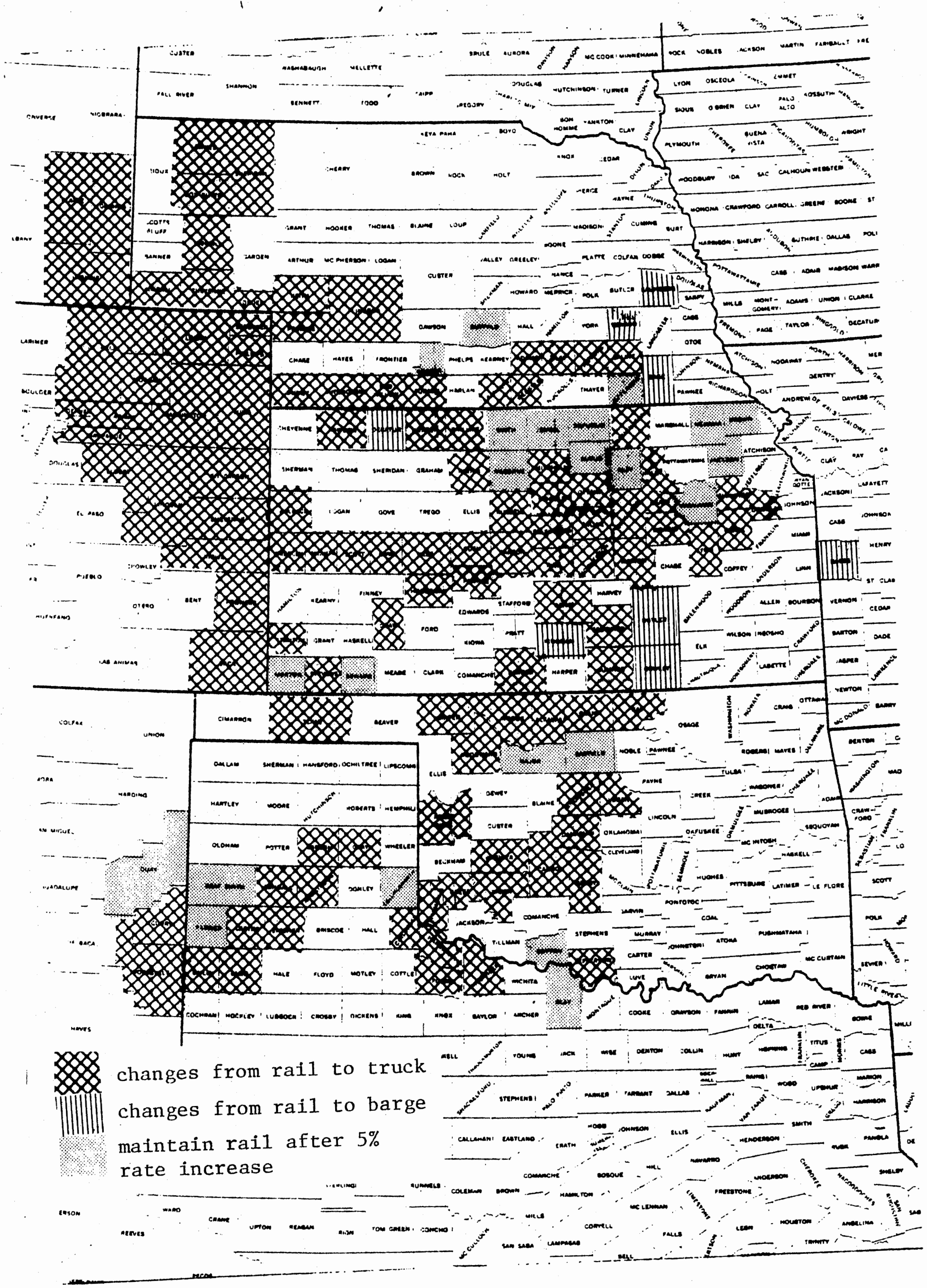


Figure 26. Modal Selection by Model IV

TABLE XVI

CHANGES IN MODAL FLOWS: MODEL IV

| Mode of Transport | Bushels Shipped: Before Increase In Rail Rate | Bushels Shipped: After Increase In Rail Rate | Percent Change and Direction | 30.5% of Shipments June - August Costs at 5% Rail Increase | 69.5% of Shipments September - May Costs at Standard Rates |
|---|---|---|---|---|---|
| | (1000 bu.) | | | (1000 bu.) | (1000 bu.) |
| Truck | 99620 | 382038 | Increase<br>283.50% | | |
| Rail | 348189 | 50474 | Decrease<br>85.50% | | |
| Barge | 43316 | 58579 | Increase<br>35.24% | | |
| Total | | | | 149,790.075<br>($96,765,658) | 34,135.925<br>($217,337,229 |

The marketing year (June 1-May 31) was divided into two time periods so as to evaluate the temporal flows and the impact of storage constraints. The two periods coincided with the wheat harvest and immediate post-harvest (June 1-August 1) and the non-harvest months of September through May. More time periods, which if discreetly determined, would have permitted seasonal transportation rate evaluations. The time frames selected lended themselves to analyzing peak-load pricing of transportation services in which rail or truck charges are increased during the high demand period of harvest. Furthermore, due to the limited commercial storage capacities, a disproportionate volume of wheat must be shipped early in the marketing year to make space available for the entire wheat harvest production and the late summer-early fall crops of milo, corn, and soybeans. The results of the temporal versions of Model IV are also reviewed in Table XVI.

### Model V: Expansion of Transportation Services

The United States Corps of Engineers, along with various Land Grant Universities, have performed feasibility studies on authorized inland waterway extensions in the study area. Specifically, the projects under consideration are the Arkansas River Waterway and the Trinity River Waterway. The Arkansas River extension above Muskogee and Catoosa, Oklahoma, would access the Wichita, Kansas, vicinity by way of either the Arkansas River or the Verdigris River.[5] The terminus would either be Derby, Kansas, or Augusta, Kansas--the latter would not only access the Wichita industrial and grain trade but also the El Dorado oil fields. Approximately 20 locks and a nine-foot minimum dredged depth would be needed for the authorized extension. The Trinity River Waterway would make the Fort Worth-Dallas, Texas, agricultural and industrial trade centers an inland river port with direct access to Houston on the Trinity River.

Model V was not meant to determine the feasibility of these projects nor evaluate their benefit-cost effectiveness. Instead, these waterway extensions were assumed complete and operable with bulk grain barge rates. These rates would rely heavily upon the number of locks along the channel, the volume of potential traffic, and the competition among products for the tugs and barges.

For the purposes of Model V, a bulk grain rate of 20 cents per bushel for wheat haulage on the Trinity River from the Fort Worth terminal complex to the Port of Houston, excluding handling charges, was used. With the addition of receiving and loadout charges attributable to the river port facilities, the total per bushel cost became competitive with the rail and truck export grain rates. A ten-cent per bushel addition was made onto the Tulsa to Gulf bulk grain rates for the extension of the Arkansas River into the Wichita, Kansas, metroplex, thereby reflecting approximately a 30-cent per bushel rate for barging hard red winter wheat from Wichita to the Baton Rouge-New Orleans ocean port facilities.

Although the figures used for the waterway extensions were mere approximations and any economic implications as to the actual volume of wheat and/or the optimum least-cost solution were merely speculative, the results relied heavily on the transshipment charges (truck-barge) and on the handling costs associated with receiving and loadout. Furthermore, with flexible rate making above and below the published supplements, seasonal rates alter the competitive structure of grain export transportation rates. The purpose of Model V was to accentuate the competitiveness of the transportation modes and to show how limited the drawing area for grain traffic would be, given the relative published export grain rates as used in Model I. As in Model IV, the two time per periods of June-August and September-May were analyzed under a seasonal pricing scheme. The resulting modal distributions are shown in Figure 27.

## Model VI: Terminal Utilization

Requirements from the Occupational Safety and Hazard Administration and the Environmental Protection Association have altered the historical open-air conveyance of grain at commercial elevators. In doing so, the potential has increased for explosion or fire from the volatile wheat dust or from the creation of gases from humidity-laden grain. Major explosions in the mid-70's occurred at Continental Grain Company, New Orleans, Louisiana, and Goodpasture Elevators, Houston, Texas.[6] When such events occurred, the traditional grain marketing and storage distribution flows were altered. Model VI permitted an evaluation of the reorganization of hard winter wheat flows given certain export facilities were not usable for hard red winter wheat. The cause need not be as destructive as an explostion; bankruptcy, seasonal use only, or best alternative opportunity usage are also examples of why a facility would not be available for wheat storage and transfer.

For ease of model building and analysis of results, all Louisiana Gulf port facilities were assumed eliminated from the normal grain marketing channels. By elimination of all of those storage facilities at Destrehan, Port Charles, New Orleans, and Baton Rouge, Louisiana, the storage and handling capacities at the Texas Gulf and Great Lakes

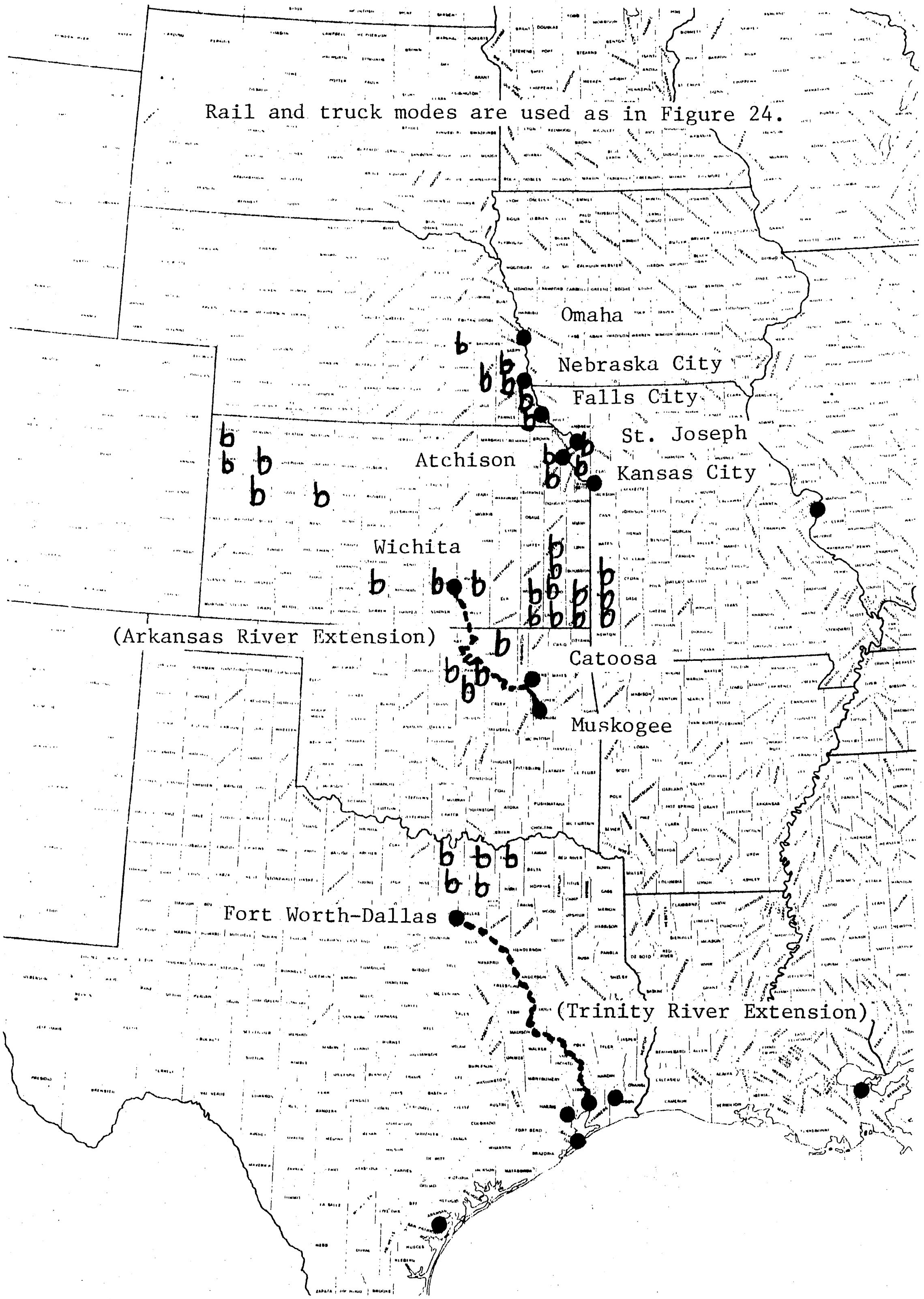


Figure 27. Modal Distribution in Model V

ports were critical to the solution. The resulting temporal shipment patterns for Model VI are shown in Figure 28 and annotated in Table XVII. The arc costs and arc bounds used were consistent with those in Model I. The minimum cost solution indicated an increase in the total transportation cost of $1,002,796 from $312,715,438 in Model I to $313,718,234 in Model VI. The methodology of Model VI lends itself to traffic management decisions seeking out alternative grain distribution flows and modal considerations in response to some intervening activity.

## Utilization of Facilities

Optimum utilization of commercial storage capacity refers to the specification of the volume of grain stored at any point in time, given the existing grain storage capacity. Because only carryover and aggregate ending inventories were introduced into the model, as depicted in Figure 12, optimum inventory positions by county or state were not developed. Furthermore, the ending inventory cited should not be interpreted as implying that this stock carryover should or will actually exist in reality, as one marketing year is not isolated from the prior or following years. In reality, a large proportion of the ending inventory would have moved out to primary markets by the end of the marketing year so that the country elevators could handle the new harvest as it leaves the combine. In addition, grain processors typically maintain a working inventory in excess of immediate needs either to ensure continuous operation or as a hedge against rising raw product prices. Thus, the ending inventory of May 31 may actually be misstated.

The extent to which inland terminal storage capacity for each facility was utilized is presented in Table XVIII. The data reflects

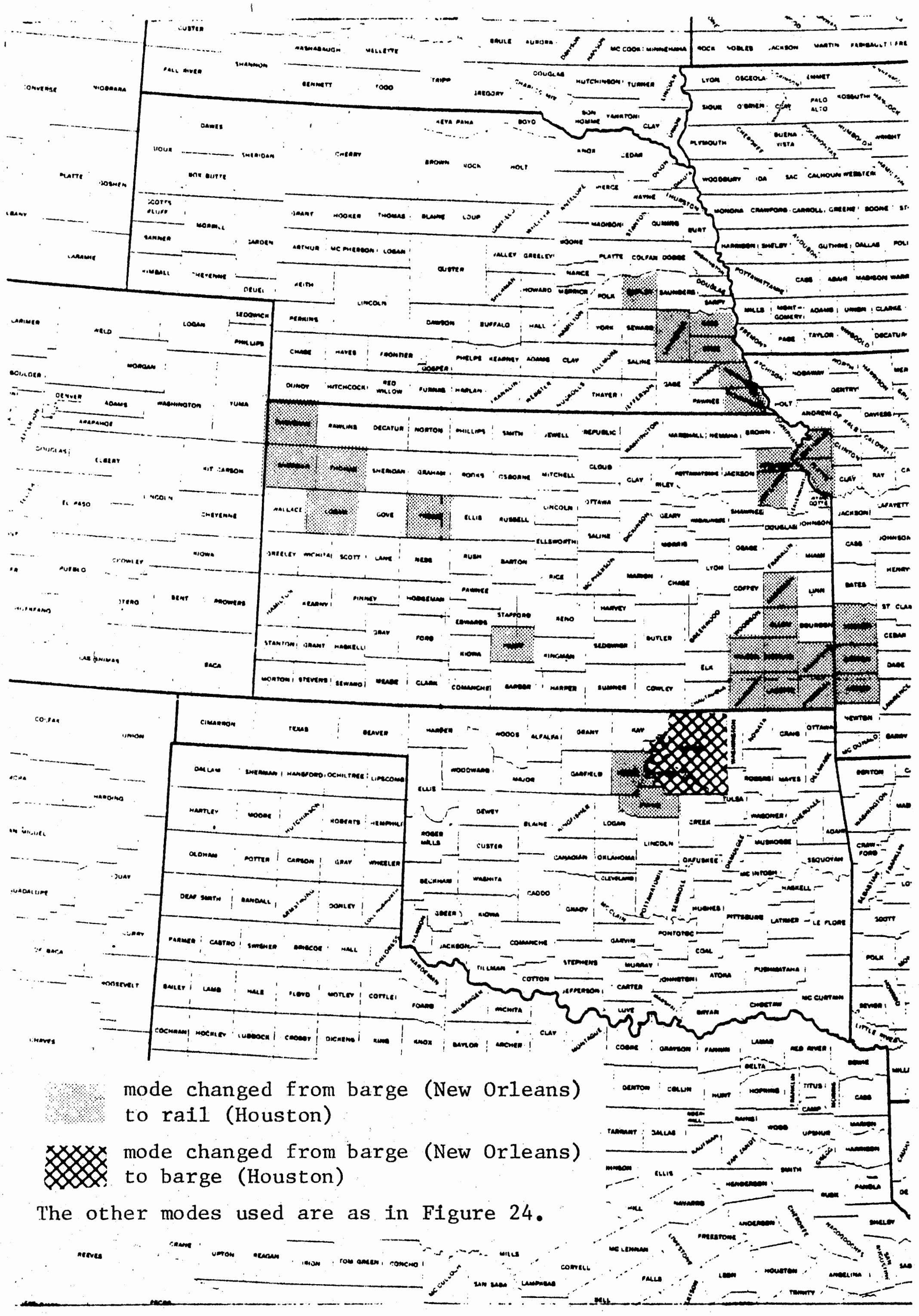


Figure 28. Shipment Pattern by Model VI

## TABLE XVII

## MODEL VI: CHANGES IN MODAL FLOWS

| | With La. Port | | | | Without La. Port | | | |
|---|---|---|---|---|---|---|---|---|
| | June-August | | September-May | | June-August | | September-May | |
| Mode | Volume | Charge | Volume | Charge | Volume | Charge | Volume | Charge |
| | (1000 bu.) | | (1000 bu.) | | (1000 bu.) | | (1000 bu.) | |
| Truck | 30384 | | 69236 | | 30384 | | 69236 | |
| Rail | 106195 | | 241984 | | 118972 | | 271099 | |
| Barge | 13211 | | 30105 | | 434* | | 990* | |
| | | $95378209 | | $217337229 | | $95684061 | | $218034172 |

*Houston area barge delivery along Inter-coastal Waterway.

## TABLE XVIII

## STORAGE FACILITY UTILIZATION

| County Code | 3-Year Production Average | Licensed Storage | Ratio of Production Storage |
|---|---|---|---|
| | | (1000 bushel) | |
| Texas | | | |
| 101 | 1221 | 84 | 14.536 |
| 102 | 1702 | 3634 | .468 |
| 103 | 1469 | 5781 | .254 |
| 104 | 2100 | 582 | 3.608 |
| 105 | 1072 | 1605 | .668 |
| 106 | 3168 | 5460 | .580 |
| 107 | 3584 | 13945 | .257 |
| 108 | 985 | 185 | 5.324 |
| 109 | 1526 | 68 | 22.441 |
| 111 | 1420 | 3890 | .365 |
| 112 | 778 | 825 | .943 |
| 114 | 1123 | 649 | 1.730 |
| 115 | 2727 | 3621 | .753 |
| 116 | 7784 | 14789 | .526 |
| 117 | 1491 | 1281 | 1.164 |
| 118 | 771 | 564 | 1.367 |
| 120 | 2712 | 6610 | .410 |
| 121 | 1729 | 657 | 2.632 |
| 122 | 2126 | 995 | 2.137 |
| 123 | 1251 | 3949 | .317 |
| 124 | 2037 | 52179 | .081 |
| 125 | 5403 | 6370 | .848 |
| 126 | 2825 | 2993 | .944 |
| 127 | 2421 | 2444 | .991 |
| 128 | 1770 | 532 | 3.327 |
| 230 | 1640 | 0 | N.A. |
| 131 | 2224 | 1042 | 2.134 |
| 132 | 2918 | 1873 | 1.558 |
| 133 | 1140 | 9691 | .118 |
| 134 | 1630 | 0 | N.A. |
| 136 | 2432 | 1885 | 1.290 |
| 137 | 4010 | 1857 | 2.159 |
| 139 | 3331 | 4720 | .706 |
| 140 | 3639 | 9182 | .396 |
| 141 | 1091 | 1372 | .796 |
| 142 | 3908 | 6010 | .650 |
| 143 | 3501 | 12694 | .276 |
| 144 | 1325 | 568 | 2.333 |
| 145 | 917 | 362 | 2.533 |
| 146 | 2257 | 3054 | .739 |
| 147 | 2886 | 5887 | .490 |
| 148 | 1137 | 1149 | .990 |

TABLE XVIII (Continued)

| County Code | 3-Year Production Average | Licensed Storage | Ratio of Production Storage |
|---|---|---|---|
| | | (1000 bushel) | |
| Oklahoma | | | |
| 201 | 7786 | 5347 | 1.456 |
| 202 | 3740 | 2060 | 1.816 |
| 203 | 2058 | 1309 | 1.572 |
| 204 | 5314 | 5615 | .946 |
| 205 | 6059 | 3409 | 1.777 |
| 206 | 6203 | 8499 | .730 |
| 207 | 3088 | 3308 | .933 |
| 208 | 5971 | 2118 | 2.819 |
| 209 | 4476 | 1582 | 2.829 |
| 210 | 6632 | 5726 | 1.158 |
| 211 | 3105 | 1836 | 1.691 |
| 212 | 1909 | 1310 | 1.457 |
| 213 | 10357 | 7001 | 1.479 |
| 214 | 2280 | 1561 | 1.461 |
| 215 | 11433 | 5621 | 2.034 |
| 216 | 2083 | 250 | 8.332 |
| 217 | 1573 | 337 | 4.668 |
| 218 | 2484 | 1005 | 2.472 |
| 219 | 4787 | 4353 | 1.100 |
| 220 | 859 | 316 | 2.718 |
| 221 | 9380 | 6645 | 1.412 |
| 222 | 6870 | 4773 | 1.439 |
| 223 | 5984 | 3015 | 1.985 |
| 224 | 2839 | 1762 | 1.611 |
| 225 | 4046 | 2810 | 1.440 |
| 226 | 4550 | 2937 | 1.549 |
| 227 | 1128 | 45 | 25.067 |
| 228 | 890 | 154 | 5.779 |
| 229 | 1135 | 1398 | .812 |
| 230 | 1579 | 355 | 4.448 |
| 231 | 1171 | 390 | 3.003 |
| 232 | 6713 | 9734 | .690 |
| 233 | 6504 | 4854 | 1.350 |
| 234 | 5647 | 2292 | 2.464 |
| 235 | 6296 | 7002 | .899 |
| 236 | 2698 | 1927 | 1.400 |
| Kansas | | | |
| 301 | 942 | 397 | 2.373 |
| 302 | 949 | 1866 | .509 |
| 303 | 776 | 5027 | .154 |
| 304 | 4365 | 3220 | 1.356 |

TABLE XVIII (Continued)

| County Code | 3-Year Production Average | Licensed Storage | Ratio of Production Storage |
|---|---|---|---|
| | | (1000 bushel) | |
| 305 | 6618 | 7338 | .902 |
| 306 | 1635 | 4921 | .332 |
| 307 | 2474 | 1970 | 1.256 |
| 308 | 1936 | 1378 | 1.405 |
| 309 | 4326 | 2684 | 1.612 |
| 310 | 2119 | 3197 | .663 |
| 311 | 3167 | 3742 | .846 |
| 312 | 4777 | 3411 | 1.400 |
| 313 | 1118 | 854 | 1.309 |
| 314 | 6328 | 2603 | 2.431 |
| 315 | 3478 | 1711 | 2.033 |
| 316 | 886 | 1820 | .487 |
| 317 | 4524 | 1785 | 2.534 |
| 318 | 4856 | 5842 | .831 |
| 319 | 830 | 1690 | .491 |
| 320 | 3567 | 3850 | .926 |
| 321 | 4027 | 2837 | 1.419 |
| 322 | 3888 | 3396 | 1.145 |
| 323 | 6440 | 7744 | .832 |
| 324 | 6308 | 11585 | .544 |
| 325 | 822 | 1226 | .670 |
| 326 | 4813 | 4043 | 1.190 |
| 327 | 3566 | 1980 | 1.801 |
| 328 | 2279 | 7594 | .300 |
| 329 | 4827 | 9681 | .499 |
| 330 | 3921 | 3261 | 1.202 |
| 331 | 2670 | 3435 | .777 |
| 332 | 7851 | 5349 | 1.468 |
| 333 | 3756 | 4269 | .880 |
| 334 | 3533 | 8745 | .404 |
| 335 | 4081 | 2201 | 1.854 |
| 336 | 929 | 995 | .934 |
| 337 | 779 | 954 | .817 |
| 338 | 4062 | 2308 | 1.760 |
| 339 | 3275 | 1374 | 1.729 |
| 340 | 7056 | 3576 | 1.973 |
| 341 | 2607 | 3270 | .797 |
| 342 | 1952 | 1541 | 1.267 |
| 343 | 3958 | 5461 | .725 |
| 344 | 4485 | 2142 | 2.094 |
| 345 | 4874 | 4459 | 1.093 |
| 346 | 1403 | 1515 | .926 |
| 347 | 6796 | 7970 | .853 |
| 348 | 4221 | 4286 | .985 |
| 349 | 3106 | 4860 | .639 |

TABLE XVIII (Continued)

| County Code | 3-Year Production Average | Licensed Storage | Ratio of Production Storage |
|---|---|---|---|
| | | (1000 bushel) | |
| 350 | 3002 | 5934 | .506 |
| 351 | 6065 | 3421 | 1.773 |
| 352 | 1604 | 606 | 2.649 |
| 353 | 1553 | 1070 | 1.451 |
| 354 | 1355 | 4652 | .291 |
| 355 | 1665 | 2581 | .645 |
| 356 | 1054 | 787 | 1.339 |
| 357 | 5841 | 7086 | .824 |
| 358 | 4139 | 2415 | 1.714 |
| 359 | 1161 | 1601 | .725 |
| 360 | 4672 | 2167 | 2.156 |
| 361 | 4735 | 4222 | 1.122 |
| 362 | 5736 | 5025 | 1.141 |
| 363 | 3517 | 3601 | .977 |
| 364 | 1170 | 1319 | .877 |
| 365 | 5364 | 5754 | 1.041 |
| 366 | 5481 | 1619 | 3.385 |
| 367 | 9671 | 8073 | 1.198 |
| 368 | 3617 | 3244 | 1.115 |
| 369 | 5809 | 7474 | .777 |
| 370 | 1150 | 1818 | .633 |
| 371 | 4111 | 3519 | 1.168 |
| 372 | 4652 | 3226 | 1.442 |
| 373 | 4364 | 3085 | 1.415 |
| 374 | 4056 | 4961 | .818 |
| 375 | 4276 | 6014 | .711 |
| 376 | 7241 | 7525 | .962 |
| 377 | 2263 | 2339 | .968 |
| 378 | 929 | 2745 | .338 |
| 379 | 4034 | 2074 | 1.945 |
| 380 | 5694 | 6964 | .818 |
| 381 | 4267 | 3124 | 1.366 |
| 382 | 5559 | 6510 | .854 |
| 383 | 2856 | 5745 | .497 |
| 384 | 2161 | 6368 | .339 |
| 385 | 12694 | 18735 | .678 |
| 386 | 7812 | 9155 | .853 |
| 387 | 3957 | 2369 | 1.677 |
| 388 | 823 | 306 | 2.690 |
| 389 | 2791 | 3208 | .870 |
| 390 | 3606 | 6021 | .718 |
| 391 | 3404 | 5548 | .614 |
| 392 | 1210 | 456 | 2.654 |

TABLE XVIII (Continued)

| County Code | 3-Year Production Average | Licensed Storage | Ratio of Production Storage |
|---|---|---|---|
| | | (1000 bushel) | |
| Nebraska | | | |
| 401 | 1670 | 2099 | .796 |
| 402 | 2587 | 2203 | 1.174 |
| 403 | 3794 | 3566 | 1.064 |
| 404 | 794 | 1564 | .508 |
| 405 | 1085 | 1737 | .625 |
| 406 | 1216 | 1816 | .670 |
| 407 | 1918 | 2258 | .849 |
| 408 | 7666 | 6862 | 1.117 |
| 409 | 1151 | 1777 | .648 |
| 410 | 1251 | 1838 | .681 |
| 411 | 1674 | 2101 | .797 |
| 412 | 3366 | 3251 | 1.035 |
| 413 | 1411 | 1936 | .729 |
| 414 | 2143 | 2405 | .891 |
| 415 | 981 | 1675 | .856 |
| 416 | 2160 | 2409 | .892 |
| 417 | 3001 | 2990 | 1.004 |
| 418 | 2678 | 2765 | .969 |
| 419 | 2355 | 2546 | .925 |
| 420 | 855 | 1618 | .547 |
| 421 | 1630 | 2011 | .761 |
| 422 | 1894 | 2242 | .845 |
| 423 | 3104 | 3063 | 1.013 |
| 424 | 6819 | 5190 | 1.121 |
| 425 | 1179 | 1794 | .657 |
| 426 | 2658 | 2751 | .966 |
| 427 | 4516 | 4167 | 1.084 |
| 428 | 2524 | 2660 | .949 |
| 429 | 1620 | 2067 | .784 |
| 430 | 1117 | 1756 | .636 |
| 431 | 967 | 1666 | .580 |
| 432 | 1437 | 1953 | .736 |
| 433 | 1349 | 1898 | .711 |
| 434 | 5531 | 4946 | 1.118 |
| 435 | 3106 | 3065 | 1.013 |
| 436 | 944 | 1653 | .571 |
| 437 | 2341 | 2536 | .923 |
| 438 | 1074 | 1730 | .621 |
| 439 | 1196 | 1804 | .662 |
| 440 | 1407 | 1934 | .728 |
| 441 | 2293 | 2504 | .916 |
| 442 | 1217 | 1817 | .670 |

TABLE XVIII (Continued)

| County Code | 3-Year Production Average | Licensed Storage | Ratio of Production Storage |
|---|---|---|---|
| | | (1000 bushel) | |
| Wyoming | | | |
| 501 | 1237 | 1829 | .676 |
| 502 | 2204 | 2445 | .901 |
| 503 | 852 | 1598 | .533 |
| Colorado | | | |
| 601 | 4426 | 4049 | 1.093 |
| 602 | 1346 | 1896 | .710 |
| 603 | 2384 | 2565 | .929 |
| 604 | 928 | 1653 | .565 |
| 605 | 809 | 1573 | .514 |
| 606 | 1694 | 2114 | .801 |
| 607 | 3987 | 3712 | 1.074 |
| 608 | 2178 | 2428 | .897 |
| 609 | 3594 | 3418 | 1.051 |
| 610 | 1411 | 1936 | .729 |
| 611 | 3471 | 3328 | 1.043 |
| 612 | 1922 | 2260 | .850 |
| 613 | 2445 | 2606 | .938 |
| 614 | 6668 | 5936 | 1.123 |
| 615 | 3923 | 3663 | 1.071 |
| 616 | 3113 | 3070 | 1.014 |
| New Mexico | | | |
| 701 | 4515 | 4119 | 1.096 |
| 702 | 1232 | 1826 | .675 |
| 703 | 1214 | 1815 | .669 |
| Missouri | | | |
| 801 | 1049 | 1806 | .581 |
| 802 | 1659 | 2239 | .741 |
| 803 | 893 | 1590 | .562 |
| 804 | 1126 | 1818 | .619 |
| 805 | 1035 | 1666 | .621 |
| 806 | 1378 | 2038 | .676 |
| Inland and Port Terminals* | | | *** |
| 10** | | 47890 | 9.353 |
| 15 | | 24450 | 1.738 |
| 19 | | 26780 | .096 |

TABLE XVIII (Continued)

| County Code | 3-Year Production Average | Licensed Storage | Ratio of Production Storage |
|---|---|---|---|
| | | (1000 bushel) | |
| 51 | | 46481 | .562 |
| 52 | | 8900 | .344 |
| 53 | | 65852 | .634 |
| 54 | | 43930 | 1.336 |
| 55 | | 39125 | 1.019 |
| 56 | | 36510 | .333 |
| 57 | | 9032 | .189 |
| 58 | | 42910 | .321 |
| 59 | | 56440 | .018 |
| 60 | | 61371 | 1.007 |
| 61 | | 63460 | .089 |
| 62 | | 25895 | .561 |
| 63 | | 46324 | .367 |

*Excludes Transit Privilege by Railroad.

**Excludes Goodpasture Elevators, Inc.

***Reflects Utilization by Hard Red Winter Wheat Only (Excludes Other Grains).

the proportion of estimated operable capacity used for the transfer of hard red winter wheat. The data does not indicate the presence of competing feed grains or soybeans which would or would not constrain the storage available for hard winter wheat. For the three-month "harvest" period of June 1-August 31, the competition for the limited storage facilities is generally not a factor, but for the other time period, the utilization proportion is misleading without due understanding of the model.

The data indicates several states had excess storage capacity. The level of aggregation involved in the study precludes specifying the storage capacity needs by community since the size and distribution of firms and country elevators making up the total county capacity were not evaluated sequentially. Results may indicate a low utilization in a region when in fact a particular locality may be experiencing a shortage of commercial capacity. Further complicating the results in the availability of on-farm storage, either in commercially available grain bins or in converted farm storage sheds. Wheat producers are price-takers and, when possible, hold their harvest off the market until the price is auitable to them. On-farm storage permits them to do so without incurring daily storage charges at the grain elevators. In areas where on-farm storage capacities are extensive, the rates of commercial storage utilization may be low.

Utilization of port elevators is in some respects quite unlike country elevators. Whereas most of the grain stored in interior elevators is for the account of the owner, the grain at the port terminal is mainly for the account of the grain exporting firms. The main function of a port facility is to elevate grain from receiving vehicles into the elevator for storage only until ready to be loaded into ocean-going vessels. Utilization therefore reflects a turnover rate in inventories. A low ratio suggests a slow turnover and the potential for excess capacity. The rates are also cited in Table XVIII.

# FOOTNOTES

[1] Robert L. Oehrtman, *Costs of Receiving and Loading Grain by Truck, Rail, and Water, and the Costs of Storing Grain at All Commercial Facilities for the Fiscal Years 1964-65 to 1977-78*, Oklahoma State University, Department of Agricultural Economics Report No. 7718 (Stillwater, 1977), pp. 3-4.

[2] Mark N. Leath and Leo V. Blakley, *An Interregional Analysis of the U. S. Grain-Marketing Industry, 1966-67*, U. S. Department of Agricultural Economics Research Service ERS Technical Bulletin No. 1444 (Washington, 1971), pp. 29-30.

[3] Stephen Fuller and Chiyyarath Shammugham, "Network Flow Models: Use in Rural Freight Transportation Analysis and a Comparison with Linear Programmins," *Southern Journal of Agricultural Economics*, X (1978), pp. 186-7.

[4] Jerry A. Fedeler, Earl O. Heady, and Won W. Koo, "A National Grain Transportation Mode," *Spatial Sector Programming Models in Agriculture* (Ames, 1975), pp. 463-8.

[5] L. W. Schruber, L. O. Sorenson, and R. Phillips, *How Extending River Navigation into Kansas, the Mid-Arkansas River Basin, and Central Oklahoma Would Affect Transportation Costs of Wheat*, Kansas State University AES Publication No. 542 (Manhattan, 1974).

[6] "Grain Elevator Explosion in New Orleans," *Oklahoma City Times*, Oklahoma Publishing Company (Oklahoma City, June 3, 1977), p. 1.

# CHAPTER VI

# SUMMARY AND CONCLUSIONS

## Summary

The heart of the interregional movement of hard red winter wheat from the harvest to the consumer, especially in the export marketing sector of the industry, is an intricate and complex transportation and distribution system whose cost of transport accounts for more than seven percent of the cost of marketing agricultural products. A number of "shocks" to the historical transportation network for hard red winter wheat, and the other grains, became severe in the 1970's in the Plains States. These problems include shortages of transportation equipment, energy shortages and increased transport costs, rail-line abandonment, curtailment of storage services at grain terminals due to grain dust explosions, increased demand for transportation services, and the uncertainty of future rail service through rail reorganization. Some of these shocks are difficult to quantify when building a grain transportation and distribution model while the impacts of others can be evaluated in analyzing alternative routes and modes so as to maintain normal wheat marketing operations.

Interruption of the transportation services by way of these shocks may seriously disrupt the normal operations of grain producers, country elevators, grain processors, terminal elevators, and export facilities.

Inefficiencies and higher costs for transportation services may result from the disruptions mentioned earlier.

Relative to the sensitivity of commodity flow, wheat is the most fluid agricultural commodity known in transportation as the grades of wheat have long been standardized commercially and the transportation rate structure for bulk grains permits movement freely in all directions. The stages of an agricultural commodity's production, handling, processing, storage, and transportation system are generally interdependent. Consequently, an efficiency-related modification at one stage often influences the overall cost-performance of the activity of which it is a part. Therefore, only in a systems context can many marketing-transportation efficiency questions be accurately resolved. Systems models are especially useful to 1) anticipate the results of alternative courses of action, 2) assist in the discovery of normative solutions which can be contrasted with real-world conditions, and 3) carry out ex-post analyses of actual situations to learn where improved efficiency might be realized.

The objectives of this study were to: 1) develop a transportation network capable of analyzing a multi-mode, multi-region, multi-stage transportation problem of the hard red winter wheat marketing system; 2) determine interregional flows consistent with the available regional transportation and storage capacities; 3) determine an efficient distribution pattern which minimizes the total cost of receiving, loadout, and transport for the hard red winter wheat marketing system; 4) determine an efficient distribution pattern which maximizes the flow of grain from harvest to export terminals; 5) determine an efficient distribution pattern which will minimize the total time required for transshipment of hard winter wheat; 6) analyze the effects of modal transportation rate changes on the distribution pattern; 7) analyze the effects of altering the availability of transportation or distribution services on the distribution flow; and 8) analyze the effects of a grain handling facility's termination upon the grain marketing system.

Objective (1) was accomplished by combining the highway system, the railroad network, and the inland waterways into one transportation network serving the study area and the export of hard red winter wheat.

The costs of transporting hard red winter wheat by the three modes of transportation considered (truck, rail, and barge) were synthesized from various data sources. The method used to accomplish objectives (2) through (8) was a constrained network flow consisting of nodes and arcs characterized by finite lower and upper bounds. The Out-of-Kilter Algorithm was the specific analytical vehicle used. The objective was to estimate a set of flows through the arcs which satisfies all demands without violating the capacity limitations of the network. The solution yields the flow that optimizes either total cost, time, or physical flow subject to a circulation principle that what flows into a node must flow out and subject to the lower and upper capacities on the arcs.

Two hundred forty hard red winter wheat producing counties and three port facility complexes were specified to represent the hard red winter wheat export marketing system for the methodological analysis of the study. Corresponding data on supplies, demands, storage capacity, and associated costs of handling were incorporated into the models. Six analyses were made and presented as Models I through VI; the first three were aggregate models based on annual data, whereas the last three were time-staged so as to be multi-period.

Model I represented the total cost minimization of the transportation network depiction for hard red winter wheat based on the transportation rates, and the location and capacity of facilities which existed in the 1977 grain marketing year (June 1, 1977-May 31, 1978). Optimum least-cost export flows for hard winter wheat were determined for the eight-state study area of Texas, Oklahoma, Kansas, Nebraska, Missouri, Wyoming, Colorado, and New Mexico. The commodity flow possibilities included direct shipments from harvest to export terminal and transshipments through intermediate sites by way of truck and/or rail and/or barge, without constraining the availability of transportation services. The algorithm arrived at an optimal solution cost minimization of $312,715,438 for the export shipments of 491,115,000 bushels.

Model II maximized the physical flow of grain from harvest to port terminals using the same transportation network assumed in Model I. Rather than assimilating costs associated with transportation rates, all arc flow costs were set to zero, and the upper bound constraints were set to annual operational storage capacity. The results indicated that on a county by county basis, typically more storage is incurred than is the licensed capacity. However, in light of country elevators anticipating rotational storage turns of approximately 1.35 (on the average), where a turn is the ratio of bushels stored and transshipped by a facility to the bushels of licensed capacity, no shortage of commercial storage appears to exist. There may be specific locations within a county which are experiencing storage shortages, but the county shows a surplus of storage. With the inclusion of estimated on-farm storage capacity, the surplus of available hard red winter wheat storage is further exemplified. Subject to the restraints imposed, 2,754,623,000 bushels of wheat could be exported from the study area without exceeding anticipated "normal" operating conditions, given an unlimited availability of transportation medium.

A simplistic export transportation model was assumed in Model III for the determination of the minimum time required for transfer of hard red winter wheat to the ports, without consideration for minimum transportation cost. No limitations on transportation availability were included. The potential for Great Lakes traffic was ignored, focusing on the Gulf of Mexico port facilities.

Due to the fewer days lost in transporting grain by truck, the reverse of the typical cost-distance relationships resulted. The trucking industry was the prominent grain hauler, especially for those counties over 500 miles from the ports. Railroads serviced those counties nearest the port terminals and barges never entered the solution as their days lost exceeded the truck and railroad days lost in all distance zones.

Models IV, V, and VI were time-staged models that scrutinized the temporal receipt and shipment patterns for hard red winter wheat and the effects of changes in the grain marketing and transportation system upon distribution flows.

Model IV evaluated the changes in the export distribution patterns cited in Model I when the railway freight rates for bulk grain are increased five percent. The concept of peak load pricing (charging higher transportation rates during periods of increased transportation service demand) has been investigated by several research economists. Recent developments in the rail transportation scheme have been the talk of eliminating the transit privilege for certain up-country elevators.

Such a change would also increase the rail transportation rates of moving wheat from harvest to port terminals.

The net changes in modal flows highlight the fluidity of grain in transportation flows and the compeititiveness of the modes in their rate structures. The few cents change in the per bushel rates charged by one mode altered not only the choice of mode for transport but also the direction and composition of traffic from direct rail shipments to truck and truck-barge shipments to the Texas and Louisiana port terminals.

Model V was primarily an elaboration of the methodology and versatility of the Out-of-Kilter Algorithm. Bulk grain rates were hypothesized for assumed river ports on authorized waterway extensions in Texas and Kansas. The purpose of the model was to accentuate the competitiveness of the transportation rates. Although the figures used for the waterway extensions were merely approximations and the results of the model were purely speculative, the solution relied heavily on the transshipment and handling charges in indicating the limited drawing area of these new river ports for grain traffic.

Model VI exemplified the relative impact on export distribution flows with the termination of export grain handling facilities in the Louisiana Gulf port terminal complex. The grain handling capacity constraints at the Texas facilities made the Great Lakes ports viable grain export destinations for the hard red winter wheat produced in the northernmost counties in Nebraska.

Grain dust explosions at inalnd and port terminals in the 1970's have made this type of analytical analysis appropriate for traffic managers seeking alternative routes and modes in response to just such occurrences.

In evaluating the utilization of storage capacity, the Out-of-Kilter algorithm's solutions indicate several states had excess storage capacity although certain communities in specific counties may actually have encountered a storage shortage. With the inclusion of on-farm storage estimates, the rates of commercial stroage utilization were depressed proportionately more.

## Conclusions

### The Out-of-Kilter Network Algorithm

While networks can be used to model a variety of actual problems, ingenuity is often called for in formulating the network to describe the problem. If the network can be properly formulated, however, it is far more efficient to solve a minimal cost circulation problem than the equivalent linear programming problem. Furthermore, the behavior of a solution is frequently examined as the parameters vary. Subsequently, if a process can be modeled as a network, and the criterion for evaluating performance of the process can be related to the variables corresponding to flows in the network, then determining a minimum cost flow is equivalent to determining an optimal set of variables for the process.

Fulkerson's Out-of-Kilter Algorithm is an extremely efficient and general method for solving minimum cost flow problems, such as transportation systems and personnel assignment actions. The algorithm operates by defining conditions which must be satisfied by an optimal "circulation" in a capacitated network--roughly, a flow which satisfies capacity restrictions on all arcs and also satisfies stated conservation of flow conditions at all nodes. When such an optimal circulation is determined, all arcs are "in-kilter". At some point in the operation of the algorithm, if such a circulation does not exist, some arcs are "out-of-kilter"--hence, the name of the algorithm. The algorithm arbitrarily selects an out-of-kilter arc, and tries to rearrange flows to bring that arc into kilter while not forcing any other arc farther out-of-kilter. If the out-of-kilter arc can be brought into kilter, the algorithm selects another out-of-kilter arc and repeats the process. Since there are only a finite number of arcs, repetition of this procedure eventually results in an optimal solution. If an arc cannot be brought into kilter, the problem cannot be solved.

The Out-of-Kilter Algorithm is designed to start with any circulation and any set of node prices. Therefore, a previously derived solution can be used to begin a new problem with resultant savings in computational time.

A special network flow problem is the capacitated transportation problem, or the shipment of a fixed level of flow through a network from an origin to a destination at minimum cost. Two other important special cases of the general minimal cost circulation problem are 1) determining maximum flow in a capacitated network, and 2) finding the shortest route through a network in which costs on arcs are either times or distances. While there are specialized computer algorithms for each case, the OKA handles each one, and in the process indicates how to construct a more specialized algorithm. Models I through III each exemplify these network flow problems as addressed in the export flows of hard red winter wheat.

## Implications

The results presented in the preceding chapter were obtained by formulating constrained network models of the hard red winter wheat marketing and transportation systems and generating analytical solutions by use of the Out-of-Kilter Algorithm. The analyses were based on data from the 1975 through 1977 marketing years (June 1 through May 31) and were not intended to be predictions of how the grain marketing system will operate in the future. The results were intended, however, to show the versatility of the algorithm and to ascribe to the methodology of systems and network analysis. The analytical tool was an optimization technique which described the flows and activity levels that should have occurred given the supply and demand conditions for hard red winter wheat, the location of the country elevators, inland terminals, and port terminals, and the competitive transportation rate structure for bulk grain haulage by truck, rail, and barge. Each of the specified models had differentiable objective functions and although the input data for a few of the models were merely approximations, meaningful conclusions can be drawn concerning the results.

Since complete data on actual county flows of hard red winter wheat were not available for the marketing years investigated, comparison of the results with actual flows was not accomplished. Nor had a total dollar transportation charge been made available for comparative analysis. Model I's results did indicate the railroads are the dominant carrier of export grain. The total freight bill, including handling charges, reflected an average 63.67 cents per bushel transportation charge. Of course, those shipments originating nearer the port destination had proportionately lower average assessments.

The potential for "minimum cost" results, as obtained in Model I, have corporate policy-making ramifications for the traffic manager and the financial analyst of a grain marketing and storage terminal. Given the specific conditions for the business (i.e., market price, inventory, customer demand, etc.) and the competitive transportation rate structure facing the firm, the financial manager can evaluate the least-cost distribution flow so as to incur the desired marketing margin. Utilizing existing business conditions permits "what if..." analyses rather than ex post or hindsight situation appraisals.

On a larger scale of operation, such as the railroads or barge companies, the minimum cost solution depicts the direction and magnitude of flows necessary to achieve the least-cost or optimal solution. Although such flows may or may not represent a specific shipper's modal preferences, the network flows indicate the potential traffic for the mode of transportation or the particular traffic for the mode of transportation on the particular network arc in question. Such information is desired in cost-benefit analysis for rail line abandonment, railroad line improvements, or inland river waterway extension recommendations. By incorporating relevant transportation rates, the grain marketing and transportation industry can evaluate potential market share activities by the various modes. The impact of handling and storage costs attributed to each mode and grain facility type can further be analyzed.

Analyses of the nature of Model I accentuate the issue of what should one do in order to minimize the total transportation freight bill. In the aggregate form presented in this study, little if anything, can be said of the management decisions at the cellular level within the hard red winter wheat producting counties as to achieving minimum costs for the particular elevator or terminal. In the context of this model, minimum costs is an optimal dollar value solution that could be achieved by the entire grain marketing and transportation system, as depicted in Figure 12, given the transportation rates, the capacities, and the supplies and demands. Because the management costs of producers, elevators, terminals, and transportation modes are excluded from the scope of this study, the results revealed by the algorithm may, in fact, not be the least-cost marketing and transportation procedure for an individual or group of individuals.

Model II, the grain flow maximization model, maximized the distribution flow of grain from harvest to export facility subject to the transportation and storage capacities depicted in Model I. The results imply that at the investigated levels of production, ample commercial storage exists for har red winter wheat harvest consistent with the state of the arts in production and harvesting technologies. Included in this volume of grain needing storage was the carryover on May 31 and the ending inventory on the following May 31. The surplus storage capacity was further magnified with the inclusion of recorded on-farm storage capacity.

This analysis does not ignore the possibility of a community having a shortage within the county, but in the aggregate, a surplus of storage capacity exists. In those instances of a shortfall of commercial storage, producers may utilize convertable farm facilities for grain storage and these temporary grain storage facilities were excluded from the model, although they exist.

Granted, Model II did not consider competition for the limited storage by other grain commodities, however the results indicated an ample volume of bushel storage capacity existed even then when the seasonality of the various grain harvests and peak shipments was considered. The principal crops competing for storage capacity and transportation services with hard red winter wheat are corn, grain sorghum, and soybeans which are harvested in the late summer and early fall and primarily transferred from harvest regions to consuming areas in the late fall and during the winter. Due to the quantity purchased and held for domestic disappearance by grain processors in the summer and the quantity exported immediately post-harvest, the utilization of storage facilities by hard winter wheat as the fall harvest begins is not a constraining factor on the operations of the elevators and terminals.

The results of Model II imply the flow bottlenecks and constraints during peak demand periods, such as during the Russian wheat deal of 1972-73, are not a function of storage limitations, but rather a function of the availability of transportation services. The availability or supply of covered hopper rail cars, flat-bottom and hopper grain trucks, or nine-foot draft grain barges is a constraint on the export movement of hard red winter wheat to the ports. Historical wheat production volumes do not exceed the combined on-farm and commercial grain storage capacities in the system. This supports the contention of many managers of inland terminals.

The situation analyzed in Model III was that of transporting the commodity to the port terminals along the Gulf of Mexico by the most expeditious manner possible, without regard to specific minimization of total costs. If speed or minimum transport time was critical, such as in meeting a contract dealine, the algorithm indicates five-axle hopper trucks were the vehicles to use, especially for the facilities further from the ports. By constraining the availability of grain trucks, railroads entered the solution by hauling wheat from those producing counties nearest the Gulf. Because of the locations of the river ports and of the days lost in traversing the locks on the navigable rivers, barge traffic never entered the computer solution.

Consequently, the results to Model III disclosed the opposite of the typical cost-distance relationships of hauling merchandise by truck, rail, and barge, respectively, as distance travelled increased. The speed versus cost analysis is coincidental in that the slowest mode is the cheapest in transporting goods the longest distances. The cost-distance relationship is a function of terminal charges and per unit per mile transportation rates, whereas speed is a function of the shortest path and the least amount of off-load or idle time.

Model III was an exercise which highlighted the versatility of the Out-of-Kilter Algorithm in addressing management problems. The same type of analysis can be applied to assignment problems or production problems in which a time minimization criteria is involved.

The competitiveness of the transportation rate structure for bulk export grain permitted the sensitivity evaluation of grain flows in Movel IV. This model depicted the changes in export distribution flows resulting from a seven percent increase in rail rates.

Unlike Models I through III which were marketing year analyses, Model IV (and the remaining two models) was time-staged which permitted review of the temporal distribution patterns coinciding with the harvest months of June through August and the non-harvest period of September through May. Temporal or seasonal studies permitted analyses of the limited storage on the grain marketing system as storage facilities generally turn or rotate their inventory stock more than once a marketing year. A turn can be defined as the ratio of grain volume handled and/or stored by a facility to the volume of licensed capacity of that facility approximating one. Typically, a larger proportion of storage space is used in the first three months (June-August) so as to make storage available to the grain stored by the producer on the farm and for the fall harvest.

By altering the rail transportation rate just a few cents per bushel, not only the choice of mode but also the direction of flow was altered. Personal preferences by traffic managers were omitted. The hard winter wheat was assumed free flowing among modes and shipment patterns to the optimal cost minimization solution. As a result, rail lost a large contingent of grain traffic to the competing modes. Furthermore, the Great Lakes ports of Duluth and Superior acquired limited shipments from the northernmost counties in the study area, as compared with the results obtained in Model I.

Model V was a spin-off of the feasibility-type analysis of Model II, specifically evaluating the drawing power of extended inland waterways to barge traffic for grain. Hypothesized barge rates were administered to nonexistent, but authorized, extensions of the Arkansas and Trinity River waterways. This model was not intended as a feasibility or cost-benefit analysis. The results obtained by Model V relied heavily upon the handling costs of receiving and loadout by the three modes at the different facility-types even though the assumed transportation rates were purely speculative. Therefore, this model accentuated the competitiveness of the transportation rate structure by indicating the relative sensitivity of the grain marketing and transportation system to alterations in the bulk grain transportation export rates. Two different pricing or rate schemes were employed, one for each of the two time periods.

This model (Model V) lends itself to analyzing the effects of peak load pricing by railroads or seasonal pricing by barges or any other problem in which flexible transportation rates might be utilized. Comparison of the opportunity cost and actual cost of storage for an extended period with the increased transportation charges, or evaluating the storage needs for the longer time frame with the existent storage capacity are possible issues that can be similarly addressed.

The rationale behind Model VI was the delineation of distribution flow changes to the network flow patterns observed in the preceding models when a large storage facility, such as at the port terminals, is no longer serviceable. Reasons for such an occurrence can be a dust explosion, rail abandonment, bankruptcy, and other such shocks. For the purposes of model evaluation, the grain handling facilities at the Louisiana Gulf ports were assumed terminated. Such an activity resulted in shifts not only in direction of flow but also the modal composition of flow. With the inclusion of storage constraints, not all of the grain could be handled by the Texas ports in the same time period without decreasing the storage capacity maintained for other grains. As a result, the northernmost counties in the study area shipped limited quantities of hard red winter wheat through the Great Lakes ports.

The methodology of Model VI followed the types of decisions addressed by transportation managers seeking alternative least-cost distribution patterns and modal considerations, regardless of the commodity, in response to some chock or constraint on the "normal" transportation and marketing channels.

## Limitations

Although the algorithm employed and the results of the six analyses have provided insights into the methdology of the Out-of-Kilter Algorithm, needed adjustments in transportation services, and the competitive position and competitive advantage of various counties and facilities in hard red winter wheat marketing, there were some notable limitations that should be pointed out.

First, domestic disappearance of hard winter wheat was assumed out of the scope of the study, only export flows and rates were included. In reality, a large proportion of the domestic disappearance was in the form of flour which is milled in the Southeastern part of the United States. Transshipment of the wheat for flour and other domestic uses to areas outside the study region by domestic rates would have increased the total transportation bill, had domestic flows been an objective for analysis.

Second, hard red winter wheat was assumed of homogeneous quality when, in fact, some wheat varieties have a higher protein content. The high protein wheat is used primarily by the flour milling industry and is therefore differentiable early in the crop year from other varieties.

Third, the assumption that the most economical mode of transportation could provide sufficient equipment and services to perform the necessary transportation may be violated in reality, as implied in some of the analyses. In many counties, especially at the country elevators, shortages of equipment exist around harvest, and this could alter the timeliness of flows depicted in the model. In addition, personal preferences of traffic managers as to the transportation mode selected are not considered. Similarly, the line-ownership of specific country elevators by certain inland terminals and major grain export companies may prevail on the selection and availability of modal services, as contractual arrangements may preassign the flows and alter those flows depicted in the model.

Another limitation is the degree of aggregation which fails to address the specific issues and problems of the producer. In a truly micro-sense, the preferences of the individual could be incorporated into the model, at the expense of increased model complexity. However, the structure of the grain marketing and transportation system is such that local elevator prices are based on Gulf bid prices plus transportation charges to the Gulf (as incurred by the elevator), and handling and storage charges assessed by the country elevator. Consequently, except for the individual who can store and transport his own winter wheat without utilizing commercial elevator or terminal services, the cellular level of the grain handling and storage facility is as micro-oriented or disaggregated as logically realistic.

## Need for Further Study

Although this study addressed the export transportation of hard red winter wheat, an expansion of the model to include domestic grain marketing could provide valuable information concerning the effects of alternative export marketing techniques and strategies on the structure of domestic grain marketing firms and domestic price levels.

A model such as the one formulated could be quite useful in predicting the effects on geographic flows and regional price differentials or relationships under alternative transport rate structures as well as changes in geographic supplies and demands.

The effect of various export marketing techniques and strategies with respect to price responsiveness and price uncertainty can be evaluated by establishing priorities on economic incentives and quantifying the benefits of adoption of cost reducing technologies and market organization.

Many problems of the spatial equilibrium and transportation model-type lend themselves to time-stages or temporal transshipment models. Formulations using the Out-of-Kilter Algorithm are feasible for many commodity or agricultural commodity groups. The solutions to such problems describing the activities of an individual firm or an entire industry involved in marketing particular merchandise could be useful to firms entering the marketing system by suggesting facility utilization, or location of operation, or market involvement.

# A SELECTED BIBLIOGRAPHY

Agrawal, R. C. and Earl O. Heady. Operations Research Methods for Agricultural Decisions. Ames: Iowa State University Press, 1972.

Anderson, D. H. and S. Brewer. Wheat and Rye Flows from Nebraska Origins: 1969. Lincoln: University of Nebraska, Department of Agricultural Economics, Report No. AE 58, 1979.

Arrow Transportation Company. Guide to Published Barge Rates on Bulk Grain, Schedule No. 8, Supplement No. 3 to Schedule No. 8. Sheffield, Alabama: 1976.

Baumol, C. P., T. P. Drinka, D. R. Lifferth, and J. L. Miller. An Economic Analysis of Alternative Grain Transportation Systems: A Case Study. Washington: Department of Transportation, FRA-OE-7-3-4, 1973.

Baumol, C. P., T. P. Drinka, J. L. Miller, and C. O'Riley. "How Far Will Farmers Haul Grain to Subterminals?" Feedstuffs, XLVIII (June 1976), p. 21.

Baumol, C. P., R. N. Wisner, and J. J. Miller. "On-the-Farm Versus Elevator Storage Costs." Journal of the American Society of Farm Managers and Rural Appraisers, October 1974, pp. 7-9.

Been, Richard O. "A Reconstruction of the Classical Theory of Location." (Unpublished Ph.D. dissertation, University of California, 1965.)

Blake, R. W. and B. C. McInnis. The Transportation of Export Grain Through the Houston Rail System. Houston: University of Houston, May 1976.

Breimyer, Harold F. Economics of the Product Markets in Agriculture. Ames: Iowa State University Press, 1976.

Bressler, Raymond G., Jr. and Richard A. King. Markets, Prices, and Interregional Trade. New York: John Wiley and Sons, 1970.

Chern, Wen-Shyong and Leo Polopolus. "Discontinuous Plant Cost Function and a Modification of the Stollsteimer Location Model." American Journal of Agricultural Economics, LII (1970), pp. 581-6.

Clasen, R. J. The Numerical Solution of Network Problems Using the Out-of-Kilter Algorithm. Santa Monica: The RAND Corporation, Memorandum No. RM-5456-PR, 1968.

Coffel, Harry. OK Grain Company. Catoosa, Oklahoma: Personal Interview, February 26, 1979.

Colorado Department of Agriculture. Colorado Agricultural Statistics, 1975 (and subsequent issues). Denver: Colorado Crop and Livestock Reporting Service, 1976-78.

Colorado Feed and Grain Association. Annual Directory, 1975. Denver: 1976.

Copeland, Ray. Fort Worth Operations, Union Equity Cooperative Exchange. Fort Worth: Personal Interview, August 22, 1978.

Doeksen, Gerald A. and Robert L. Oehrtman. "Optimum Locations for a Rural Fire System: A Study of Major County, Oklahoma." Southern Journal of Agricultural Economics, VIII (1976), pp. 121-7.

Dreyfus, Stuart E. "An Appraisal of Some Shortest Path Algorithms." Operations Research, XVII (1969), pp. 395-412.

Enid Board of Trade. Exparte X-357 Export Rates. Enid: Joe Neal Hampton, General Manager, 1979.

Fair, Marvin L. and Ernest W. Williams. Economics of Transportation. New York: Harper and Brothers, 1959.

Fedeler, Jerry A. and Earl O. Heady. "Grain Marketing and Transportation Interdependencies: A National Model." American Journal of Agricultural Economics, LVIII (1976), pp. 224-35.

Fedeler, Jerry A., Earl O. Heady, and Won W. Koo. "A National Grain Transportation Model." Chapter 12 in Earl O. Heady and Uma K. Srivastava, Spatial Sector Programming Models in Agriculture. Ames: Iowa State University Press, 1975.

Ford, L. R., Jr. Network Flow Theory. Santa Monica: The RAND Corporation, Paper No. P-923, 1956.

Fulkerson, D. "Fulkerson Out-of-Kilter Model." Journal of Soc. Indust. Appl. Math., March 9, 1961, pp. 18-27.

Fuller, Stephen W. and Mechel S. Paggi. Port of Houston: Intermodal Grain Transfer System and Market Area, 1976-77. Austin: The Texas Agricultural Experiment Station Bulletin No. B-1190, October 1978.

Fuller, S. W., M. Paggi, and D. Engler. Texas Wheat Flow Patterns and Utilized Transportation Modes, 1975. College Station: Texas Agricultural Experiment Station, Report No. B-1179, 1977.

Fuller, Stephen W., Paul Randolph, and Darwin Klingman. "Optimizing Subindustry Marketing Organizations: A Network Analysis Approach." American Journal of Agricultural Economics, LVIII (1976), pp. 425-36.

Fuller, Stephen and Chiyyarath Shammugham. "Network Flow Models: Use in Rural Freight Transportation Analysis and a Comparison with Linear Programming." *Southern Journal of Agricultural Economics*, X (1978), pp. 183-8.

Fuller, Stephen and Robert Sieklen. *A Solution Procedure for the Modified Stollsteimer Model*. College Station: Texas A & M University, Department of Agricultural Economics, Technical Paper No. TA 14420, 1978.

Gaibler, Floyd D. *Water Carriers and Inland Waterways in Agricultural Transportation*. Washington: USDA, ERS Agricultural Economics Report No. 379, 1977.

Hallberg, Milton C. and W. R. Kriebel. *Designing Efficient Pickup and Delivery Route Systems by Computer*. State College: The Pennsylvania State University Agricultural Experiment Station, Bulletin No. 782, 1972.

Hammond, Jerome J. and Michael S. Salvador. "Simulation Analysis of Export Grain Flows Through Gulf Ports." State College: American Agricultural Economics Association Contributed Papers Session, 1976.

Helmers, G. A. and W. F. Lagrone. *Wheat and Feed Grains in the Great Plains and Northwest: Supply Response and Resource Use*. Lincoln: University of Nebraska Agricultural Experiment Station, Great Plains Agricultural Council Publication No. 38, Research Bulletin No. 236, 1970.

Hillier, Frederick S. and Gerald J. Lieberman. *Operations Research*. San Francisco: Holden Day, 1964.

Hoover, Edgar M. *The Location of Economic Activity*. New York: McGraw Hill Book Company, Inc., 1974.

Household Goods Carriers Bureau. *Household Goods Carriers Bureau Mileage Guide, No. 9*. Washington: 1967.

Hu, T. C. *Integer Programming and Network Flows*. Boston: Addison-Wesley Publishing Company, 1970.

Isard, Walter. *Location and Space Economy*. Cambridge: The Massachusetts Institute of Technology Press, 1956.

Johnson, Marc A. *Oklahoma Railroads and Freight Service*. Stillwater: Oklahoma State University Agricultural Experiment Station, Research Report No. P-757, 1977.

__________. *Railroad Cost for Moving Wheat on the Plains*. Stillwater: Oklahoma State University, Department of Agricultural Economics, Paper No. AE 7810, 1978.

Johnson, Marc A. and Gary M. Mennem. "Market Area Sensitivity as a Measure of Railroad-Barge Competition in the Oklahoma-Kansas Wheat Transportation Market." Southern Journal of Agricultural Economics, VIII (1976), pp. 115-20.

Johnson, Marc A., Gary M. Mennem, and Robert L. Oehrtman. Rail Wheat Transportation Efficiency Study (Problem Assessment). Stillwater: Oklahoma State University, Department of Agricultural Economics, Paper No. AE 7708, 1976.

Just, Richard E. Algorithms for Developing Least-Cost Transportation Systems With Multiple Transportation Modes. Stillwater: Oklahoma State University Agricultural Experiment Station, Technical Bulletin No. T-138, 1974.

Kansas Grain and Feed Dealers Association. Kansas Official Directory, 1977. Hutchinson: 1977.

Kansas State Department of Agriculture. Kansas Agricultural Statistics, 1975 (and subsequent issues). Topeka: Kansas Crop and Livestock Reporting Service, 1976-78.

King, Gordan A. and Samuel H. Logan. "Optimum Location, Number, and Size of Processing Plants with Raw Product and Final Product Shipments." Journal of Farm Economics, XLVI (1964), pp. 94-108.

Ladd, George W. and Dennis R. Lifferth. "An Analysis of Alternative Grain Distribution Systems." American Journal of Agricultural Economics, XVII (1975), pp. 420-30.

Lamberton, C. F. and R. K. Rudel. A Pilot Study to Investigate Efficient Grain Transportation and Marketing Systems for South Dakota. Washington: Department of Transportation, Report No. DOT-OS-50229, 1976.

Larson, A. L. and T. W. Yates. Effect of Motor Trucks on Movement of Wheat in Oklahoma. Stillwater: Oklahoma State University Agricultural Experiment Station, Processed Series No. P-436, 1963.

Larson, Donald W. and Michael D. Kane. "An Economic Analysis of Rail Abandonment in Central and Southwestern Ohio Grain Producing Areas." Blacksburg: American Agricultural Economics Association Contributed Papers Session, 1978.

Leath, Mack N. and Leo V. Blakley. An Interregional Analysis of the U. S. Grain-Marketing Industry, 1966-67. Washington: USDA, ERS Technical Bulletin No. 1444, 1971.

Leath, Mack N. and James E. Martin. "The Transhipment Problem with Inequality Restraints." Journal of Farm Economics, XLVII (1966), pp. 894-908.

Losch, August. The Economics of Location. Translated from the 2nd revised edition by William H. Woglam with the assistance of Wolfgang F. Stapler. New Haven: Yale University Press, 1954.

Mennem, G. M. and R. L. Oehrtman. Costs of Holding Wheat. Stillwater: Oklahoma State University, Department of Agricultural Economics, OSU Extension Facts No. 428, 1977.

Milling and Baking News. "Six States Show More Than One Billion Bushels Storage Capacity." Milling and Baking News, (August 22, 1978), p. 57.

Missouri Department of Agriculture. Missouri Agricultural Statistics, 1975 (and subsequent issues). Jefferson City: Missouri Crop and Livestock Reporting Service, 1976-78.

Missouri Feed and Grain Dealers Association. Annual Directory, 1975-76. Kansas City: 1976.

Nebraska Department of Agriculture. Nebraska Agricultural Statistics, 1975 (and subsequent issues). Lincoln: Nebraska Crop and Livestock Reporting Service, 1976-78.

Nebraska Feed and Grain Dealers Association. Annual Directory, 1976. Omaha: 1976.

New Mexico Department of Agriculture. New Mexico Agricultural Statistics, 1975 (and subsequent issues). Albequerque: New Mexico Crop and Livestock Reporting Service, 1976-78.

New Mexico Feed and Grain Association. Annual Directory, 1975. Albequerque: 1976.

Nourse, Hugh O. Regional Economics. New York: McGraw Hill Book Company, Inc., 1968.

Oehrtman, R. L. Barge Rates for Transporting Bulk Grain from the Tulsa Port of Catoosa to Selected Destinations, 1976-77. Stillwater: Oklahoma State University, Department of Agricultural Economics, Report No. AE 7715, 1977.

__________. Cost of Receiving, and Loading Grain by Truck, Rail, and Water, and the Costs of Storing Grain at Inland Terminals for Fiscal Years 1964-65 to 1977-78. Stillwater: Oklahoma State University, Department of Agricultural Economics, Report No. AE 7714, 1977.

__________. Costs of Receiving, and Loading Grain by Truck, Rail, and Water, and the Costs of Storing Grain at Port Terminals for Fiscal Years 1964-65 to 1977-78. Stillwater: Oklahoma State University, Department of Agricultural Economics, Report No. AE 7716, 1977.

Oklahoma Feed and Grain Association. Annual Directory, 1976. Oklahoma City: 1977.

Oklahoma Publishing Company. "Grain Elevator Explosion in New Orleans." Oklahoma City Times. Oklahoma City: Oklahoma Publishing Company, June 3, 1977.

Oklahoma State Department of Agriculture. Oklahoma Agricultural Statistics, 1975 (and subsequent issues). Oklahoma City: Oklahoma Crop and Livestock Reporting Service, 1976-78.

Phillips, Don T., A. Ravindran, and James J. Solberg. Operations Research. New York: John Wiley and Sons, 1976.

Plane, D. R. and C. McMillan, Jr. Discrete Optimization. New Jersey: Prentice Hall, 1971.

Rand McNally and Company. Rand McNally Handy Railroad Atlas of the United States. Chicago: Rand McNally, 1973.

Rupprecht, Erhardt O., Jr. "Demand for Freight Cars in the Movement of Grains." Pennsylvania State University: American Agricultural Economics Association Contributed Papers Session, Summer 1976.

Sampson, Roy J. and Martin T. Farris. Domestic Transportation: Practice, Theory, and Policy. Boston: Houghton Miffin Company, 1966.

Saylor, Thomas. Associate Director, Foreign Agricultural Service, United States Department of Agriculture. Agricultural Policy Seminar. Stillwater: Oklahoma State University Student Union, March 9, 1979.

Schienbern, Allen. "Cost of Storing and Handling Grain in Commercial Elevators, Projections for 1974-75." Feedstuffs, CCLII (February 1974), pp. 31-41.

Schruben, L. W., L. O. Sorenson, and R. Phillips. How Extending River Navigation into Kansas, the Mid-Arkansas River Basin, and Central Oklahoma Would Affect Transportation Costs of Wheat. Manhattan: Kansas State University, Department of Agricultural Economics, Publication No. AES 542, 1974.

Schnake, L. D. and John R. Franzmann. Analysis of the Effects of Cost-of-Service Transportation Rates on the U. S. Grain Marketing System. Washington: USDA, ERS Technical Bulletin No. 1484, 1973.

Shouse, James C. and Marc A. Johnson. Anticipated Consequences of Seasonal Railroad Rates in the Oklahoma Wheat Transportation Market. Stillwater: Oklahoma State University Agricultural Experiment Station, Research Report No. P-773, 1978.

Sorenson, L. Orlo. "Rail-Barge Competition in Transporting Winter Wheat." American Journal of Agricultural Economics, LV (1973), pp. 184-9.

__________. Wheat Shipments from Kansas, 1972-73. Manhattan: Kansas State University, Department of Agricultural Economics, Report No. AES 575, 1974.

Stallings, J. L., J. M. Harris, and C. Sappington. *Grain Movements Between Southern and Corn Belt States*. Southern Cooperative Series, Bulletin No. 209, 1976.

Stollsteimer, John F. "A Working Model for Plant Numbers and Locations." *Journal of Farm Economics*, XLV (1963), pp. 631-46.

Texas Department of Agriculture. *Texas Agricultural Statistics, 1975: Small Grains* (and subsequent issues). Austin: Texas Crop and Livestock Reporting Service, 1976-78.

__________. *Texas Grain Warehouses 1975-76*. Austin: 1976.

Texas Feed and Grain Association. *Annual Directory, 1975-76*. Austin: 1976.

Thowsen, Arlid and Bayliss C. McInnis. *On Rail Transportation of Export Grain from Upcountry Elevators Through the Houston Rail System*. Houston: University of Houston, 1976.

Tyrchniewicz, Edward W. and Robert J. Tosterud. "A Model for Rationalizing the Canadian Grain Transportation and Handling System on a Regional Basis." *American Journal of Agricultural Economics*, LV (1973), pp. 805-13.

Union Equity Cooperative Exchange. "Opening Statement of Union Equity Cooperative Exchange Before the Interstate Commerce Commission Ex Parte No. 270 (Sub. No. 9) Investigation of Railroad Freight Rate Structure--Grain and Grain Products." February 25, 1976.

U. S. Department of Agriculture. *Cost of Storing and Handling Grain and Controlling Dust in Commercial Elevators, 1971-72, and Projections for 1973-74*. Washington: Economice Research Service, ERS-513, 1973.

__________. *Cost of Storing and Handling Grains in Commercial Elevators, 1964-65*. Washington: Economic Research Service, ERS-288, 1966.

__________. *Cost of Storing and Handling Grains in Commercial Elevators, 1967-68, and Projections for 1969-70*. Washington: Economic Research Service, ERS-401, 1969.

__________. *Cost of Storing and Handling Grains in Commercial Elevators, 1970-71, and Projections for 1972-73*. Washington: Economic Research Service, ERS-501, 1972.

__________. *Estimated Cost of Storing and Handling Grain in Commercial Elevators, 1971-72*. Washington: Economic Research Service, ERS-475, 1971.

__________. *Crop Production, 1975 Annual Summary, Acreage, Yield, Production, By States*. Washington: Statistical Reporting Service Publication No. CrPr 2-1(75), 1975 (and subsequent reports).

__________. *Distribution of the Varieties and Classes of Wheat in the United States*. Washington: Statistial Reporting Service Stat. Bull. 369, 1964.

__________. *Feed and Seed Crops, Production, Farm Use, Sales, Value, By States, 1975-76*. Washington: Statistics Reporting Service Publication No. CrPr 1(77), 1977.

__________. *Wheat Situation*. Washington: Economics, Statistics and Cooperative Service, WS-244, 1978.

U. S. Department of Transportation. *Highway Statistics: 1977*. Washington: Bureau of Public Roads, 1978.

von Oppen, M. and J. T. Scott. "A Spatial Equilibrium Model for Plant Location and Interregional Trade." *American Journal of Agricultural Economics*, LVIII (1976), pp. 437-45.

von Thunen, Johann Heinrich. *The Isolated State*. Chicago: Loyola University Press, 1960.

Warrack, Allan A. and Lehman B. Fletcher. "Plant Location Model Suboptimization for Large Problems." *American Journal of Agricultural Economics*, LII (1970), pp. 587-90.

Waterway Freight Bureau. *Schedule of Grain Handling Facilities at Points on the Inland Waterway System*. Washington: Department of Transportation, 1972.

Weber, Alfred. *Theory of the Location of Industries*. Translated with an Introduction and Notes by Carl J. Friedrich. Chicago: The University of Chicago Press, 1929.

Wright, B. H. *Regional and Sectoral Analysis of the Wheat-Flour Economy: A Transportation Study*. Washington: USDA, ERS Memorandum Report No. MRR 858, 1969.

Wyoming Department of Agriculture. *Wyoming Agricultural Statistics, 1975* (and subsequent issues). Laramie: Wyoming Crop and Livestock Reporting Service, 1976-78.

Wyoming Feed and Grain Association. *Annual Directory, 1975-76*. Cheyenne: 1976.

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