COST-EFFICIENT CARGO. . .
DISTRIBUTION AMONG TRANSPORTATION MODES

by

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FOREWORD

Attaining transportation efficiency, that is moving as large a load as possible at the lowest possible average cost, is an objective beneficial to both consumers and individual firms. Such a goal becomes more difficult to reach when three different transportation modes--rail, truck, and barge--are responsible for moving a given load among a number of locations throughout the United States. Often a particular load of goods may need to be transshipped from one mode onto another in order to let the shipment arrive at its destination. Coordination and logistics for such an effort become quite complex and thus operations become costly. Poor management and inadequate coordination can rapidly accelerate the cost of operation and in turn reduce efficiency.

This report in its limited scope will recommend a least-cost transportation system that will move a given payload at minimum cost.

Special recognition is given to Dr. Carlton E. Ruch who contributed significantly in the acquisition of basic statistical data for inclusion into the linear programming model.

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ABSTRACT

The hypothesis to be verified in this study states that the present method of distributing chemicals, fuel and lubricants, and primary iron and steel products between certain locations is ineffecient.

As production processes become more specialized due to location-specific resource availability, transportation becomes the important link between production centers and the consuming public. Chemical plants and refinery operations, for example, are concentrated in the northeastern sector of the Texas coastal zone. From this point of manufacture, the finished or intermediate product must be shipped to the ultimate users.

The linear programming (LP) model formulated in this study seeks to minimize the total cost of distributing a given volume of commodities among given locations. Since this analysis considers rail, truck, and barge modes, the locations included in the model must be accessible by all three transportation modes. The five cities are: Corpus Christi, Houston, Beaumont/Port Arthur, New Orleans, and St. Louis.

According to the LP formulation, the present distribution scheme could be improved to reduce total distribution costs and still satisfy the demand requirements for each city. Certain simplifying assumptions were specified to allow the model to work. Thus, all results must be considered in light of the stated assumptions, and the implications should be evaluated accordingly.

Price responsiveness to changes in modal capacity restrictions were approximated in what-if fashion. That is, how much will the price of barge transporation service change as barge capacity is altered? Likewise, how will modal capacities respond to changes in the price charged for the respective transportation services? From this analysis, it was concluded that barge and truck modes were highly complementary, while rail transportation behaves more as a substitute service. In other words, barges move goods over long hauls, while trucks are employed for short hauls. Rail, on the other hand, moves the overflow of quantities beyond existing barge and truck carrying capability, according to the model. Based on known customer requirements, known travel times for each transport mode, availability of the desired mode between any two locations, and prior planning, an efficient movement scheme can be developed even without introducing a time variable into the formulation.

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INTRODUCTION

"Economics is the study of how man and society end up choosing, with or without the use of money, to employ scarce productive resources that could have alternative uses, to produce various commodities and distribute them for consumption, now or in the future, among various people and groups in society. It analyzes the costs and benefits of improving patterns of resource allocation."[1]

This study concerns itself primarily with the allocation of a relatively limited resource used in distributing both raw and finished goods, namely transportation. Unlike a commodity such as a ton of steel or a gallon of crude oil, transportation is a service. Nevertheless, provision of such a service is limited by a number of constraints such as the number of carriers available, capacity per carrier, operating cost per carrier, distances to be traveled, time, labor, and profitability. The controlling essentials for efficient carrier performance whether modal or intermodal are:[2]

1. to insure, if possible, a continuous flow of goods and thus minimize backhaul handling, transfer, and delay
2. to move the optimum unit of cargo. That is, cargo specification should conform to carrier capability.

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[1]Paul A. Samuelson, Economics, 9th Edition, McGraw-Hill Book Company, New York, 1973.

[2]Marvin L. Four & Ernest W. Williams, Economics of Transportation and Logistics, Business Publications, Inc., Dallas, Texas, 1975.

3. to use the maximum vehicle unit. This principle stems from the simple fact that operating costs per vehicle unit do not increase proportionately with size. Also, the cost of handling, dispatching, and documentation tend to be the same regardless of size
4. to adapt a vehicle unit to volume and to the nature of the traffic
5. to standardize vehicles, terminals, and procedures
6. to insure compatibility of standard unit loads and equipment
7. to obtain a minimum ratio of deadweight to total weight of unit of movement
8. to optimally utilize capital, equipment, and personnel

The primary objective in this study is to evaluate the operational efficiency of the existing transportation network between selected locations that are all served by rail, truck, and barge modes.

A cursory review of the literature reveals that transportation policies and regulations of the past and even of today accomplish little in promoting an effective transportation mechanism. Rather than encourage cooperation among transportation carriers, the present system induces not only competition which is healthy to a degree, but current regulations and their enforcement cause individual firms to do everything but cooperate. As a result, U. S. transportation policy has become a maze consisting of disassociated laws aimed at enhancing or curtailing selected transportation sectors. The U. S. simply does not have in effect a comprehensive transportation program to further the domestic movement of goods, which leads to a possible and highly probable hypothesis that cargo movement can be improved. Improvement, in the connotation of this study, refers to reducing the cost of transportation and also reducing time in travel assuming existing carrier capacity is fully utilized.

BACKGROUND

A number of Sea Grant publications describe various aspects of the Texas Coastal Zone.[3] They document what was previously assumed. Specifically, the impact of the Gulf Intracoastal Waterway on the Texas economy is shown in Primary Economic Impact of the Gulf Intracoastal Waterway Commerce in Texas, and in the Indirect Economic Effect from Gulf Intracoastal Waterway Commerce in Texas. Industrial development along the Texas Coast, especially between Corpus Christi and Beaumont/Port Arthur has been rapid as evidenced by the continuous influx of new firms. Observed changes in population, employment, and income over the last decade alone verify the progress experienced within the Texas coastal zone. A good proxy for industrial growth is the accelerated rise in the volume of goods that are shipped on the waterway alone. The increase in commodity flows as reported by Texas ports rose from 170.3 million in 1960 to 226.4 million in 1973, equivalent to a 32.94 percent change. These totals included all goods handled by ports regardless of origin and not limited to the intracoastal waterway only. Total U. S. water movement traffic rose from 120.8 million ton miles in 1960 to 237 million ton miles in 1973, or 96.2 percent. But water transportation is not the only means of distribution. Rail, truck, and pipeline also experienced significant increases in volume. In terms of freight ton-miles, railroad inter-

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[3]These Sea Grant Publications are listed in the Bibliography.

city volume in the U. S. rose from 579.1 million ton-miles in 1960 to 860.0 ton miles in 1973,[4] or increased by 48.51 percent. Truck cargo volume rose from 285.5 million ton-miles in 1960 to 510.0 million ton-miles in 1973, amounting to a 78.63 percent change.[5]

The strain placed on the existing transportation network must be tremendous. It is for this reason that a more concerted effort should be made to improve the system by encouraging closer cooperation among the many carriers. This could lead to reduced cost to shippers, especially in these days of higher energy costs, and result in better service to the public.

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[4]The 1974 Yearbook of Railroad Facts

[5]Ibid.

PROBLEM STATEMENT

The Gulf Intracoastal Waterway has been proven to exert a significant economic impact on Texas. Demands on transportation services by industries located along this low-cost, high-capacity transportation artery are continuously rising while both domestic and international trade fluctuations place additional strains on Waterway capacity.

This raises questions about the ability of the Waterway in its current condition to accomodate anticipated changes. If its capacity is exceeded, then a "need"[6] arises to establish an efficient transportation system for moving the larger volume given cost, capacity and commodity restrictions.

The Waterway is only one of five available transportation modes in Texas. If the Waterway cannot adequately handle the traffic, then a combination of oceangoing vessels, railroads, trucks and pipeline might be coordinated into a systematic transportation network.

Primary emphasis in this study will be to determine costs of moving the existing and anticipated flow of commodities on the Texas Intracoastal Waterway via a combination of different transportation modes, given relevant constraints. The three modes under consideration include barges, railroads and trucks. Subject to location and capacity constraints, this study will estimate the optimum (least-cost) combination of modes required to efficiently move a known quantity of goods to their respective destinations.

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[6]It is not a purpose of this research to assess the benefits of additional transportation services vis-a-vis costs. Rather the purpose is limited to determining the least-cost package of transportation services to meet alternative volumes--thus the quotation marks around the word "need."

METHODOLOGY AND AVAILABILITY OF DATA

Assessment of current commodity flows on the Texas Gulf Intracoastal Waterway was accomplished through the use of secondary data provided by a number of institutions and publications (listed in the Bibliography).

From these flow estimates, three types of commodities will enter the linear programming formulation. The commodities chosen are chemicals, petroleum products, and iron and steel products because they represent commodity types carried by all three modes to all the specified locations in significant quantities.

A conventional linear programming (LP) model provides an efficient transportation system including three alternative modes--barge, truck and rail--subject to a number of variables.

Minimize $z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$

Subject to the restrictions:

$$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \geq b_1$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$a_{m}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \geq b_m$$

and $x_1 - 0,\ x_2 - 0,\ \ldots,\ x_n \geq 0$

This general formulation consists of:

1. an objective function (z) with teh purpose, in an economic sense, to either maximize profits or minimize costs. Given a number of decision variables (x_n) reflecting the activity that occurs between any two locations, the objective in this study will be to choose their values so as to minimize costs.[7]

2. resource restrictions imposed on the decision variables called functional constraints. An obvious restriction in this model, for example, will be the carrying capacity constraint for each individual mode. Time may also serve as a constraint if shippers must deliver their goods within a given time frame.

3. input constants, which in the objective function, refer to the cost coefficients (c_n) related to each respective decision variable (x_n). The parameters in the functional constraint are the input coefficient (a_{mn}) and the value in the right-hand side (b_m) representing the amount of resource available.

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[7]Hillier, Fredrick S. and Lieberman, Gerald J. Operations Research. Holden-Day, Inc., San Francisco, California, 1974.

THE MODEL

An initial tableau was established to determine an optimal transportation scheme for movement of the present commodity flow. The actual flows between a number of locations, both within and outside the Texas coastal area, were estimated. Table 1 displays such a commodity flow of chemicals shipped by rail. Tables 2 and 3 provide similar information for truck and barge modes, respectively.

Along with the quantity of chemicals that move between the specified locations, the cost of transportation between any two points is entered as C_{ij} in the objective function of the LP model. Tables 4 through 6 give the appropriate transportation cost figures.[8]

Corresponding constraints were also placed on the carrying capacity of each particular transportation mode.

Knowing the transportation costs for each mode and assuming that the tonnage capacity for each mode cannot exceed the tonnage presently carried by each mode, the model can now solve for the least-cost combination of transportation modes needed to move a known quantity of commodities between the following cities: St. Louis, New Orleans, Beaumont/Port Arthur, Houston, and Corpus Christi.

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[8] These cost data are the most current figures available. Because each mode quotes its respective price on the basis of a certain minimum quantity of pounds or tons, displayed data were all converted into dollars per ton.

TABLE 1

CURRENT TONNAGE DISTRIBUTION
(TONNAGES 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	AMOUNT SHIPPED
ST. LOUIS		24	4	12	3	43
NEW ORLEANS	55		86	177	31	349
BEAUMONT/ PORT ARTHUR	0	37		157	0	194
HOUSTON	19	193	111		77	400
CORPUS CHRISTI	2	18	22	50		92
AMOUNT RECEIVED	76	272	223	395	111	1,078

PRODUCT Chemicals

MODE Rail

SOURCE: A. T. Kearney, Inc. Domestic Waterborne Shipping Market Analysis. Springfield, Virginia, 1974.

TABLE 2

CURRENT TONNAGE DISTRIBUTION
(TONNAGES 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	AMOUNT SHIPPED
ST. LOUIS		33	3	18	3	57
NEW ORLEANS	4		4	20	3	31
BEAUMONT/ PORT ARTHUR	7	28		118	19	172
HOUSTON	23	95	69		66	253
CORPUS CHRISTI	2	9	7	38		56
AMOUNT RECEIVED	36	165	83	194	91	569

PRODUCT Chemicals

MODE Truck

SOURCE: A. T. Kearney, Inc. Domestic Waterborne Shipping Market Analysis. Springfield, Virginia, 1974.

TABLE 3

CURRENT TONNAGE DISTRIBUTION
(TONNAGES 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	AMOUNT SHIPPED
ST. LOUIS		16	1	16	4	37
NEW ORLEANS	283		84	327	47	741
BEAUMONT/ PORT ARTHUR	33	75		352	44	504
HOUSTON	194	537	165		243	1,139
CORPUS CHRISTI	10	29	10	516		565
AMOUNT RECEIVED	520	657	260	1,211	338	2,986

PRODUCT Chemicals

MODE Barge

SOURCE: A. T. Kearney, Inc. Domestic Waterborne Shipping Market Analysis. Springfield, Virginia, 1974.

TABLE 4

TRANSPORTATION RATES
CHEMICALS

	RAIL	BARGE*	TRUCKLOAD
	60,000 lbs except as noted by X	1,400 tons	40,000 lbs
FROM: BEAUMONT			
TO:			
NEW ORLEANS	$28.20/ton	$ 4.50/ton	$22.40/ton
ST. LOUIS	48.00/ton	12.00/ton	61.40/ton
CORPUS CHRISTI	27.20/ton	3.75/ton	21.20/ton
HOUSTON	15.60/ton	2.00/ton	11.80/ton
PORT ARTHUR	10.00/ton	1.00/ton	8.00/ton
FROM: PORT ARTHUR			
TO:			
NEW ORLEANS	$28.20/ton	$ 3.85/ton	$22.20/ton
ST. LOUIS	48.00/ton	11.90/ton	62.60/ton
BEAUMONT	10.00/ton	1.00/ton	8.00/ton
CORPUS CHRISTI	28.80/ton	3.55/ton	21.20/ton
HOUSTON	17.00/ton	1.40/ton	12.60/ton

SOURCE: Southern Shippers Association, Inc., 3601 S. Sandman, Houston, Texas, April, 1975.

X Min Weight 98% Car Capacity but not less than 26,000 lbs.

Min Weight 132,000 lbs.

* Barge rates for chemicals are estimate rates; as these products are handled on contract basis only.

TABLE 5

TRANSPORTATION RATES
CHEMICALS

		RAIL	BARGE*	TRUCKLOAD
		60,000 lbs except as noted by X	1,400 tons	40,000 lbs
FROM:	CORPUS CHRISTI			
TO:	NEW ORLEANS	$41.80/ton	$ 7.25/ton	$46.80/ton
	ST. LOUIS	56.20/ton	14.15/ton	80.00/ton
	BEAUMONT	27.20/ton	3.75/ton	21.20/ton
	HOUSTON	24.60/ton	2.50/ton	17.60/ton
	PORT ARTHUR	28.80/ton	3.55/ton	21.20/ton
FROM:	HOUSTON			
TO:	NEW ORLEANS	$32.80/ton	$ 5.15/ton	$28.60/ton
	ST. LOUIS	49.40/ton	12.95/ton	62.60/ton
	BEAUMONT	15.60/ton	2.00/ton	11.80/ton
	CORPUS CHRISTI	24.60/ton	2.50/ton	17.60/ton
	PORT ARTHUR	17.00/ton	1.40/ton	12.60/ton

SOURCE: Southern Shippers Association, Inc., 3601 S. Sandman, Houston, Texas, April, 1975.

X Min Weight 98% Car Capacity but not less than 26,000 lbs.

Min Weight 132,000 lbs.

* Barge rates for chemicals are estimate rates; as these products are handled on contract basis only.

TABLE 6

TRANSPORTATION RATES
CHEMICALS

		RAIL	BARGE*	TRUCKLOAD
		60,000 lbs except as noted by X	1,400 tons	40,000 lbs
FROM:	NEW ORLEANS			
TO:	ST. LOUIS	$41.60/ton	$ 9.35/ton	$55.20/ton
	BEAUMONT	28.20/ton	4.50/ton	22.40/ton
	CORPUS CHRISTI	41.80/ton	7.25/ton	46.80/ton
	HOUSTON	32.80/ton	5.15/ton	28.60/ton
	PORT ARTHUR	28.20/ton	3.85/ton	22.40/ton
FROM:	ST. LOUIS			
TO:	NEW ORLEANS	$41.60/ton	$ 5.70/ton	$55.20/ton
	BEAUMONT	48.00/ton	7.30/ton	61.40/ton
	CORPUS CHRISTI	56.20/ton	8.65/ton	80.00/ton
	HOUSTON	49.40/ton	7.90/ton	62.60/ton
	PORT ARTHUR	48.00/ton	7.30/ton	62.60/ton

SOURCE: Southern Shippers Association, Inc., 3601 S. Sandman, Houston, Texas, April, 1975.

X Min Weight 98% Car Capacity but not less than 26,000 lbs.

Min Weight 132,000 lbs.

* Barge rates for chemicals are estimate rates; as these products are handled on contract basis only.

ASSUMPTIONS

Results from the linear programming model, referred to as the "optimal" solution, are optimal only in the sense that the quantities to be moved are allocated among the three modes in such a way as to satisfy the destination demands, and still minimize total cost of transportation subject to a number of assumptions.

A clear and concise statement of assumptions may be more important than the results. Assumptions essentially are the foundations of any discussion, argument or model. It is from this foundation that the logic for an argument is developed and eventually evolves into a meaningful conclusion. If the assumptions are unrealistic, then the conclusion, although properly developed, will be worthless.

Detailed discussions of the concept and the underlying assumptions characteristic of a linear programming model can be easily found in the literature on applied quantitative economics or operations research methods.

The applicability of these assumptions to this research effort, however, will be briefly explained.

Implicit in the linear programming model formulation are the assumptions of (1) proportionality, (2) additivity, (3) divisibility, and (4) determinability.[9]

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[9]Hillier, Fredrick S. and Lieberman, Gerald J. Operations Research. Holden-Day, Inc., San Francisco, California, 1974.

Proportionality implies that each activity in the model, in this case the movement between any two locations, is directly proportional to the measure of effectiveness or the final objective. This simply means, for example, that the cost of moving the first ton of chemicals between two points is equal to the cost of moving the last ton along the same distance.

The additivity assumption complements the proportionality assumption. It requires that for any given activity level, the quantity demanded at each location, and the resulting cost of moving a specified quantity to that destination, must equal the sum of the corresponding costs generated by each individual movement conducted by itself. Specifically, the total cost of moving the entire volume of goods to their respective destinations from the existing origins must equal the sum of the individual movement costs.

Divisibility requires that activity units, which in this case are the tonnages to be transported, can be divided into any fractional level. Such division is entirely permissible in the movement of the type of cargo studied here.

Determinability requires that all parameters of the model be constants. That is, costs and quantities supplied or demanded must be known in order to attain a single-valued solution.

Inherent in the model is the assumption that rail, truck, and barge capacity will be avilable in sufficient quantity at any time. So, if the linear programming results call for a 570,000-ton truck movement between

Beaumont, Port Arthur, and Houston during one year, it is automatically assumed that a sufficient number of trucks are instantly available to move this volume. Although such carrying capacity may not always exist at any one time, it can be argued that with prior planning and prior knowledge of the production cycle and product demand, each firm can at least approximate future transportation needs ahead of time. Thus, the assumption of capacity availability, when needed, can be easily accepted with certain restraints.

This transportation problem was transformed into a linear programming format and, therefore, does not consider the possibility of cargo transshipments. That is, unloading cargo at a specified location from one transportation mode to another en route to a final destination, and the additional cost involved in such a transshipment process are not included. The model simply estimates the minimum total cost of cargo movement of a specified quantity of goods with a fixed carrier capacity, where each carrier once loaded will proceed directly to the respective destination excluding intermediate stops. Political and institutional characteristics that may influence this distribution process are not included.

The constraints introduced into the model describe existing supply and demand conditions. Supply restrictions are equivalent to the actual quantities supplied by each city, while demand restrictions are equal to the amount of chemicals currently being received by each city regardless of the mode that is moving the goods. This allows the model to allocate the limited source of chemicals to the various destinations according to their respective demands given the prevailing rate structures.

INTERPRETATION OF RESULTS

Analysis of the Existing Market:

Before the optimal results can be meaningfully interpreted, the situation, as it exists today, will first be described. Then the optimal solution provided by the model will be presented followed by a comparison between the existing transportation resource allocation and the optimal solution.

Table 1 delineates the actual movement of chemicals by rail between any two of five possible locations. Houston, for example, ships 19,000 tons of chemicals to St. Louis; 193,000 tons to New Orleans; 111,000 tons to Beaumont/Port Arthur; and 77,000 tons to Corpus Christi. In effect, total shipments by rail from Houston for the purpose of this model, are 400,000 tons. On the other hand, interpretation of the column numbers refers to quantity of chemicals that are received by the respective destinations. This is equivalent to saying that New Orleans, for instance, demands a total of 395,000 tons of chemicals.

A comparison of the quantities supplied and the quantities demanded by individual cities reveals an inequality between the two. Notice that Houston supplies 400,000 tons, but only requires 395,000 tons, resulting in a 5,000 ton surplus. Yet other locations, such as Corpus Christi, only supplies 92,000 tons, but demands 111,000 tons for a deficit of 19,000 tons. What must occur then in this closed model limited to only five cities is that cities with a surplus should supply those cities experiencing a shortage. The ultimate objective being the attainment of an eventual equilibrium between supply and demand. The grand total of 1,077,000 tons of chemicals shipped by rail represents both the total supply and the total demand for chemicals.

The rationale or the actual process used to distribute the total volume of resources in such a way as to satisfy all demands in the existing market as shown in Table 1 is not quite clear. As shall be demonstrated later, the present allocation process based on current transportation rates is not very efficient--it is too costly.

Tables 2 and 3 can be interpreted similarly with the exception that the allocation scheme pertains to movement of chemicals by the truck and barge mode, respectively.

To determine the total cost of distributing the given volume of chemicals according to Tables 1, 2, and 3, these quantities must simply be multiplied by the individual costs per ton as they apply to each mode between any two locations. These rates are shown in Tables 4, 5, and 6.

Costs associated with the movement Tables (1, 2, and 3) are displayed in Tables 7, 8, and 9.

Each cost entered represents the product of the quantity moved and its associated transportation rate expressed in dollars per ton. As an example: the total cost for moving 243,000 tons between Houston and Corpus Christi by barge, times the respective barge rate of \$2.50 per ton equals \$607,500. On a slightly larger scale, the cost of shipping 2.986 million tons of chemicals by barge amounts to 14.595 million dollars. Adding the separate totals for barge, truck, and rail shipments equivalent to 4.632 million tons and multiplying them by their corresponding

TABLE 7

CURRENT DISTRIBUTION SCHEME

TOTAL COSTS

(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS	$	$ 998.4	$ 192.0	$ 592.8	$ 168.6	$1,951.8
NEW ORLEANS	2,288.0		2,425.2	5,805.6	1,295.8	11,814.6
BEAUMONT/ PORT ARTHUR		1,043.4		2,542.8		3,586.2
HOUSTON	938.6	6,330.4	1,809.3		1,894.2	10,972.5
CORPUS CHRISTI	112.4	752.4	616.0	1,230.0		2,710.8
REVENUES RECEIVED	3,339.0	9,124.5	5,042.5	10,171.2	3,358.6	31,035.9

PRODUCT Chemicals

MODE Rail

TABLE 8

CURRENT DISTRIBUTION SCHEME
TOTAL COSTS
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS	$	$1,821.6	$ 186.0	$1,126.8	$ 240.0	$3,374.4
NEW ORLEANS	220.8		89.6	572.0	140.4	1,022.8
BEAUMONT/ PORT ARTHUR	434.0	627.2		1,439.6	402.8	2,903.6
HOUSTON	1,439.8	2,717.0	841.8		1,161.6	6,160.2
CORPUS CHRISTI	160.0	421.2	148.4	668.8		1,398.4
REVENUES RECEIVED	2,254.6	5,587.0	1,265.8	3,807.2	1,944.8	14,859.4

PRODUCT Chemicals

MODE Truck

TABLE 9

CURRENT DISTRIBUTION SCHEME

TOTAL COSTS

(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORATION COSTS
ST. LOUIS	$	$ 91.20	$ 7.30	$ 126.40	$ 34.60	$ 259.50
NEW ORLEANS	2,646.05		352.80	1,684.05	340.75	4,023.65
BEAUMONT/ PORT ARTHUR	394.35	315.00		598.40	160.60	1,468.35
HOUSTON	2,512.30	2,765.55	280.50		607.50	6,165.85
CORPUS CHRISTI	141.5	210.25	36.50	1,290.0		1,678.25
REVENUES RECEIVED	5,694.20	3,734.80	2,008.35	2,355.55	802.70	14,595.60

PRODUCT Chemicals

MODE Barge

rates amounts to a total cost of transportation equal to 60.491 million dollars. This amount represents the total cost for moving chemicals under the current allocation scheme.

OPTIMAL ALLOCATION SCHEME

The linear programming (LP) approach shows that this same volume of chemicals can be better allocated to reduce total transportation costs, yet still satisfy destination requirements. An optimal allocation scheme for each transportation mode, according to the LP model, is shown in Tables 10, 11, and 12.

Evidently in the example of rail and truck transportation, only relatively small quantities of chemicals move among the specified locations under present circumstances. The LP formulation, in contrast, recommends that railroad and truck services should be used primarily over shorter distances, allowing barge lines to handle the long-haul freight. Obviously, the time element is often used as a likely reason for choosing either rail or truck modes. A definite trade off between time and cost is apparent. The LB model did not consider a time constraint. However, it seems reasonable to assume that if shippers, both suppliers and buyers, know the time of travel between a given distance for any mode, and they know the respective rates, then management should be able to plan ahead. If a customer needs a certain order delivered on a specified date, then the suppliers, familiar with their own production schedules, and with the time and rate

TABLE 10

OPTIMAL DISTRIBUTION SCHEME

TOTAL COSTS

(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS						
BEAUMONT/ PORT ARTHUR				\$16.3/ton 869,000 ton \$14,164,700		869,000 ton \$14,164,700
HOUSTON			\$16.3/ton 209,000 ton \$3,406,700			209,000 \$3,406,700
CORPUS CHRISTI						
REVENUES RECEIVED			209,000 ton \$3,406,700	869,000 ton \$14,164,700		1,078,000 ton \$17,571,400

PRODUCT Chemicals

MODE Rail

TABLE 11

OPTIMAL DISTRIBUTION SCHEME
TOTAL COSTS
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS						
NEW ORLEANS						
BEAUMONT/ PORT ARTHUR						
HOUSTON			$12.2/ton 570,000 ton $6,954,000			570,000 ton $6,954,000
CORPUS CHRISTI						
REVENUES RECEIVED			570,000 ton $6,954,000			570,000 ton $6,954,000

PRODUCT Chemicals

MODE Truck

TABLE 12

OPTIMAL DISTRIBUTION SCHEME
TOTAL COSTS
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORATION COSTS
ST. LOUIS		$5.7/ton 137,000 ton $780,900				137,000 ton $780,900
NEW ORLEANS	$9.35/ton 137,000 ton $1,280,950		$4.20/ton 614,000 ton $2,578,800	$5.15/ton 370,000 ton $1,905,500		1,121,000 ton $5,765,250
BEAUMONT/ PORT ARTHUR						
HOUSTON		$5.15/ton 300,000 ton $1,545,000			$2.50/ton 713,000 ton $1,782,500	1,013,000 ton $3,327,500
CORPUS CHRISTI		$7.25/ton 160,000 ton $1,160,000		$2.50/ton 553,000 ton $1,382,500		713,000 ton $2,542,500
REVENUES RECEIVED	137,000 ton $1,280,950	597,000 ton $3,485,900	614,000 ton $2,578,800	923,000 ton $3,288,000	713,000 ton $1,782,500	2,984,000 ton $12,416,150

PRODUCT Chemicals

MODE Barge

structúres for transportation, can simply plan to dispatch an order of goods sufficiently in advance. The "optimal" allocation scheme does not violate any constraints. Rail, truck, and barge capacities are fully utilized, destination demands are met, available supplies are exhausted, and the prevailing transportation costs per ton are paid. Again, multiplying the number of tons to be shipped between locations according to the model, by the corresponding costs per ton, brings the overall cost of transporting the same 4.632 million tons to 36,942 million dollars. When compared to the existing distribution scheme that costs 60.491 million dollars, the proposed LP allocation would result in a 23.549 million dollar savings, equivalent to a 38.9 percent cost reduction.

A second LP formulation addressing the distribution of fuels and lubricants shows similar results.[10] The optimal solution once more implies that total transportation costs within the limited market area could be reduced from 38.797 million dollars to 23.233 million dollars. This difference of 15.564 million dollars is equivalent to a possible 40.12 percent savings.

The distribution of primary iron and steel seems to be the most efficient of the three commodities under consideration. Tables 10-12 in the Appendix show the total cost of moving 907,000 tons of steel to be approximately $8.6 million under the present movement scheme. The LP formulation redistributes the flow of the commodities to

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[10] These results may be found in the Appendix.

reduce total transportation costs to $7.2 million. While continuing to meet the same demand as before, the new allocation scheme produces a 19.8 percent cost savings.

Without more detailed investigation into the underlying reasons responsible for such significant cost differences, it would be premature to designate the existing transportation system as being inefficient. The significant cost difference, however, certainly points to an immediate need for analysis of the present distribution system in light of today's apparent fuel limitations.

SENSITIVITY ANALYSIS

Now that an "optimal" plan has been developed, the stability of the plan may be questioned. Some answers to questions like the following may provide a better understanding.

1. What is the advantage of these activities which entered the plan over those which were not included?
2. How would an increase in the quantity shipped or a rise in the quantity demanded, or a larger capacity in any mode affect the "optimal" distribution scheme?
3. How would changes in the rate structure affect the plan?

Information regarding these questions can be derived from a careful analysis of the shadow prices included in a conventional MPS-360 range report.[11]

Shadow price is a synonym for marginal value product which is obtained by multiplying the marginal product of a variable productive service by the market price of the commodity in question.[12] Marginal product of an input which in this case refers to transportation services, is defined as "the addition to total product (total tons moved) attributable to the addition of one unit of the variable input (transportation)."[13] That is, if one tractor-trailer were added to the transportation system, and as a result total volume shipped increased from 570,000 tons to 570,100 tons, then the marginal product of adding one tractor-trailer

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[11]MPS-360 is the name of the particular computer algorithm used to solve this type of linear programming problem.

[12]C. E. Ferguson, Microeconomic Theory, Revised Edition, Richard D. Inc., Homewood, Illinois, 1969.

[13]Ibid.

is 100. Multiplying the marginal product of 100 by the prevailing price of the service, let us say $16.30, results in a marginal value product of $1630 to be realized from one additional tractor-trailer. This type of information is precisely what a manager needs to know in deciding whether to expand capacity, alter the volume of goods being moved, or change the price for his services. In effect, when the marginal value product is plotted against the quantity of inputs (trucks, railroad cars, or barges), a derived demand for the inputs can be constructed. Derived from total product demand, the derived input demand which relates price and quantity of inputs, exerts a direct influence on a firm's total revenue.

A conventional MPS-360 "range" report comes in four sections. Only the relevant sections and only the important variables in the range report will be described.

Section 1 concerns itself with the resources that are fully utilized. According to the model, all chemicals available for shipment by the five ports in question are used while all but the Beaumont/Port Arthur demands are fully satisfied. In the process, the entire shipping capacity of rail, truck, and barge is utilized. Interpretation of the "shadow" prices shows that if truck capacity were to be increased by one ton, total cost of shipments would increase by $4.10 within the range of 570,000 tons to 779,000 tons. Similarly, a one-ton increase in barge capacity between 2,984,000 tons and 3,144,000 tons would increase total transportation cost by $16.85. Beyond this upper limit of 3.144 million tons, the shadow price is not known. Nevertheless, it gives the manager some idea as to the estimated cost of expanding his shipping capacity.

Increasing rail capacity beyond its current limit of 1.078 million tons would raise costs by $4.10 per ton up to and including 1.648 million tons.

Section 2 of the "range" report refers to those activities included in the model which did not enter into the optimal plan. The "range" report estimates the penalty a manager would have to pay if he insisted on employing an activity not included in the plan. Activity in this context describes the movement of chemicals by any one of three modes between any two of the five cities used in the model. For example, if a manager insisted on shipping chemicals by rail between Corpus Christi and New Orleans (211)[14] it would cost him an additional $17.70 per ton of chemicals. Also the report reveals that if the rail rate for shipping chemicals between Corpus Christi and New Orleans were to be reduced from a current level of $41.80 down to $24.10, then this activity would enter the plan at an 80,000 ton level. That is, at a rate of $24.10, 80,000 tons of chemicals would be shipped between those two locations. These penalty costs arising from the movement of goods between locations not deemed efficient by the model account for the significant difference in total transportation costs between the current and the optimal distribution scheme. The total penalty for moving 18,000 tons of chemicals by rail between Corpus Christi and New Orleans, which is the amount currently moved between the two towns, would be equal to 18,000 tons times $17.70 (penalty) or $318,000. Adding all other similar penalty costs corresponding to the current distribution scheme results in the total cost difference between the total costs of transportation paid today, and the total costs advocated by the model.

[14] The code (211) describes the route between the origin 2 (Corpus Christi) to to destination 1 (New Orleans) by mode 1 (rail). A complete listing of these codes is in Tables 13-15 in the Appendix.

Section 3 is concerned with those restraints or resource restrictions which are not limiting. In this case, Section 3 does not apply since all resources are utilized to their maximum, or to their upper limit making all resources in this formulation limiting.

Section 4 reports those activities which entered the plan. Because it delineates the optimum distribution plan, this section is the most important part of the range report. Effects from diverging from the plan in any activity, at a level either higher or lower than specified in the optimal scheme, can be analysed. The range analysis provides insight into the size of the additional costs which apply to departures from the optimum on either side.

Activity 141, movement between Beaumont/Port Arthur to Houston by rail, occurs at a level of 869,000 tons with a per ton cost equal to $16.30. Input cost should be interpreted as the prevailing transportation rate quoted by a firm. Here is where the price stability over a range of quantity levels can be estimated. In this example, the transportation rate of $16.30 will remain stable over the range covering 869,000 tons (optimal level) down to 299,000.1 tons. Below this point, the rate will change, but the magnitude of such a change is not known. This naturally implies that a downward deviation from the optimal level of 869,000 tons will not bring about any penalty costs.

Activity 331, Houston to Beaumont/Port Arthur by <u>rail</u>, shows 209,000 tons to be traveling between these two cities at a cost of $16.30 per ton. It appears that a penalty cost of $5.25 is imposed for every ton of chemicals below 209,000 tons down to 49,000 tons with no penalty costs applying for shipments over the optimum level up to 779,000 tons. At a rate of $21.55 per ton, total quantities moved would decline to 49,000 tons while at a rate of $16.30 (the quoted rate) total tonnage may rise up to 779,000 tons. In effect, the $16.30 rate is stable over the 49,000 ton to 779,000 ton range.

Activity 332, Houston to Beaumont/Port Arthur by <u>truck</u>, indicates that the current truck rate of $12.20 over the specified route, is the same from one ton up to the resource limit of 570,000 tons. Beyond this tonnage limit, cost may become extremely large.

Activity 213, Corpus Christi to New Orleans by <u>barge</u>, is at a 160,000 ton level, given a barge rate of $7.25. This rate remains unaltered between the one ton and the 460,000 ton level, at which point the barge rate drops to $5.00 per ton. It may also be argued that the rate may vary from $7.25 down to $5.00 before changes in the level of quantities shipped would occur.

Activity 243, Corpus Christi to Houston by <u>barge</u>, exhibits an optimum quantity level of 553,000 tons at a $2.50 movement cost per ton. Movement of a lesser quantity would impose a penalty of $2.10 per ton, while quantity levels above 553,000, but below 713,000, will have no extra costs. This $2.50 rate may vary up to $4.60 before the quantity level will change. At $4.60, movement of chemicals between the two cities would drop to zero, while at a rate of $2.50 as many as 713,000 tons may be moved.

Activity 313, Houston to New Orleans by barge, moves a 300,000-ton quantity of chemicals at a cost of $5.15 per ton. Without incurring any penalty costs, this $5.15 rate is consistent within the zero- to 460,000-ton range.

Activity 343, Houston to Corpus Christi by barge, demonstrates an optimal quantity level of 713,000 tons with $2.50 per ton shipping charge. This charge may vary all the way down to zero before a change in quantity would occur.

Activity 413, New Orleans to St. Louis by barge, proves to be a bit more interesting. The optimal solution advocates a volume of 137,000 tons, charging $9.35 for shipping. However, any quantity below this level down to zero would incur a penalty cost of $7.45 per ton, while movement of quantities at levels higher than optimum up to 661,000 tons, would experience a $5.15 penalty charge.

In other words, the current rate of $9.35 may vary between $16.80 and $4.20 before the level of quantities transported over this distance would alter. At $16.80, this volume would drop to zero, while at a $4.20 rate, the volume would rise to 661,000 tons.

Activity 423, New Orleans to Beaumont/Port Arthur by barge, calls for a movement of 614,000 tons of chemicals with a corresponding $4.20 transportation levy. Shipments below this level incur no penalty cost as long as the level does not go below 314,000 tons. Shipments above the optimal level, but below 774,000 tons would bring forth a penalty cost of $2.35 per ton. In terms of rate stability, the model allows the quoted

$4.20 rate to vary down to $1.85 before changes in volume occur. That is, if the rate in this particular instance were reduced from $4.20 to $1.85, as many as 774,000 tons of chemicals would be moved over this stretch.

Activity 443, New Orleans to Houston by barge, is activated at the 370,000 ton level at the prevailing barge rate of $5.15, which appears to be the ideal rate for shipping this commodity in the 21,000 ton to 67,000 ton range.

Activity 513, St. Louis to New Orleans by barge, occurs at a 137,000 ton level. The $5.70 rate may vary from $11.30 at which time no chemicals would be shipped over this route, down to almost zero cost in which case 137,000 tons would be moved.

With this information, a manager knows or can determine his operating flexibility with regard to volume size and its corresponding effect on transportation costs. As we have seen, transportation rates remain constant over certain ranges. Once either the upper or lower limit of such a specified range has been exceeded, respective rates will change while occasional penalty costs will be imposed simultaneously. Once a particular rate changes, commodities between the five locations will be rerouted or the distribution of the total volume among modes may alter.

Another concern to the manager would be the effect of a change in either rail, truck, or barge capacity on total transportation cost. If truck capacity were to increase, would this cause a larger volume of goods to be shipped by truck, or would the modal share be unaffected? If truck carriers were to gain more business, then it must be decided which competitor(s), rail or barge, would have to give up proportionate amount(s). Any change in capacity, demand for a product, or the rate structure can further cause shadow prices (marginal value product) to respond correspondingly.

In effect, management would like to have an estimate of a demand schedule for the service provided, and also wants to be able to plan for capacity expansions in response to transportation rate fluctuations.

These types of questions will be discussed in the next section under the heading of Post Optimum Analysis.

POST OPTIMUM ANALYSIS

Two types of procedures are usually identified with a post optimum procedure. One procedure calls for changing the coefficients in the objective function a specified number of times, and evaluating the resulting changes in activity levels. Specific to this model, the transportation rates will be increased to thirty-five dollars above the current level in ten increments. The resulting changes in the volume of chemicals shipped along any previously described route will then provide some helpful insights into the supply responsiveness of services rendered to changes in the price per unit of service.

A second procedure allows the constraints to be altered. Trucks, rail, or barge capacity may be expanded, restricted even more, or may become totally unconstrained. Resource supply or demand for the resource may also vary. The significance here pertains to the effect on transportation rates or the price of transportation services as any one or several of the specified constraints are relaxed.

PROCEDURE 1: Estimation of supply responsiveness.

A rise in the price for transportation services should lead the suppliers to provide more services by increasing carrying capacity.

In this model, only the price for barge transportation is revised while both rail and truck rates will be held constant. This action is supported by the recent controversy over imposition of user charges on barge carriers. Therefore, it would be of interest to see how changes in barge rates may affect the distribution of chemicals among rail, truck, and barge modes.

At first, barge rates were increased by ten percent. This raise, however, had no effect on the distribution shares. Not until rates were increased by $16.85 per ton did a change in the distribution scheme occur. In fact, most of the change occurred in barge traffic rerouting. The only significant alteration was the transfer of 58,000 tons, which first moved by barge between Houston and New Orleans, to rail between Houston and Beaumont/Port Arthur. This naturally caused other tonnages to shift around in such a manner as to still meet the destination demands while utilizing all resources.

In reality, firms usually do not respond instantly to small price changes. Prices tend to hold over a range. Only at the margin, either at the lower or upper limit of the range, do prices begin to vary. For example, the extreme upper range limit where the price is still $16.85 above the initial price, 206,800 tons of chemicals are suddenly transferred to the truck mode servicing the distance between Beaumont/Port Arthur and Houston. A subsequent chain reaction follows to reallocate the total volume in order to minimize total transportation costs subject to the higher prices. Results are displayed in Table 13 and Figures 1 and 2.

TABLE 13

SUMMARY OF SOLUTIONS

ACTIVITY	OBJ + 0 OBJ		OBJ + 16.85 OBJ		OBJ + 16.85 OBJ		OBJ + 35.00 OBJ	
	PRICE	ACTIVITY LEVEL	PRICE	ACTIVITY LEVEL	PRICE	ACTIVITY LEVEL	PRICE	ACTIVITY LEVEL
x113	4.2	242,000	21.05	242,000	21.05	352,000	39.02	352,000
x213	7.25	160,000	24.10	218,000	24.10	424,800	42.25	424,800
x243	2.50	553,000	19.35	495,000	19.35	288,200	37.50	288,200
x313	5.15	58,000	22.00	0	22.00	0	40.15	0
x343	2.50	713,000	19.35	713,000	19.35	713,000	37.50	713,000
x413	9.35	137,000	26.20	137,000	26.20	137,000	44.35	137,000
x423	4.20	372,000	21.05	314,000	21.05	314,000	39.20	314,000
x443	5.15	612,000	22.00	670,000	22.00	670,000	40.15	670,000
x513	5.70	137,000	22.55	137,000	22.55	137,000	40.70	137,000
x331	16.30	1,021,000	16.30	1,079,000	16.30	206,800	16.30	206,800
x141	16.30	0	16.30	0				
x142	12.2	0	12.2	627,000	12.20	627,000	12.20	627,000

SOURCE: Industrial Economics Research Division, Texas Engineering Experiment Station, Texas A&M University.

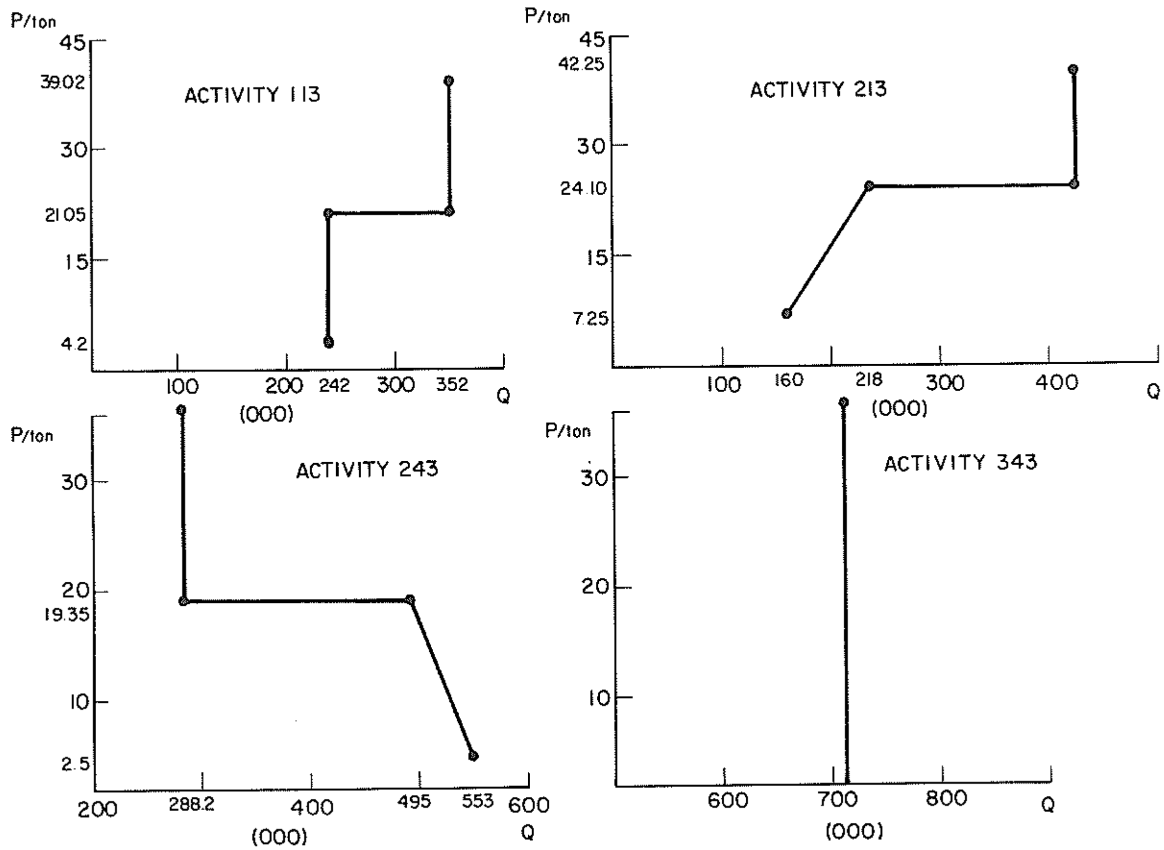

FIGURE I

SUPPLY RESPONSE CURVES FOR ACTIVITIES 113, 213, 243, 343

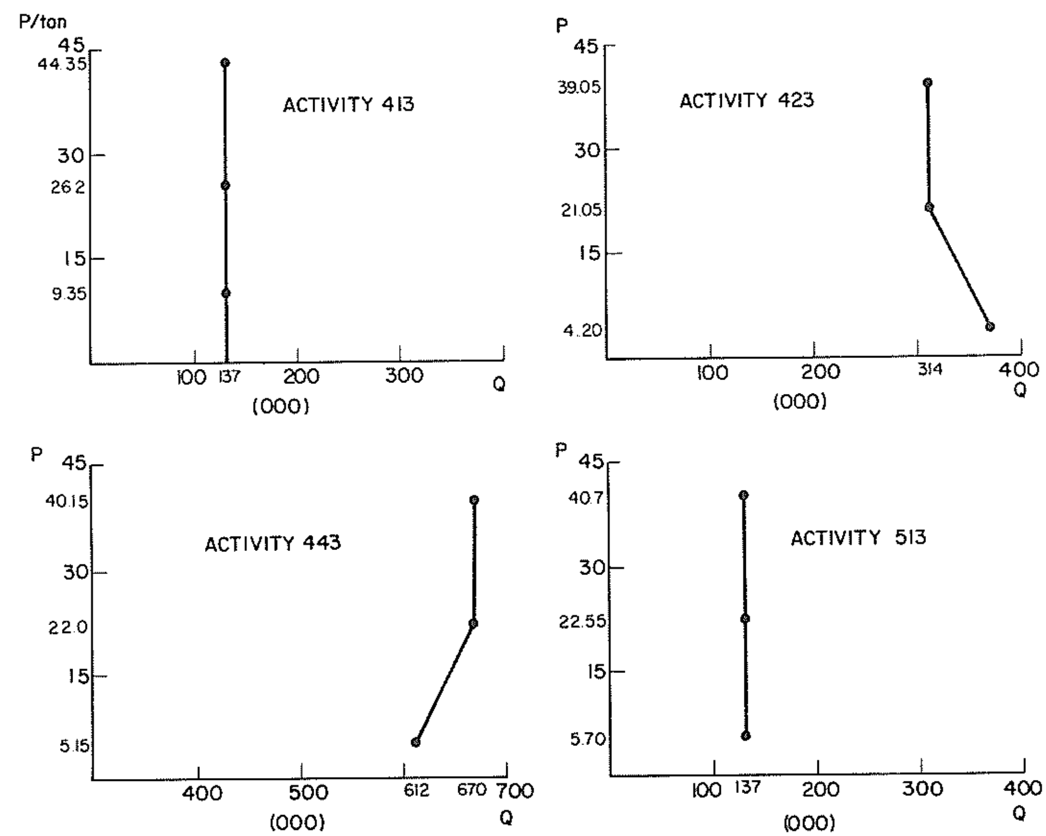

FIGURE 2

SUPPLY RESPONSE CURVES FOR ACTIVITIES 413,423,443,513

By allowing total rail and truck capacity to increase by ten percent, the total cost of transportation declined from $36.942 million to $36.708 million. Additional rail and truck capacity let the system take advantage of more efficient short distance mode, namely truck carriers, and therefore caused total costs to diminish.

The same procedure was repeated except for one slight deviation. This time restrictions on rail and truck capacity were removed while barge capacity remained constant. The basis for such a formulation is the assumption that barge capacity can be less readily increased because (1) long lead-time required for producing new barges and (2) because barges outside this study area are assumed to be fully utilized and thus not available on short notice.

As soon as truck- and rail-capacity restrictions are relaxed, total transportation costs diminish while the model automatically shifts all tonnages previously moved by rail over to truck carriers. Specifically, activity 331, Houston to Beaumont/Port Arthur by rail, was eliminated and the tonnage of 1,021,000 was distributed between activity 142, Beaumont/Port Arthur to Houston, by truck, and activity 332, Houston to Beaumont/Port Arthur, by truck. Conclusively, this points to an inherent advantage of truck transportation above rail movement for short distances. Long-distance hauls, according to the model, are performed by barges. Thus, barges and trucks are highly complementary to each other for the movement of chemicals within the purview of the specified geographic area.

As barge rates continue to rise parametrically, the volume of chemicals moving by barge decreases and is transferred to truck, and then further to rail. Redistribution is not only confined to intermodal transfers, but also applies to quantity rearrangements among the various water routes. Where prior to the relaxation of capacity constraints activity 113, Beaumont/Port Arthur to New Orleans by barge, was handling 242,000 tons, this activity is now eliminated. Instead this tonnage has been redistributed among the other routes.

The changing allocation scheme, as barge prices rise while rail and truck capacities are unconstrained, may be viewed in Table 14.

Interpretation of Table 14 should become clear by way of an example. Activity 433, movement between New Orleans and Corpus Christi by barge, recommends that 160,000 tons of chemicals be moved at $7.25 per ton. As this $7.25 price level increased to $20.79, the tonnage moved by this route rose to 713,000 tons, and remained at that level up to a barge rate of $39.29. At this point, barge traffic over the particular route ceased. At first glance, the rise in volume when price increased would seem strange. But while volume may have risen for activity 433, other activities including 243, 313, 343, and 423, all serviced by barge, actually had declined. Overall, the total volume moved by barge had diminished as barge rates had increased. Naturally, the reduced volume moved by barges was absorbed immediately; first, by truck, and at the more extreme barge rate levels, rail carriers also shared in the gains.

Likewise, Table 15 presents a comparable analysis of volume redistributions among transportation modes as truck rates increase parametrically leaving barge capacity unrestricted.

TABLE 14

SUMMARY OF SOLUTIONS TO PARAMETRIC CHANGES OF BARGE RATE WHILE RAIL AND TRUCK CAPACITIES ARE UNCONSTRAINED

ACTIVITY	OBJ + 0 CHROW 1		OBJ + 12.81 CHROW 1		OBJ + 14.85 CHROW 1		OBJ + 19.82 CHROW 1		OBJ + 31.31 CHROW 1		OBJ + 35.33 CHROW 1	
	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)
x411									41.60	137,000	41.60	137,000
x511											41.60	137,000
x112							22.40	61,000	22.40	0*		
x142	12.20	869,000	12.20	869,000	12.20	869,000	12.20	808,000*	12.20	869,000*	12.20	869,000
x242					17.60	652,000	17.60	713,000	17.60	713,000	17.60	713,000
x312									28.60	460,000	28.60	460,000
x332	12.20	779,000	12.20	1,332,000*	12.20	1,393,000*	12.20	1,393,000	12.20	619,000*	12.20	619,000
x342									17.60	713,000	17.60	713,000
x422									22.40	774,000	22.40	774,000
x442									28.60	210,000	28.60	210,000
x213					22.83	61,000	27.80	0*	39.29	0		
x243	2.50	713,000	15.56	713,000	17.60	0*	22.57	0	34.06	0		
x313	5.15	460,000	18.48	460,000	20.50	399,000*	25.49	399,000	36.98	0*		
x343	2.50	553,000	15.56	0*	17.60	0	22.57	0	34.06	0		
x413	9.35	137,000	23.10	137,000	25.14	137,000	30.11	137,000	41.60	0*		
x423	4.20	614,000	17.43	61,000*	19.47	0*	24.44	0	35.93	0		
x433	7.25	160,000	20.79	713,000*	22.83	713,000	27.80	713,000	39.29	0*		
x443	5.10	210,000	18.48	210,000	20.52	271,000*	25.49	271,000	36.98	0*		
x513	5.70	137,000	19.08	137,000	21.12	137,000	26.09	137,000	37.58	137,000		

*Signifies changing activity levels.

SOURCE: Industrial Economics Research Division, Texas Engineering Experiment Station, Texas A&M University.

TABLE 15

SUMMARY OF SOLUTIONS TO PARAMETRIC CHANGES IN TRUCK RATES
WHILE BARGE AND RAIL CAPACITIES ARE UNCONSTRAINED

	OBJ + 0 CHROW 1		OBJ + .65 CHROW 1		OBJ + .75 CHROW 1		OBJ + .99 CHROW 1		OBJ + 2.38 CHROW 1		OBJ + 2.81 CHROW 1		OBJ + 4.77 CHRO	
	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)
x242	17.6	0	2.41	713,000	2.51	713,000	2.75	0*	4.14	0				
x312	28.6	0	3.51	460,000	3.61	460,000	3.85	460,000	5.24	0				
x332	12.2	0	1.87	0*	1.97	0	2.21	0	3.60	0				
x342	17.6	0	2.41	713,000	2.51	713,000	2.75	0*	4.14	0				
x412	55.2	0	6.17	137,000	6.27	137,000	6.51	137,000	7.9	137,000	8.33	137,000		
x422	22.4	0	2.89	774,000	2.99	774,000	3.23	774,000	4.62	0*	5.05	0		
x442	28.6	0	3.51	210,000	3.61	210,000	3.85	210,000	5.24	670,000	5.67	0*		
x512	55.2	0	6.17	137,000	6.27	0*	6.51	0	7.90	0				
x113									4.62	460,000	4.62	0*		
x143	1.7	869,000	1.87	869,000	1.87	869,000	1.87	869,000	1.87	409,000*	1.87	869,000*	1.87	869,000
x243	2.5	713,000					2.75	713,000	2.75	713,000	2.75	713,000	2.75	713,000
x313	5.15	460,000									5.67	460,000	5.67	460,000
x333	1.70	619,000	1.87	619,000	1.87	619,000	1.87	619,000	1.87	1,079,000*	1.87	619,000	1.87	619,000
x343	2.50	713,000					2.75	713,000	2.75	713,000	2.75	713,000	2.75	713,000
x413	9.35	137,000											10.29	137,000
x423	4.20	774,000							4.62	314,000	4.62	774,000*	4.62	774,000
x443	5.15	210,000									5.67	210,000	5.67	210,000
x513	5.70	137,000			6.27	137,000	6.27	137,000	6.27	137,000	6.27	137,000	6.27	137,000

*Signifies changing activity levels.

SOURCE: Industrial Economics Research Division, Texas Engineering Experiment Station, Texas A&M University.

During this parametric routine, the marginal value products changed as actual prices varied. Although only barge prices were allowed to vary, the marginal value product for the remaining two modes was also affected.

Reflecting back on the derivation of the marginal value product (MVP = MPP x Price), it becomes clear that the MVP must vary proportionately with changes in price. In terms of the change in MVP for truck and rail services, the underlying reason is not so obvious.

Theory would imply that when the price of barge transportation increases, the tendency to substitute into a cheaper alternative mode of transportation arises. Thus, the penalty cost for using an alternate mode would logically diminish. A penalty cost is the extra cost incurred from following other than optimal plan of distribution. The model supports this thesis. As barge prices rise, the marginal value product for rail and truck services is reduced. The larger the price increase in barge transportation, the larger the penalty cost for using barges, but the less is the penalty cost for utilizing rail or truck carriers. Table 16 gives an insight into the reaction of transportation charges in response to continuous increases in barge capacity, while truck and rail capacities are fixed at some level above the minimum level required to move the total volume. As barge capacities increase, the marginal value product per ton of cargo moved by barge decreases. This relationship between quantity and marginal value product represents the derived demand curve for barge transportation services. While the demand for barge services develops, and as barge capacity rises, the demand for truck service becomes perfectly inelastic. In other words, the volume of chemicals moved by truck remains the same, even though its marginal value product diminished sequentially from 5.8 to 5.6, and to 4.1. Marginal value product for rail transportation, on the other hand, appears to rise for certain activities as barge capacity expands. It stands to reason that as the cheaper mode becomes available in greater quantities, volume should be shifted over to that mode. At the same time, the cost for using one additional unit of rail space (the more expensive mode) increases with expansion of the less expensive barge capacity. Logically as a cheaper mode becomes available in greater quantities, volume would shift over to that mode. At the same time, the cost for using one additional unit of rail space (the more expensive mode) increases with expansion of the less expensive barge capacity. That is, the marginal value product, or shadow force, for assorted rail activities rises as the cheaper barge service is introduced.

TABLE 16

SUMMARY OF SOLUTIONS TO PARAMETRIC INCREASES IN BARGE CAPACITY

	RH1 + 0 RH5		RH1 + 1.0 RH5		RH1 + 4.0 RH5		RH1 + 5.0 RH5		RH1 + 7.0 RH5		RH1 + 10.0 RH5	
	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)	QUANTITY (TONS)	PRICE ($)
Rail Cap.	3,029,743	0	2,731,343	0	1,836,143	0	1,537,743	0	940,943	0	45,743	0
Truck Cap.	1,602,157	5.8	1,602,157	5.8	1,602,157	5.6*	1,602,157	4.1*	1,602,157	4.1	1,602,157	4.1
Barge Cap.	100	35.9*	298,500	28.05*	1,193,700	27.65*	1,492,100	24.65*	2,088,900	19.2*	2,984,100	16.85*

*Signifies changing activity levels.

SOURCE: Industrial Economics Research Division, Texas Engineering Experiment Station, Texas A&M University.

It is not surprising to find that the total volume of chemicals would necessarily be transported by barge if no capacity restrictions existed on any mode. The model, in this case, simply assigns a given volume to the lowest cost carrier. However, if cost of barge transportation increases, an eventual shift to both truck and rail would occur. Eventually, at a barge rate of $35.00 above the original rate, barge movement would be completely eliminated.

Obviously the upper extremes of something like a $35.00 multiple of the initial rate increase is unrealistic. But at the lower extreme of price increases, some important conclusions can be drawn.

The first procedure with the assumption of fixed modal capacity limits revealed that not until the price was raised to a level equal to $16.85 above the original price level did a reallocation of goods among modes and routes occur. Transportation prices are, therefore, relatively stable over considerable quantity ranges. It logically follows from this model and its stated assumptions, that any barge rate increase below $16.85 would have no visible effect on the existing shares of the total cargo traffic enjoyed by rail, truck, or barge carriers.

With truck capacity free to expand, Figure 3 demonstrates the responsiveness of truck capacity availability as barge rates increase. Cross-elasticity, a measurement commonly used to describe such cross effects, estimates the change in tonnage moved by truck as the price of rail service rises. According to Figure 3,

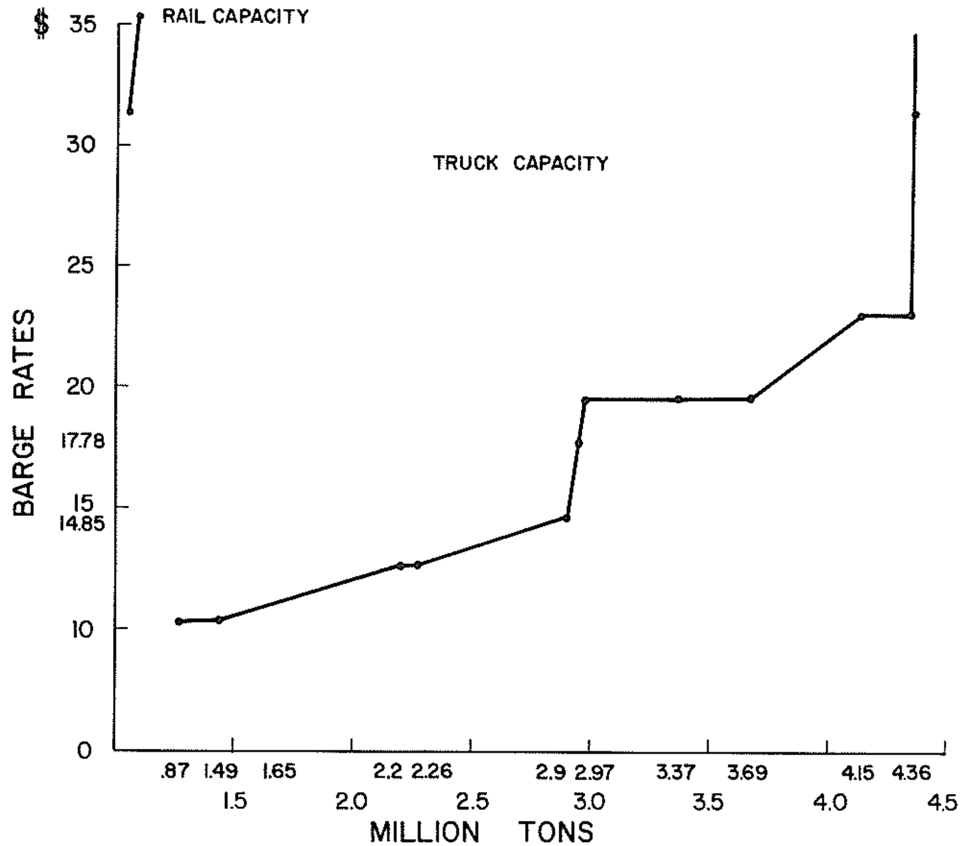

FIGURE 3

AVAILABLE TRUCK CAPACITY IN RESPONSE TO BARGE RATE INCREASES such a transfer of tonnages from barge to truck does not occur until barge rates have increased by $10.33. At this point, the volume moved by truck increases from 570,000 tons to 869,000 tons. Over the price range of $10.33 to $14.85, a sizable shift in volume from barge to truck occurs up to 1.41 million tons. Thus, the cross price elasticity over this range is 2.16. Another relative eleastic plateau is observed in the $19.82 to $22.93 interval, at which point truck capacity becomes almost fixed.

The most important implication from the cross-elasticity measurement is the fact that the shipping price by barge must be raised substantially before any type of quantity reallocation comes about. Consequently, based on this model, imposition of user charges on barge operations will undoubtedly raise the transportation price, but not by a magnitude such as to cause barge business to be diverted to other modes.

Quantity transfers from barge to rail occur only at relatively high barge rates. In fact, such barge-rail shifts take place when barge rates reach the $31.31 level. Again it is emphasized that these results are based on the assumptions of unlimited modal capacity and freedom of transfer of quantities among modes in accordance with specified price changes.

A similar curve is constructed for barge transportation in response to changes in truck rates. Figure 4 shows the supply of barge space to be highly responsive to even minor variations in truck rates. A 52 percent increase in truck rates, for example, causes a 251 percent rise in the quantity of chemicals being carried by barge. Past this level, the curve became more elastic until finally at a truck rate of $4.77, the total volume of chemicals will be carried by barge, assuming that barge capacity is unlimited.

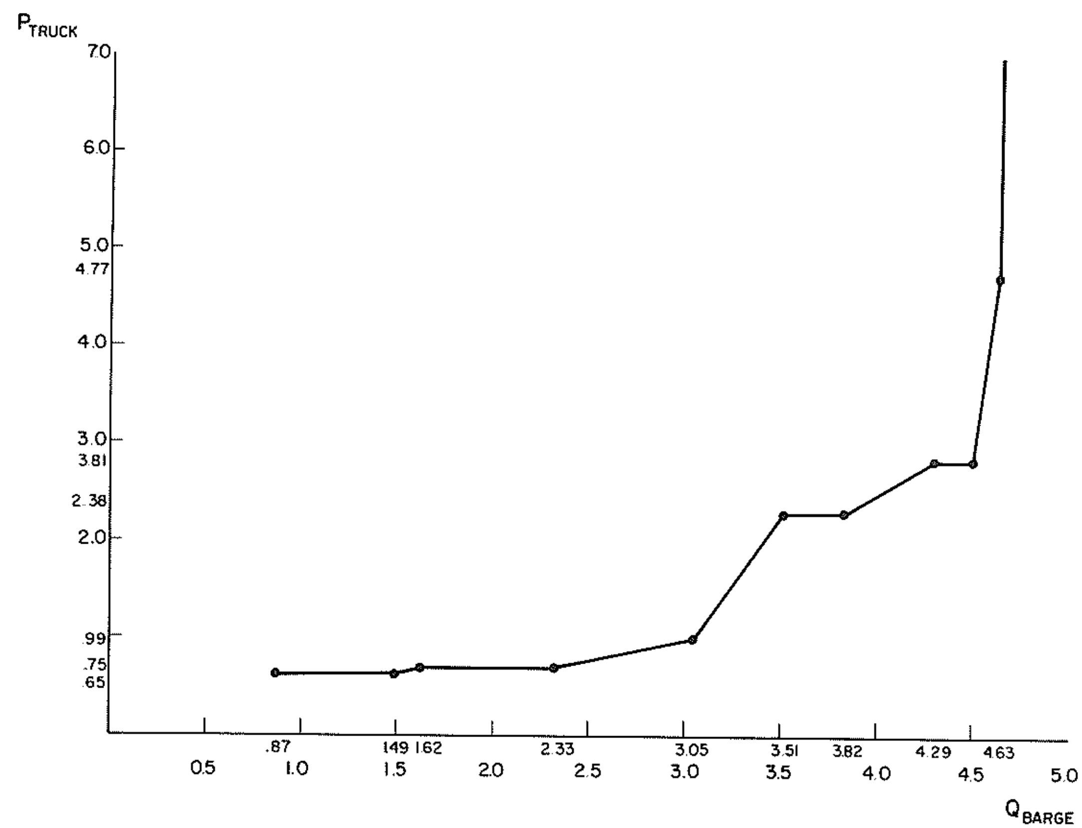

FIGURE 4

BARGE CAPACITY RESPONSE TO
CHANGING TRUCK RATES

Truck operators should, therefore, be careful with regard to their pricing policies to prevent such a possible quantity transfer to barge carriers.

Procedure 2: Estimation of demand responsiveness.

This procedure estimates changes in shadow prices in response to changes in the quantity of resources available. In terms of transportation, the responsiveness of transportation changes are scrutinized as the availability of storage space for each transportation mode varies.

A mere increase of available storage space in any of the three modes would naturally have no effect on the price charged for using an additional unit of space since the supply of chemicals has not increased. In other words, if no extra quantity is available for movement, then utilization of additional capacity becomes unnecessary. Although excess capacity does not alter prices, a transfer of quantities from rail to truck occurs while the value of goods moved by barge remains constant. Logically, as added capacity of the more efficient truck mode becomes available for shorter distances, customers will naturally shift to the less expensive carrier.

In order to derive a demand curve for barge transportation, the problem was temporarily set up in a way to permit only rail and truck carriers to move the entire 4.632 million ton volume of chemicals among the five cities, while barge capacity was held at only 100 tons. Then barge storage availability was parametrically increased up to a 2.98 million ton capability. During this process, the change in prices was observed and plotted in Figure 5.

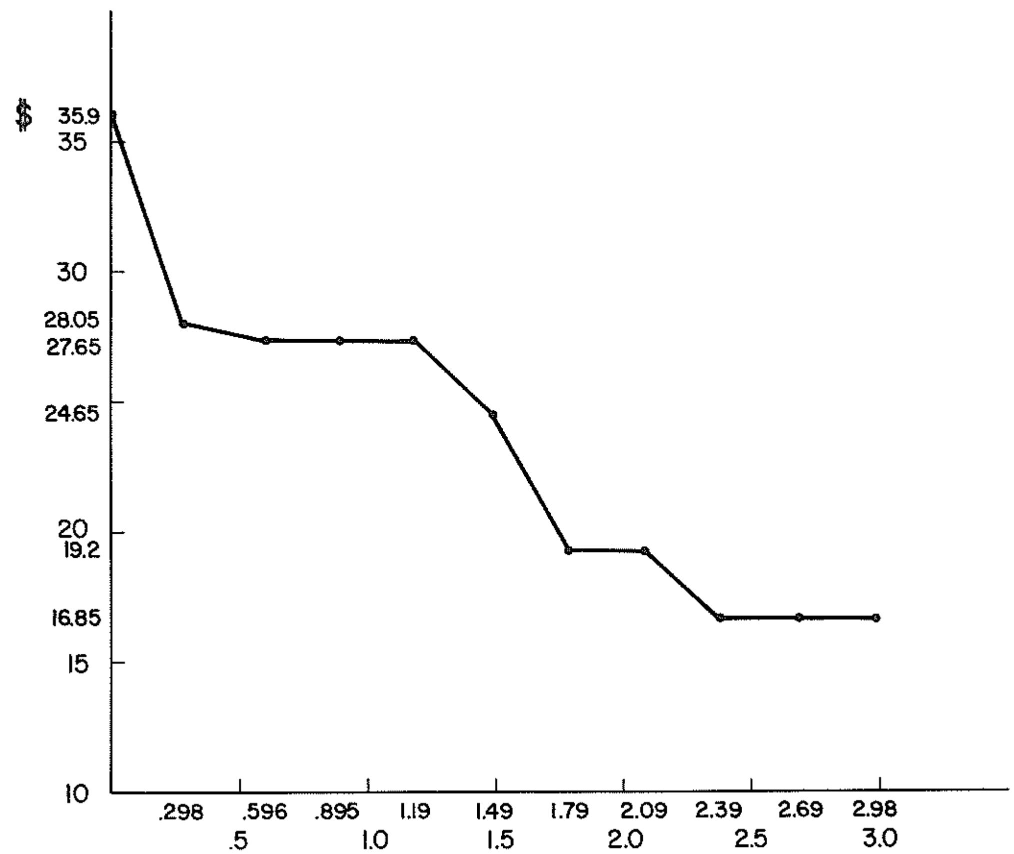

FIGURE 5

DEMAND FOR BARGE TRANSPORTATION

This demand curve then measures the price flexibility for barge transportation. That is, for any predetermined quantity level, the price for barge service can be estimated. Most noteworthy is the decrease in cost from \$27.65 to \$19.20 as volume rises from 1.19 million tons to 1.79 million tons, which is equivalent to a price flexibility of 0.87. The ratio of 0.87 simply says that as quantity changes by one percent, price will change by .87.[15]

Transfer to rail carriers occurs only when barge rates climb to relatively high levels in excess of \$31.31. Thus, under the assumption of the model where the time element is not considered, rail transportation would be utilized minimally.

Admittedly, as time considerations are introduced, the choice or the trade off between barge and rail use will become a function of both cost and time. Yet, it may be argued that if travel duration along any route is known for any mode, efficient firms should be able to incorporate the required travel time into their corresponding plans.

When capacity is limited, all modes are utilized in accordance to a scheme which will minimize total transportation cost. It was revealed,

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[15]Price flexibility should not be confused with price elasticity. The former estimates the change in price as quantity is altered by a predetermined amount. Price elasticity, on the other hand, measures the change in price. These two measures are simply reciprocals of each other, or when the price flexibility is 0.87, then price elasticity equals to 1/0.87 = 1.15. Decision on which of the two measurements to use depends on whether quantity or price is determined exogenously or outside the model.

however, that if modal capacities were free to adjust by relaxing some of the restrictions, barge and truck carriers would be moving the bulk of the total shipment.

CONCLUSIONS AND RECOMMENDATIONS

According to the LP model with its stipulated assumptions, the present distribution of chemicals, fuel and lubricants, and primary iron and steel products appears to be inefficient. Inefficient in the context of this study refers to the overly costly mechanism by which a given volume of commodities is distributed among five cities by three transportation means. Each of the five cities is serviced by railroads, trucks, and barge carriers.

Some of the inherent assumptions postulated initially tend to simplify real world conditions. Consequently, the quoted cost savings between the existing distribution network and the one proposed by the model are overstated. Yet the results are not overstated to the extent that the obvious implications for future attention and research into this problem can be neglected.

A similar study incorporating more relevant assumptions should be conducted. The time element is certainly a relevant element to be considered. The problem becomes more involved and relevant in the case where a customer requires a given volume of goods to be shipped within a specified time frame, yet will want costs to be minimized. Still, the carrying capacity by the various modes is limited. This may require goods to be transshipped from one mode onto another while en route.

Since the complementarity and/or substitutability between transportation modes has been established, further attention must be given to their interactions. It was pointed out, for example, that slight variations in the pricing policy exercised by truckers may significantly affect not only their own operations, but also the operations of barge and rail carriers.

Another worthwhile effort should be directed to an analysis of the pricing mechanism. What criteria or what elements do operators consider in determining their respective prices? How do certain market forces or general economic fluctuations affect the competitiveness of the transportation market? For instance, has inflation affected all transportation modes equally? Would a ten percent increase in fuel costs affect the different carrier modes equally? How would deregulation of the transportation industry as a whole affect operations within the study area in question?

To answer these relevant questions which are of immediate concern not only to shippers but to consumers as well, the model described here must be expanded considerably, and more detailed knowledge of the industry and its participants must be gained. In the final analysis, as some of these questions are answered, average transportation costs should diminish, services to the consumer should improve, while the nation can make a significant stride towards fuel conservation.

APPENDIX

TABLE 1

CURRENT DISTRIBUTION COSTS
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS						
NEW ORLEANS	$ 512.0	$	$1,010.0	$1,392.0	$ 331.2	$3,245.2
BEAUMONT/ PORT ARTHUR	545.2	296.4		533.6	181.9	1,557.1
HOUSTON	1,454.4	750.4	653.2		248.0	3,106.0
CORPUS CHRISTI	72.6	24.9				97.5
REVENUES RECEIVED	2,584.2	1,071.7	1,663.2	1,925.6	761.1	8,005.8

PRODUCT Fuel and Lubricants

MODE Rail

TABLE 2

CURRENT DISTRIBUTION COSTS
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS						
NEW ORLEANS	$ 38.4	$	$ 86.0	$ 697.6	$ 164.0	$ 986.0
BEAUMONT/ PORT ARTHUR	86.2	670.8		3,041.5	937.2	4,735.7
HOUSTON	87.6	915.6	546.7		803.0	2,352.9
CORPUS CHRISTI		163.0	113.6	517.0		793.6
REVENUES RECEIVED	212.2	1,749.4	746.3	4,256.1	1,904.2	8,868.2

PRODUCT Fuel and Lubricants

MODE Truck

TABLE 3

CURRENT DISTRIBUTION COSTS
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORATION COSTS
ST. LOUIS						
NEW ORLEANS	$2,425.20	$	$1,503.84	$2,134.35	$ 144.00	$6,207.39
BEAUMONT/ PORT ARTHUR	2,248.48	2,104.96		625.60	275.40	5,254.44
HOUSTON	1,689.90	3,200.25	362.10		501.25	5,753.50
CORPUS CHRISTI	1,384.50	586.80	1,800.05	936.25		4,707.60
REVENUES RECEIVED	7,748.08	5,892.01	3,665.99	3,696.20	920.65	21,922.93

PRODUCT Fuel and Lubricants

MODE Barge

TABLE 4

CURRENT TONNAGE DISTRIBUTION
(TONNAGES 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	AMOUNT SHIPPED
ST. LOUIS		0	0	0	0	0
NEW ORLEANS	32		101	116	23	272
BEAUMONT/ PORT ARTHUR	29	26		116	17	188
HOUSTON	72	56	142		31	301
CORPUS CHRISTI	3	15	0	0		18
AMOUNT RECEIVED	136	97	243	232	71	779

PRODUCT Fuel and Lubricants

MODE Rail

TABLE 5

CURRENT TONNAGE DISTRIBUTION

(TONNAGES 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	AMOUNT SHIPPED
ST. LOUIS		0	0	0	0	0
NEW ORLEANS	1		5	32	5	43
BEAUMONT/ PORT ARTHUR	2	39		395	66	502
HOUSTON	2	42	71		73	188
CORPUS CHRISTI	0	5	8	47		60
AMOUNT RECEIVED	5	86	84	474	144	793

PRODUCT Fuel and Lubricants

MODE Truck

TABLE 6

CURRENT TONNAGE DISTRIBUTION
(TONNAGES 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	AMOUNT SHIPPED
ST. LOUIS		0	0	0	0	0
NEW ORLEANS	516		723	837	40	2,116
BEAUMONT/ PORT ARTHUR	376	1,012		736	153	2,277
HOUSTON	262	1,255	426		401	2,344
CORPUS CHRISTI	195	163	973	749		2,080
AMOUNT RECEIVED	1,349	2,430	2,122	2,322	594	8,817

PRODUCT Fuel and Lubricants

MODE Barge

TABLE 7

CURRENT DISTRIBUTION SCHEME FOR IRON AND STEEL
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS		$23.2/ton 20,000 ton $464,000	$23.8/ton 23,000 ton $547,000	$24.8/ton 10,000 ton $248,000		53,000 tons $1,259,000
NEW ORLEANS				$14.2/ton 6,000 ton $85,200		6,000 tons $85,200
BEAUMONT/ PORT ARTHUR		$11.8/ton 21,000 ton $247,800		$6.4/ton 10,000 ton $640,000		31,000 tons $887,800
HOUSTON		$14.2/ton 55,000 ton $781,000	$6.4/ton 124,000 ton $793,600		$9.6/ton 3,000 ton $28,800	
CORPUS CHRISTI		$19.6/ton 4,000 ton $78,400				4,000 tons $78,400
REVENUES RECEIVED		100,000 ton $1,571,200	147,000 ton $1,340,600	26,000 ton $973,200	3,000 ton $28,800	276,000 tons $3,913,800

PRODUCT Iron and Steel

MODE Rail

TABLE 8

CURRENT DISTRIBUTION SCHEME FOR IRON AND STEEL
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS		$32.6/ton 5,000 ton $163,000		$36.8/ton 3,000 ton $110,400		8,000 tons $273,000
NEW ORLEANS						
BEAUMONT/ PORT ARTHUR						
HOUSTON	$36.8/ton 6,000 ton $220,800	$19.2/ton 32,000 ton $614,400	$7.1/ton 12,000 ton $85,200		$10.0/ton 3,000 ton $30,000	53,000 tons $940,400
CORPUS CHRISTI		$29.6/ton 1,000 ton $29,600		$10.0/ton 3,000 ton $30,000		4,000 tons 59,600
REVENUES RECEIVED	6,000 ton $220,800	38,000 ton $807,000	12,000 ton $85,200	6,000 ton $140,400	3,000 ton $30,000	65,000 tons $1,283,400

PRODUCT Iron and Steel

MODE Truck

TABLE 9

CURRENT DISTRIBUTION SCHEME FOR IRON AND STEEL

(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS		$7.93/ton 107,000 ton $848,510		$9.82/ton 26,000 ton $255,520	$14.91/ton 1,000 ton $14,910	134,000 tons $1,118,740
NEW ORLEANS	$9.82/ton 134,000 ton $1,315,800		$7.08/ton 9,000 ton $63,720	$0.96/ton 137,000 ton $131,520	$9.07/ton 2,000 ton $18,140	282,000 tons $1,529,180
BEAUMONT/ PORT ARTHUR		$7.08/ton 8,000 ton $56,640				8,000 tons $56,640
HOUSTON	$11.63/ton 5,000 ton $58,150	$4.76/ton 116,000 ton $552,160	$3.69/ton 15,000 ton $55,350		$7.02/ton 1,000 ton $7,020	137,000 tons $672,680
CORPUS CHRISTI		$9.07/ton 4,000 ton $36,280		$7.02/ton 1,000 ton $7,020		5,000 tons $43,300
REVENUES RECEIVED	139,000 ton $1,373,590	235,000 ton $1,493,590	24,000 ton $119,070	164,000 ton $393,860	4,000 ton $40,070	566,000 tons $3,420,540

PRODUCT Iron and Steel

MODE Barge

TABLE 10

OPTIMAL DISTRIBUTION SCHEME FOR IRON AND STEEL
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS						
NEW ORLEANS				$14.20/ton 95,000 ton $1,349,000		95,000 tons $1,349,000
BEAUMONT/ PORT ARTHUR				$6.40/ton 40,000 ton $256,000		40,000 tons $256,000
HOUSTON			$6.40/ton 141,000 ton $902,400			141,000 tons $902,400
CORPUS CHRISTI						
REVENUES RECEIVED			141,000 ton $902,400	135,000 ton $1,605,000		276,000 tons $2,507,400

PRODUCT Iron and Steel

MODE Rail

TABLE 11

OPTIMAL DISTRIBUTION SCHEME FOR IRON AND STEEL
(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS						
NEW ORLEANS						
BEAUMONT/ PORT ARTHUR						
HOUSTON			\$7.10/ton 42,000 ton \$298,200		\$10.00/ton 10,000 ton \$100,000	52,000 tons \$398,200
CORPUS CHRISTI				\$10.0/ton 13,000 ton \$130,000		13,000 tons \$130,000
REVENUES RECEIVED			42,000 ton \$298,200	13,000 ton \$130,000	10,000 ton \$100,000	65,000 tons \$528,200

PRODUCT Iron and Steel

MODE Truck

TABLE 12

OPTIMAL DISTRIBUTION SCHEME FOR IRON AND STEEL

(DOLLARS 1,000)

DESTINATION / ORIGIN	ST. LOUIS	NEW ORLEANS	BEAUMONT/ PORT ARTHUR	HOUSTON	CORPUS CHRISTI	TOTAL TRANSPORTATION COSTS
ST. LOUIS		$7.93/ton 195,000 ton $1,546,350				195,000 tons $1,546,350
NEW ORLEANS	$9.82/ton 145,000 ton $1,423,900			$7.08/ton 48,000 ton $339,840		193,000 tons $1,763,740
BEAUMONT/ PORT ARTHUR						
HOUSTON		$4.76/ton 178,000 ton $847,280				178,000 tons $847,280
CORPUS CHRISTI						
REVENUES RECEIVED	145,000 ton $1,423,900	373,000 ton $2,393,630		48,000 ton $339,840		566,000 tons $4,157,370

PRODUCT Iron and Steel

MODE Barge

TABLE 13

DESTINATION NAMES

RAIL				
x111	-	Beaumont/Port Arthur	to	New Orleans
x121	-	"	"	St. Louis
x131	-	"	"	Corpus Christi
x141	-	"	"	Houston
x211	-	Corpus Christi	to	New Orleans
x221	-	"	"	St. Louis
x231	-	"	"	Beaumont/Port Arthur
x241	-	"	"	Houston
x311	-	Houston	to	New Orleans
x321	-	"	"	St. Louis
x331	-	"	"	Beaumont/Port Arthur
x341	-	"	"	Corpus Christi
x411	-	New Orleans	to	St. Louis
x421	-	"	"	Beaumont/Port Arthur
x431	-	"	"	Corpus Christi
x441	-	"	"	Houston
x511	-	St. Louis	to	New Orleans
x521	-	"	"	Beaumont/Port Arthur
x531	-	"	"	Corpus Christi
x541	-	"	"	Houston

X_{ijk} - i - source
j - destination
k - mode

TABLE 14

DESTINATION NAMES

TRUCK				
x112	-	Beaumont/Port Arthur	to	New Orleans
x122	-	"		St. Louis
x132	-	"		Corpus Christi
x142	-	"		Houston
x212	-	Corpus Christi	to	New Orleans
x222	-	"		St. Louis
x232	-	"		Beaumont/Port Arthur
x242	-	"		Houston
x312	-	Houston	to	New Orleans
x322	-	"		St. Louis
x342	-	"		Corpus Christi
x412	-	New Orleans	to	St. Louis
x422	-	"		Beaumont/Port Arthur
x432	-	"		Corpus Christi
x442	-	"		Houston
x512	-	St. Louis	to	New Orleans
x522	-	"		Beaumont/Port Arthur
x532	-	"		Corpus Christi
x542	-	"		Houston

X_{ijk} - i - source
j - destination
k - mode

TABLE 15

DESTINATION NAMES

BARGE					
x113	-	Beaumont/Port Arthur	to	New Orleans
x123	-	"	"	St. Louis
x133	-	"	"	Corpus Christi
x143	-	"	"	Houston
x213	-	Corpus Christi	to	New Orleans
x223	-	"	"	St. Louis
x233	-	"	"	Beaumont/Port Arthur
x243	-	"	"	Houston
x313	-	Houston	to	New Orleans
x323	-	"	"	St. Louis
x333	-	"	"	Beaumont/Port Arthur
x343	-	"	"	Corpus Christi
x413	-	New Orleans	to	St. Louis
x423	-	"	"	Beaumont/Port Arthur
x433	-	"	"	Corpus Christi
x443	-	"	"	Houston
x513	-	St. Louis	to	New Orleans
x523	-	"	"	Beaumont/Port Arthur
x533	-	"	"	Corpus Christi
x543	-	"	"	Houston

X_{ijk} - i - source
j - destination
k - mode

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