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Freight Movement and Demand

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Abridgment

Linear Systems Model of Freight Demand Within a Comprehensive Planning Approach

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The problems of urban freight transportation today can be identified as follows: (a) poor analytic concepts and lack of a methodological framework; (b) increasing proprietary ownership of private trucks and the lack of coordination or cooperation among carriers, shippers, and receivers; (c) increasing and continuous freight transportation demand with strong temporal and spatial preference for small shipments; (d) neglect of planners and public officials in providing and managing freight transportation facilities; and (e) lack of public policy on urban goods movements. The purpose of this paper is to develop a new methodology for urban goods movement studies.

STRATEGY FOR URBAN GOODS MOVEMENT STUDIES

The conventional freight urban transportation planning (UTP) process has been characterized by the exclusive use of the truck trip as the unit of analysis. This convention has allowed the freight study to proceed in close analogy with the standard UTP process, neglecting the cause-effect hypothesis in demand models. Recently, the analyst's attention has been directed toward the development of an urban goods movement study approach (1,2,3). So far, however, no specific and explicit model has been developed in this area that is readily applicable to the freight UTP process.

Problems involved in the conventional approach will be reviewed briefly. First, the indiscriminate use of friction factors for the truck trip distribution, a standard procedure in the UTP process, has been inadequate. Subsequent studies have attempted to stratify the truck trips themselves for the purpose of deriving a distribution (4). Second, the traditional gravity-type trip distribution rationale has questionable validity when applied to multistop vehicle movements. Third, the usefulness of the regression method for truck trip-generation analysis is severely limited, not only on a regional basis but also on a selected area basis. The general regression method on a regional basis would be far less valid than that on a selected area basis because of the large between-zone variation of unincluded important variables. Finally, a recent attempt to attack the problem through the urban goods movement approach shows almost the same shortcomings as does the standard method. As a measurement technique, the carrier-oriented freight survey cannot provide sufficiently reliable data on urban goods movements to serve the needs of the urban goods movement study (5). Moreover, the results of a carrier-oriented survey tend to be severely limited for freight demand analysis because mode choice in goods movement, coupled with double-counting by modal interface, may significantly mislead the analyst (6). The only way to solve this problem is to get freight information directly from the shippers or consignees.

It is argued that economies can be achieved by combining the freight UTP process with other studies. This paper, therefore, concentrates on developing a freight UTP process within a combined regional planning framework. The basic inputs for the proposed process can be provided by regional social accounting studies and truck traffic surveys. The latter are comparable in basic design to those in the Tri-State Study (7).

OBJECTIVES AND SCOPE OF FREIGHT UTP PROCESS

The rather superficial treatment of freight UTP to date conflicts with the goal of developing the study of urban transportation as a branch of science. Both for the direct relationship of freight movement with economic and business activity and for the strategy of the planning process, the objective of freight demand analysis need not be limited to a transportation facilities plan.

Forecasts must be made of commodity movements as well as of the movements of vehicles hauling the commodities, i.e., their relation to regional development (8). Goss also identifies four major categories for urban goods movement study areas:

1. Regional goods movement,
2. Area or subregional goods movement,
3. Facility goods movement, and
4. Waste goods movement.

For the purpose of the urban transportation planning process, it is necessary to define the scope of an urban freight transportation study so that it is complementary to that of a passenger transportation study and a total transportation facilities plan (1). Freight flow can be classified broadly according to fundamental motives of flow and direct channels of shipment.

Classification by motive or purpose for commodity flows is necessary to enable the development of demand analysis that conforms to economic theory through the social accounting system. Commodities flow for the purpose of capital formation, consumption, or disposal at an ultimate destination (9).

SOCIAL ACCOUNTING SYSTEMS APPROACH

The adoption of the commodity classification of the social accounting system seems necessary. It is a prerequisite not only for regional economic and business analysis but also for freight analysis. It seems to be impracticable or uneconomical to establish a single homogeneous classification scheme of commodities, given the multiple aspects of physical and economic characteristics of goods and the behavioral characteristics of shippers and consignees (10).

The idea of multiple classification in a social accounting system, originally proposed by Stone (11) and recently adopted by the United Nations Statistical Commission, seems to be extremely useful for freight demand analysis. One procedure developed to interconnect the multiple classification systems with the linear systems model is described here.

Tables 1-3 show how multiple classifications could effectively be used in freight transportation analysis in line with the social accounting system. According to any specific attribute desired, such as

Table 1. Commodity flow coefficient matrixes.

	Consuming Establishment		Distributing Establishment		
Commodity	Intermediate[a]	Final[b]	Warehouse[c]	Wholesaler With Stock[d]	Retailer[d]
1					
.					
.					
i			M_a	M_w	M_r
.					
.					
m					
Total	q'	y^*	s'_a	s'_w	s'_r

Notes: M = merchandise goods flow matrixes in monetary terms; s = M' u: column vector of sales; ' = transpose throughout this study unless otherwise specified; u = unit column vector throughout this study unless otherwise specified; q = column vector of outputs by industry of commodity; $y^* = Y'u$: column vector of categorized final demand.

[a] By industry classification.
[b] By category of final consumer.
[c] By type of equipment for warehousing.
[d] By kind of business classifications.

Table 2. Commodity-industry flow matrixes.

	To			
From	Industry	Commodity	Final Consumer	Total
Industry	X_{dd}	X_{dc}	Y_d	q_d
Commodity	X_{cd}	X_{cc}	Y_c	q_c
Final consumer	z'_d	z'_c	0	y^*

Notes: X = matrixes of product flows in monetary terms; Y = matrixes of final demand either by industry or commodity and by category; z = column vector of primary inputs into industries or commodities; and $y = Y_d\,u$.

Table 3. Commodity-industry input coefficient matrixes.

		To		
		Industry	Commodity	Final Consumer
From		1 . . . d	1 . . . c	1 . . . f
Industry	1 . . d	0	A_{dc}	0
Commodity	1 . . c	A_{cd}	0	F_c

physical or chemical state of commodities (e.g., liquid, gaseous, bulky), the incidence matrix can be defined in terms of elements that are either zero or unity according to the proper attribute or in terms of shares of the total, if the commodity itself is aggregated. Thus, they can be combined with each other for integration, whenever necessary.

Table 2 describes how the freight demand analysis could proceed under the social accounting scheme for intermediate and final consumption establishments by combining the classification schemes for industry and commodity. Using the industry outputs (q_d), the commodity outputs (q_c), and the consumer expenditures by category (y^*), the input coefficient matrixes (see Table 3) can be defined by Equations 1 through 5. [Throughout this paper, capital letters refer to matrixes; lower-case letters refer to vectors; hatted letters refer to diagonal matrixes obtained from vectors; -1 equals inverse, otherwise specified; I equals identity matrix.]

$$A_{dc} = X_{dc}\hat{q}_c^{-1} \tag{1}$$

$$A_{cd} = X_{cd}\hat{q}_d^{-1} \tag{2}$$

$$F_c = Y_c\hat{y}^{*-1} \tag{3}$$

By definition,

$$q_d = A_{dc}q_c \tag{4}$$

From accounting properties,

$$q_c = A_{cd}q_d + Y_c u \tag{5}$$

$$q_c = A_{cd}A_{dc}q_c + Y_c u \tag{6}$$

$$q_c = (I - A_{cd}A_{dc})^{-1}\,Y_c u \tag{7}$$

Therefore,

$$q_d = A_{dc}(I - A_{cd}A_{dc})^{-1}\,Y_c u \tag{8}$$

$$q_d = (I - A_{dc}A_{cd})^{-1}\,A_{dc}Y_c u \tag{9}$$

$$q_d = (I - A_{dc}A_{cd})^{-1}\,A_{dc}F_c y^* \tag{10}$$

which gives q_c or q_d in terms of y^* with a matrix multiplier of order equal to the number of commodities or the number of industries. The procedures are valid whether matrixes A_{dc} and A_{cd} are square or rectangular. The number of commodities (size of commodity classification) is most likely much larger than that of industries (size of industry classification) in empirical studies.

The multiple classifications not only provide a unified scheme for production and consumption analysis with the input-output framework for regional economic and business analysis as such, but also directly relate the results with freight demand analysis by translating the monetary outputs into the physical quantities by commodities. This can be done by using the value-ratio matrix and then the commodity density matrix to determine the vehicle-loading capacities in terms of weight or volume as shown in Equations 11 and 12.

$$Q_i = \sum_{j}^{n} q_i s_{ij}/p_i \tag{11}$$

$$V_i = Q_i/d_i \tag{12}$$

where

Q_i = weight of the i^{th} commodity,
V_i = volume of the i^{th} commodity, and
q_i = products of commodity i in monetary terms.

The estimation of inbound freight at intermediate consumption establishments has to be made on the basis of commodity-to-commodity input coefficients rather than either on the commodity-to-industry input coefficients or on the industry-to-industry input coefficients. Thus, problems related to intraindustry commodity mix in establishing coefficients must be solved (5).

In summary, once the output commodities comprised of products and sales in monetary terms and thus activity intensity are projected on a zonal basis, the zonal input commodities and waste flow can be consistently estimated by the linear models as follows:

$$\hat{p}^{-1}\ g \rightarrow e \qquad (13)$$

$$\hat{e}\ \dot{E} \rightarrow E \qquad (14)$$

$$t'\,L \rightarrow v' \qquad (15)$$

$$\hat{v}\ \dot{V} \rightarrow V \qquad (16)$$

and

$$p'\dot{E}_g A_{dc} u \rightarrow q_g \qquad (17)$$

$$A_{cc} q_g \rightarrow r_g \qquad (18)$$

$$W_f a + W_d q_g \rightarrow d_g \quad \text{for } g = 1, \ldots, h \qquad (19)$$

$$C\,V_g \rightarrow Z_g \qquad (20)$$

where

a = number of households in zone g;
q_g = zonal output vector by commodity ($c \times 1$);
r_g = zonal input vector by commodity ($c \times 1$);
d_g = zonal waste vector by type ($v \times 1$);
z_g = zonal sales vector by commodity ($c \times 1$);
e = regional employment vector by industry ($a \times 1$);
v = regional sales vector by kind of business ($b \times 1$);
q = regional output vector by commodity ($c \times 1$);
t = regional sales vector by commodity ($c \times 1$);
$\dot{E}$ = employment share matrix ($s \times h$), i.e., E_{ig} is the proportion of zone g of the regional employment for industry i--$\sum_g [E_{ig} = 1$, for all $i]$;
$\dot{V}$ = sales share matrix ($b \times h$), i.e., V_{ig} is the proportion of zone g of regional sales by kind of business i--$\sum_g [V_{ig} = 1$, for all $i]$;
L, C = sales merchandise coefficient matrixes based on fixed-row and fixed-column assumption respectively ($c \times b$);
A_{dc}, A_{cc}, W_d, W_f = as shown in Table 2;
p = employment productivity vector ($s \times 1$); and
E_g, V_g = vectors made of g^{th} column of zonal employment matrix E ($s \times h$) and zonal sales matrix V ($b \times h$) respectively.

CONCLUSION

As an alternative to solving the problem involved in urban freight demand analysis, this study has discussed the linear systems model according to the social accounts approach and completely separate from the passenger travel demand model. At first glance, it would seem this alternative method would impose an enormous burden, but the magnitude of economies that can be achieved by combining the freight UTP processes with other studies within a comprehensive urban-regional planning process can be demonstrated (5).

In developing a methodology for the freight UTP process, this paper attempts to demonstrate that the basic freight UTP process may be designed within a combined comprehensive planning approach. The freight UTP process developed here is characterized by the spatial-general-equilibrium implementation of regional aggregate analysis, locational analysis for allocation of activities, and commodity (goods and services) and freight demand analysis.

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Abridgment

Urban Goods Consolidation Terminal Investment and Location Decisions

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The goods movement industry has become aware of significant diseconomies in the goods movement system, particularly for small shipments in urban areas (1,2). One reason for these diseconomies is that pickups and deliveries (P/Ds) made by any given truck in urban areas tend to be small in size and relatively few in number. Many trucks are used, but few of them utilize their full load capacity (3,4,5). Also, because these trucks are operated by a large number of independent freight carriers, extensive duplication in routing occurs.

In addition, external diseconomies are generated by the urban goods movement system. Inefficient truck utilization causes increased traffic congestion, air pollution, noise pollution, and energy consumption. Moreover, these environmental effects occur in the central business district (CBD) where environmental conditions are frequently at undesirable levels.

Goods movement planners have suggested that carriers organize and coordinate their activities in order to increase the efficiency of P/D operations and thereby reduce their urban operating costs. One means of achieving this coordination would be to route all small shipments—that is, those less than 453.6 kg (1000 lb)—going to or from the urban area through one or more consolidation terminals serving all carriers. Then P/Ds for all carriers can be consolidated to make effective use of vehicles. To eliminate overlapping routes the urban area would be divided into a number of P/D zones, each containing shippers and consignees; each zone would be assigned to a specific consolidation terminal for all small-shipment P/D operations. In addition, the consolidation terminals would operate trucks to deliver shipments to carrier terminals and to pick up shipments from the carriers destined for consignees in the urban area.

The benefits of a consolidation terminal can be determined by comparing the total terminal and P/D costs expected if one or more consolidation terminals were in operation with the total costs incurred by the present system. Terminal costs depend on the throughput volume through each terminal, the timing of capital expansion investment, the location of each terminal, and the terminal design or the material-handling system employed. Total P/D costs depend on the required number of truck trips, the distances trucks must travel, and the amount of time drivers must expend picking up and delivering goods at the shipper, carrier terminal, consignee, and consolidation terminal locations. In turn, these variables are directly related to the spatial and temporal distributions of demand for P/Ds. Moreover, P/D costs are related to the spatial relationships among consolidation terminals, carrier terminals, shippers, and consignees. These relationships are certainly dependent on the characteristics of the urban area served and the design of the consolidation terminal system. However, what is good for one urban area may not be desirable for another.

Consequently, this paper presents a model, called the Urban Terminal Investment Model (UTIM), that can be applied in diverse urban areas to evaluate the economic feasibility of the consolidation terminal concept and to determine the following preferred system design variables based on a least-cost criterion:

1. Number of terminals;
2. Terminal locations, e.g., sites selected;
3. Timing of terminal capacity investments; and
4. Terminal zone assignments.

Moreover, iterative application of UTIM for alternative variable sets will yield preferred values of these system design variables: limitation on shipment sizes consolidated and urban zonal boundaries.

Least cost is the basic criterion for selecting preferred system designs because the terminal system will not be implemented without economic benefits. Also, social benefits are directly correlated with economic benefits because the savings in truck utilization will result in reduced congestion, air and noise pollution, and energy consumption.

COMPARISON OF SINGLE- AND MULTIPLE-TERMINAL SYSTEMS

The structure of UTIM is dependent on whether multiple terminals offer potential cost savings over a single terminal. This is true because a single-terminal system can be located and analyzed by a relatively simple model; but situations permitting two or more terminals present a very large number of possible alternatives (e.g., location, terminal-zone assignments, and construction plans) that require a mathematical optimization model to determine the least-cost system design. Accordingly, a simple but representative system is analyzed to indicate the potential for two terminals instead of one.

Comparison of a single-terminal system with a two-terminal system is essentially a trade-off between terminal costs and truck travel costs. One terminal is cheaper to build than two; however, truck travel costs should be less for a properly located two-terminal system. The terminal costs should dominate for a small urban area, whereas the truck travel cost savings will make a two-terminal system more economical for a larger urban area. The interaction among these variables is analyzed using the system depicted in Figure 1 where the distance between all system components is proportional to the distance D. The single-terminal systems have a terminal located at site S2, and the two-terminal systems have terminals located at sites S1 and S3. For analytical purposes, the carrier terminals are grouped into carrier clusters containing carrier terminals located near each other. S1 and S3 are colocated with carrier terminal clusters C1 and C2. The performance measure of interest is the distance D* where two-terminal systems with $D > D^*$ become less expensive than single-terminal systems.

Figure 1 depicts a system assumed to have a total goods movement volume approximately equal to the small-shipment consolidatable freight volume—362 874 kg/d (800 000 lb/d)—for the CBD of Columbus, Ohio (6). That is, the flow between each carrier cluster and P/D zone is 45 359 kg/d (100 000 lb/d); half reflects pickups in the zone and the other half, deliveries. Other system characteristics are presented in Table 1 (7). Note that the total truck cost includes both the hourly and the distance costs. Also, terminal fixed costs consist of site acquisition, terminal con-

Figure 1. Metropolitan area example.

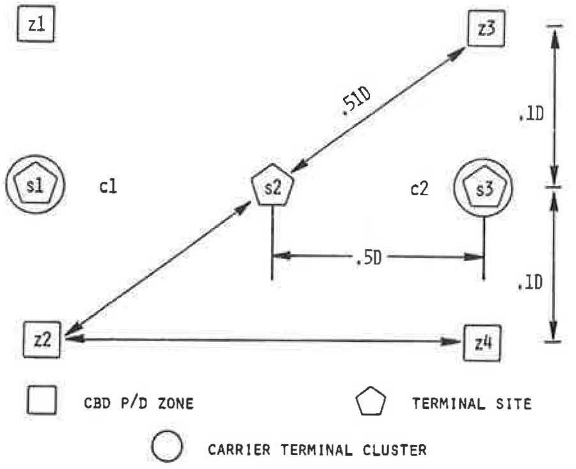


Table 1. System cost data.

Variable	Value
Truck length	8.5-m semitrailer
Maximum truck load	7711 kg
Average truck load	4534 kg
Truck cost/kilometer	\$0.18
Truck cost/hour	\$13.19
Terminal fixed cost	
181 437 kg/d	\$0.005 952/kg
362 874 kg/d	\$0.004 630/kg
Terminal operating cost	\$0.011 02/kg

Note: 1 m = 3.3 ft; 1 km = 0.6 mile; and 1 kg = 2.2 lb.

struction, and administrative costs; operating costs include billing, platform labor, loss, and damage.

The value of D* where two-terminal systems become less expensive is dependent on the average speed assumed for truck travel. Robeson and McDermott (6) recorded an average speed of 8 km/h (5 mph) in the Columbus CBD; however, Blatner (8) estimated the average speed to be 21.2 km/h (13.2 mph) for all classes of trucks in Chicago. The value of D* is 10.8 km (6.7 miles) for an average speed of 8 km/h (5 mph), 19.5 km (12.1 miles) for an average speed of 16.1 km/h (10 mph), and 26.9 km (17.7 miles) for an average speed of 24.1 km/h (15 mph). Thus, multiple terminals may be preferred by even moderately sized metropolitan areas.

URBAN TERMINAL INVESTMENT MODEL (UTIM)

The investment model for the purpose of determining the least costly design of a terminal system is described in this section. Cost here means the present value of all operating construction, and P/D costs are those that occur during a planning horizon of T years, e.g., 12 years. All costs are discounted to reflect the lower value of a dollar expended in the future as opposed to an immediate expenditure; moreover, a constant inflationary rate is assumed to account for higher future costs for identical items.

For the purpose of computing transportation costs, assume that there are I possible sites selected for consideration in locating consolidation terminals. Also assume that there are K total truck clusters and J total P/D zones containing shippers and consignees. Let

e_{ij} = present value of truck costs to transport all freight to and from P/D zone j through terminal site i, for T time periods

These costs are determined from the number of round trips trucks must make between site i and zone j in addition to the round trips between site i and all k carrier clusters.

In addition to the transportation costs, terminal operating and construction costs must be determined as a function of the throughput volume through each terminal and the goods-handling capacity purchased for each terminal. The throughput volume through a given terminal is determined by the zones assigned to the terminal and the P/D volume forecasted for these zones. Let

$$z_{ij} = \begin{cases} 1 \text{ if zone j is assigned to site i} \\ 0 \text{ if otherwise} \end{cases}$$

w_{kjt} = daily P/D volume forecast between cluster k and P/D zone j in year t

d_{it} = daily throughput volume for site i in year t

Then

$$d_{it} = \sum_{k=1}^{K} \sum_{j=1}^{J} w_{kjt} z_{ij}$$

For the entire planning horizon, the vector D_i is used to represent the throughput volume for a terminal at site i, where

$$D_i = (d_{i1}, d_{i2}, d_{i3}, \ldots, d_{iT})$$

In addition to the throughput volume, the present value of terminal costs is determined by the amount of capacity purchased for the terminal and the year in which the investment is made. Let

y_{it} = terminal capacity alternative selected in period t at site i

$y_{it} = 1, 2, \ldots, M_t$

M_t = maximum number of capacity alternatives available in period t

Also, the capacity investment decisions at site i are represented by the vector Y_i, where

$$Y_i = (y_{i1}, y_{i2}, \ldots, y_{iT})$$

Each value of y_{it} has a throughput capacity (which is site independent) associated with it. That is,

$S_t(y_{it})$ = freight-handling capacity available in period t with alternative y_{it}

$S_t(1) = 0$

The present worth of terminal costs is given by the function

$f_i(Y_i, D_i)$ = present worth of terminal investment and operating costs at site i over the planning horizon of length T years given the throughput volume vector D_i and investment vector Y_i

The transportation and terminal costs can be combined to give the overall P/D cost, which is

$$C = \sum_{i=1}^{I} \sum_{j=1}^{J} e_{ij} z_{ij} + \sum_{i=1}^{I} f_i(Y_i, D_i) r_i$$

where

$$r_i = \begin{cases} 1 \text{ if site i has terminal, i.e., if } \sum_{j=1}^{J} z_{ij} > 0 \\ 0 \text{ otherwise} \end{cases}$$

C = present worth of the total P/D costs

Figure 2. Carrier clusters and potential terminal sites, Columbus, Ohio.

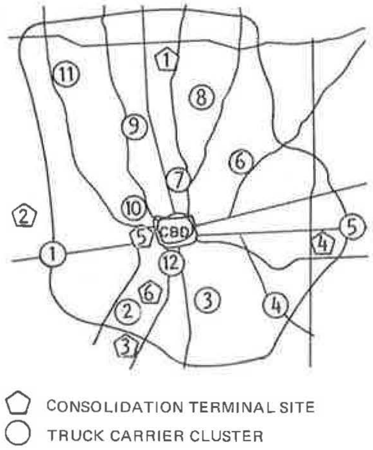
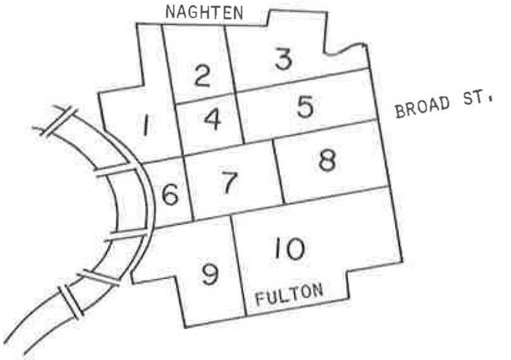


Figure 3. Central business district zones, Columbus, Ohio.



C is the criterion function for UTIM.

This criterion function is subject to a number of constraints. First, a P/D zone is assigned to exactly one terminal. Thus,

$$\sum_{i=1}^{I} z_{ij} = 1 \text{ for } j = 1, 2, \ldots, J$$

Also, a terminal must have adequate capacity to handle its throughput volume in each year of the planning horizon. Thus,

$$\sum_{p=1}^{I} S_p(y_{ip}) r_i \geq d_{it} \quad \text{for } i = 1, 2, \ldots, I \quad t = 1, 2, \ldots, T$$

A partial enumeration algorithm (7) is used to find the minimum value of the criterion function while satisfying the constraints.

APPLICATION TO COLUMBUS, OHIO

To illustrate UTIM capabilities, the CBD of Columbus was analyzed with forecasts for a 12-year period from 1974 to 1985. The forecasts were based on the 1973 estimates of zonal volumes for shipments of less than 453.6 kg (1000 lb) that could be consolidated as specified in Robeson and McDermott (6). A 4.86 percent annual volume growth was assumed to apply during the planning horizon, along with an annual inflation rate of 7 percent and an annual discount rate of 10 percent. Figures 2 and 3 show the location of carrier clusters, potential terminal sites, and CBD zones.

A single terminal at S5 was identified as the preferred system. The optimal solution cost breakdown is shown in the following table:

Cost Component	1974-1985 Present Value ($)
Terminal	15 972 000
Stem travel	3 214 000
CBD zone P/D	6 158 000
Total	25 344 000

These results indicate that a consolidation terminal would reduce the P/D cost of small shipments by approximately 40 percent since the present value of P/D costs for unconsolidated freight is estimated to be $41 940 000.

Examination of the geometry of the metropolitan area in Columbus may explain the superiority of single terminals. The CBD is highly concentrated, but the carrier clusters are dispersed; thus, multiple terminals do not offer savings in stem transportation costs with respect to the CBD zones. However, consolidation of small-shipment P/D operations in a more widely dispersed area such as the entire Columbus urban area or Chicago may be efficiently performed with multiple terminals.

ACKNOWLEDGMENT

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Abridgment

Space Allocation Guidelines for Off-Street Loading Facilities

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This report summarizes the results of the third and final year of a study related to the facilitation of urban goods movement. The first year of study dealt with data acquisition, the second year developed and validated the methodology, and the third year sought to develop guidelines for the efficient allocation of curbside and off-street space for urban goods movement. Brief descriptions of the data sources and the developed methodologies (1,2) and a detailed description of the guidelines with application examples for off-street loading requirements, primarily in downtown areas, are presented here.

DATA SOURCES

The source of information used to develop pickup and delivery (P/D) descriptions, such as generation, arrival temporal distributions, parking patterns, and dwell times, was data collected in downtown Brooklyn and in lower Manhattan in 1974 and 1975. Approximately 2500 samples were collected from 74 typical downtown land use sites. These sites included office buildings, department stores, light industrial establishments, and many retail and commercial establishments characteristic of downtown areas (3,4).

For each P/D operation sampled, information was obtained on carrier and vehicle type; time of arrival and time components of the stop; parking patterns; shipment size, weight, and commodity; mode of transportation from vehicle to destination; delays in the operation; and engine-idling time.

Using attributes of the data generators, various models were developed for describing P/D operations. Such models include trip generation (5), temporal distribution, and parking models (1,2).

SPACE ALLOCATION METHODOLOGY

The procedures used allocate space for goods movement in such a way as to minimize societal costs. These societal costs include traffic delays, carrier's delays, developer's costs, parking costs, health-related costs, and environmental costs, depending on whether the area of interest is at the curb (on-street) or at a loading dock (off-street). The total cost of allocating S spaces, on-street or off-street, for goods movement can be expressed in the following general form:

$$C(s) = c_{1(s)} + c_{2(s)} + c_{3(s)} + \ldots + c_{n(s)}$$

where C(s) is the total societal cost and $c_{i(s)}$ is the cost to interest group i of allocating S spaces to urban goods movement.

The objective is to find the number of off-street berths that minimizes some total cost function. There are costs to the several components of the moving traffic stream that can be adversely affected by a blockage of a moving lane (lines at loading docks and backing-in maneuvers); carrier costs are included as each vehicle waits for its turn to use the off-street berths. This, in turn, means that developer's costs go up as traffic and carrier costs go down. Developer's costs go up because rentable space is assigned to goods-vehicle loading and unloading, which does not produce revenue. The procedure in this space allocation model is to find the number of off-street berths that minimizes total annualized cost in dollars for all impartial groups.

Further detailed description of the analysis, as well as the sensitivity of the methodology, is found in Crowley and Habib (4). It should be noted, however, that no problems identified that would affect application of the standards are presented here.

DEFINITIONS

There are two basic on-street traffic flow patterns, an arterial pattern and a city street pattern. The arterial pattern has the severe peaks in the morning and evening work-travel periods. The city street pattern reflects the relatively high off-peak (local) traffic flows. These different patterns also affect the guidelines for off-street loading. It should also be noted that there is a different effect on traffic depending on whether a disruption occurs in the upstream, mid-block, or downstream sections of a block. These differences are reflected in Tables 1-3.

Three different land uses were considered with respect to off-street vehicle space requirements. They are office building, department store, and light industrial and warehousing.

APPLICATION OF STANDARDS

In referring to Tables 1, 2, and 3, the street and traffic characteristics on which a facility is to be developed must be considered. The size and use of the generator are determined, and then the estimated rentable value of the space slated for off-street facilities is computed. The planner may enter the variables defined on the appropriate table in order to retrieve the number of docks required to minimize societal costs using method 6—the recommended method—and assuming that all goods-vehicles generated use the off-street facility. In certain land uses, such as department stores, this assumption is rational. In others, such as office, assuming that no goods will be delivered across the curb—even though off-street facilities are provided—can be inaccurate.

To consider a particular percentage utilization of off-street dock facilities, the planner should either (a) conduct selected surveys in the central business district (CBD) to determine percent utilization of existing off-street facilities or (b) make rational assumptions on the basis of experience. The research discussed in this paper indicates:

1. For department stores, 90 percent compliance can be assumed;
2. For light industry, 80-90 percent compliance can be assumed; and
3. For office buildings, 70-90 percent compliance can be assumed.

Of course, 100 percent compliance might be achieved by strict enforcement of parking regulations in the vicinity of the generator. However, considering some noncompliance appears to be a more practical approach.

Table 1. Recommended number of off-street berths for office buildings.

Effective Size (m^2)	Upstream Access					Mid-Block Access					Downstream Access				
	$10	$15	$20	$25	$30	$10	$15	$20	$25	$30	$10	$15	$20	$25	$30
Arterial streets															
18 600	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
37 200	3	3	3	3	3	3	3	3	3	3	5	3	3	3	3
55 800	6	6	5	5	5	5	5	5	5	5	6	6	6	5	5
74 400	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
93 000	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
111 600	9	8	8	8	7	8	8	8	7	7	9	9	8	8	8
130 200	10	10	10	8	8	10	10	8	8	8	10	10	10	10	9
148 800	11	11	11	11	11	11	11	11	11	11	12	11	11	11	11
Downtown streets															
18 600	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
37 200	4	3	3	3	3	3	3	3	3	3	5	4	4	3	3
55 800	6	5	5	5	5	5	5	5	5	5	6	6	6	5	5
74 400	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
93 000	7	7	7	7	7	7	7	7	7	7	9	8	7	7	7
111 600	9	8	8	8	8	8	8	8	8	7	10	9	9	8	8
130 200	10	10	10	9	9	10	10	9	9	9	11	11	11	10	9
148 800	12	11	11	11	11	12	11	11	11	11	12	12	12	11	11

Notes: $0.09\ m^2 = 1\ ft^2$.
Dollar values refer to annual suitable value per square meter of space.

Table 2. Recommended number of off-street berths for a department store.

Number of Vehicle Arrivals per Day	Upstream Access					Mid-Block Access					Downstream Access				
	$10	$15	$20	$25	$30	$10	$15	$20	$25	$30	$10	$15	$20	$25	$30
Arterial streets															
20	4	4	3	3	3	3	3	3	3	2	4	4	4	3	3
30	4	4	3	3	3	4	3	3	3	3	4	4	4	4	3
40	5	5	5	5	5	5	5	5	3	3	5	5	5	5	5
50	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
60	6	6	6	5	5	6	5	5	5	5	6	6	6	6	6
70	6	6	6	6	6	6	6	6	5	5	6	6	6	6	6
Downtown streets															
20	4	3	3	3	3	3	3	3	2	2	4	4	3	3	3
30	4	3	3	3	3	3	3	3	3	2	4	4	4	3	3
40	5	5	5	5	5	5	4	3	3	3	5	5	5	5	5
50	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5
60	6	5	5	5	5	5	5	5	5	5	6	6	6	5	5
70	6	6	6	6	6	6	6	5	5	5	6	6	6	6	6

Notes: $0.09\ m^2 = 1\ ft^2$.
Dollar values refer to annual suitable value per square meter of space.

Example 1

Consider a 74 322-m^2 (800 000-ft^2) office building to be constructed on a four-lane downtown street with the expected access point in the downstream third of the block. Evidence indicates that 25 percent of all goods-vehicles serving this type of building will not utilize the constructed off-street facility.

To find the required number of off-street berths, the planner should calculate the effective building size (or effective generation) of the subject. In this case it is approximately 55 742 m^2 (600 000 ft^2).

Table 1 shows a range from six to five in the number of berths recommended for the various rental values given. From the developer's viewpoint, if the proposed office building is at the highest value location in the downtown area, the highest annual rentable value should be used. The lowest would be used for a building on the fringe of the CBD or possibly even outside the downtown area.

Example 2

Consider a department store to be developed on a six-lane arterial where the access point is expected to be at mid-block. It is calculated that the docks will have an effective (after noncompliance) generation of 40 goods-vehicles daily (4,5). Table 2 shows a range from five to three in the recommended number of off-street berths. The planner should consider where the site would be located with respect to the peak commercial activity center in the downtown area. This refines the selection of a recommended dock size. Light industrial buildings may be treated similarly to department stores as outlined in example 2.

To compare the findings of the examples shown here to actual standards now in use in selected downtown areas, the following text table was developed.

Off-Street Truck-Loading Facilities in Downtown Areas: Requirements and Design

Dennis Christiansen, Texas Transportation Institute, Texas A&M University

The city of Dallas, the Dallas Central Business District Association, and the Texas Transportation Institute undertook a project designed to develop alternative solutions to the goods and services distribution problem in the Dallas central business district. As a part of that project, the adequacy of existing off-street truck-loading requirements and their design were evaluated. Several major U.S. cities were queried about their requirements for off-street loading facilities. In addition, operations at existing off-street loading facilities in Dallas were observed.

The delivery of goods and services in downtown Dallas is a large-scale, intense activity. Cordon counts (1) indicate that, in the 12-h period between 6:30 a.m. and 6:30 p.m., more than 12 000 trucks enter the Dallas central business district (CBD), representing approximately 10 percent of all vehicles entering this area. Due to the availability of a freeway loop around the CBD, it is assumed that virtually all of these vehicles make at least one stop in the CBD.

During an average day, an estimated 9000 delivery/service truck stops occur in the core of the Dallas CBD as part of the goods and services distribution process (2). Because Dallas has few alleys, these stops occur either at the curb or in off-street loading facilities. Of the approximately 1300 available loading spaces in the core, only about 200 (or 15 percent) are located in off-street facilities (2). Therefore, a substantial portion of the truck parking occurs at the curb, and delivery is made across the sidewalk. This activity contributes to both vehicular and pedestrian conflicts in an already congested area.

Interviews with trucking firm personnel in downtown Dallas (2) indicate that locating a loading space is the greatest problem experienced by the trucker in the CBD. Specific problems encountered with off-street loading docks include an inadequate number of dock spaces, a lack of maneuvering space, and poorly designed loading spaces (3).

One of the more disturbing aspects of trucking activity in downtown Dallas is that much of the more severe trucking congestion occurs in the immediate vicinity of some of the larger new buildings. Further observation indicates that the design of many of these off-street spaces is inadequate and places limitations on their use.

Apparently, an evaluation of the zoning code is appropriate. A code that requires an adequate supply of well-designed off-street loading spaces serves both public and private interests and contributes to a long-range solution of the goods distribution problem in the downtown area.

LOADING SPACE REQUIREMENTS

In designing off-street loading facilities for new buildings, guidelines are needed to determine the number of loading spaces to be accommodated in the building. This issue is examined here based on the results of a survey of several U.S. cities. A theoretical determination of space requirements is also presented.

Survey of U.S. Cities, 1974

Cities have long recognized the need for off-street loading facilities; zoning ordinances requiring such facilities have existed since 1927 (4). As a part of this study project, several major U.S. cities were queried in 1974 about their requirements for off-street loading facilities. Of the cities contacted, only Houston had no requirements pertaining to off-street loading.

Because more than 65 percent of the floor space in downtown Dallas is either office or retail, this study focused on these two land uses. Off-street loading requirements for office buildings and retail department stores in various cities are compared in Figures 1 and 2 respectively. Because certain codes overlap, the individual code for each city is not plotted. Rather, the bands in which the different codes fall are plotted, and the cities represented by each band are identified.

Survey results indicate that a wide disparity exists concerning off-street loading requirements. Apparently no general base has been accepted by cities for determining the need for off-street loading facilities. Variations that exist in the codes suggest that either (a) some of the codes are grossly inadequate or (b) others require the provision of too many off-street truck-loading spaces.

Theoretical Determination of Loading Space Requirements

The bold lines on the upper portions of both Figures 1 and 2 are recommended off-street loading requirements based on theoretical analyses. Methodology and supporting data for these analyses are briefly described in this section.

Office Buildings

Two different design objectives were evaluated for typical office buildings. One is a minimum design level that provides sufficient spaces to yield an hourly capacity equal to the number of trucks arriving during the peak hour of an average day. The other is a desirable design level that provides sufficient capacity so that an arriving vehicle seldom has to wait for a space (probability ≤ 0.25) even during the peak hour.

The initial step in determining the number of loading spaces required for a specific building is to estimate the number of daily truck stops needed to serve the building. Several research studies have related daily truck stops to gross floor area. Other data suggest that factors such as gross sales or number of employees are better indicators of the number of truck stops. These variables, however, may be difficult to identify during the building design process. Thus, floor area appears to be the preferred indicator for planning purposes.

Daily truck stops generated by office buildings as determined in eight different studies ranged from 16.14 to 25.82/10 000 m^2. Truck-stop generation rates identified in these studies are reasonably consistent; the mean value (22.73) is used in these analyses (3,5,6,7,8,9,10,11).

Nearly all CBD deliveries to off-street facilities are made during the 9-h period between 8:00 a.m. and 5:00 p.m. Studies of trucking activity (2) indicate that the peak delivery hour generates approximately 25 percent more truck stops than the average hour. Interviews suggested that office buildings do not experience a significant seasonal variation in the level of trucking activity. Hence, the number of peak-hour truck stops occurring at a building housing

Table 3. Recommended number of off-street berths for a light industrial or warehouse building.

Number of Vehicle Arrivals per Day	Upstream Access					Mid-Block Access					Downstream Access				
	$10	$15	$20	$25	$30	$10	$15	$20	$25	$30	$10	$15	$20	$25	$30
Arterial streets															
20	3	3	2	2	2	3	2	2	2	2	3	3	3	2	2
30	4	4	4	4	2	4	3	2	2	2	4	4	4	4	4
40	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4
50	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
60	4	4	4	4	4	4	4	4	4	4	6	4	4	4	4
70	6	4	4	4	4	4	4	4	4	4	6	6	4	4	4
80	6	6	5	5	4	5	5	4	4	4	6	6	6	5	5
90	7	7	6	6	5	6	5	5	4	4	7	7	7	6	5
100	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7
Downtown streets															
20	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3
30	4	4	4	3	3	4	3	3	3	3	4	4	4	4	4
40	4	4	4	4	4	4	4	4	3	3	5	5	4	4	4
50	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
60	5	5	4	4	4	5	4	4	4	4	6	6	5	5	5
70	6	5	5	5	4	6	5	5	4	4	6	6	6	6	5
80	6	6	6	5	5	6	6	5	5	5	6	6	6	6	6
90	7	7	7	5	5	7	5	5	5	4	7	7	7	7	7
100	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7

Notes: $0.09\ m^2 = 1\ ft^2$.
Dollar values refer to annual suitable value per square meter of space.

Source	Values From Examples	Cincinnati	Pittsburgh	Atlanta
Office building, 74 322 m^2 (800 000 ft^2)	5-6	4	6	10
Department store (40 vehicles/d) [assumed size: 13 935 m^2 (150 000 ft^2)]	3-5	5	5	3

The examples indicate that the procedure results in standards that are within the range of values now in use. This range, as presented here, is certainly a wide one, and the availability of applicable standards should improve the process of accommodating goods-vehicles in off-street facilities.

SUMMARY

The basic premise in the space allocation guidelines is that goods movement is a part of a total transportation system. Space allocation for goods movement must recognize and accommodate other urban transportation needs.

We have tried to develop the guidelines in ready-to-use form. The planner requiring detailed information should refer to Crowley and Habib (7) because it contains guidelines for on-street space allocation, in addition to the off-street recommendation presented herein.

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Figure 1. Off-street loading requirements for downtown office buildings.

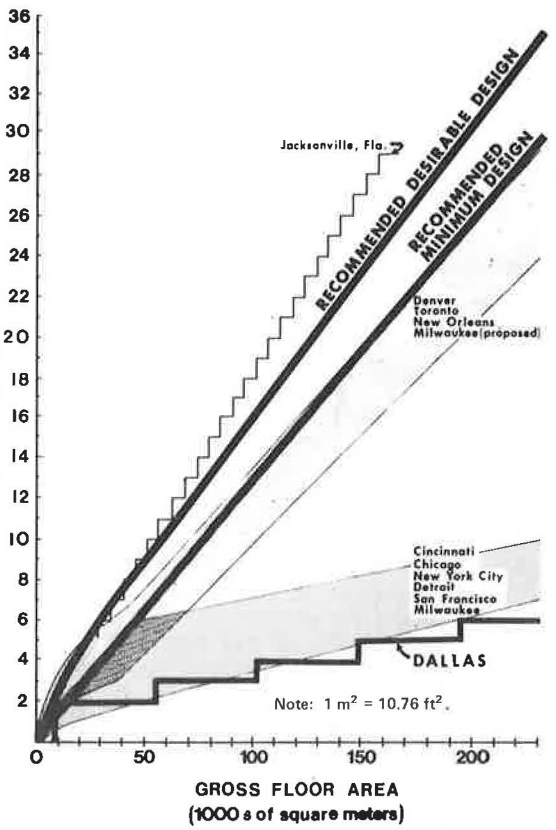
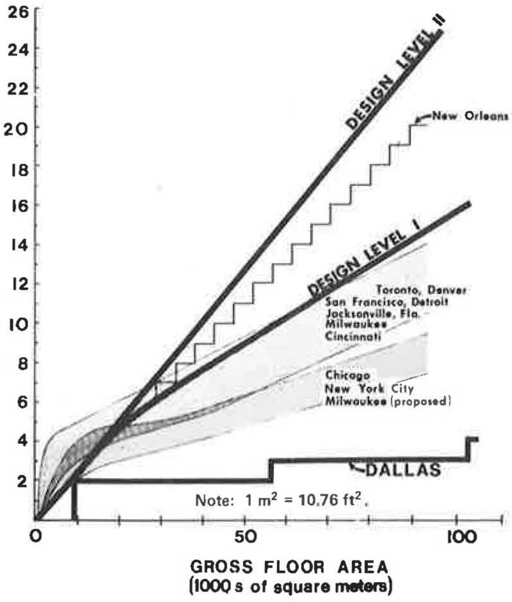


Figure 2. Off-street loading requirements for downtown retail department stores.



office space only can be estimated as follows: peak-hour deliveries = [gross office area (m^2)/10 000] x (22.73/9) x 1.25.

Other studies (8,12) indicate that an average truck stop lasts approximately 22 min. Assuming that an additional 3 min are required for the first vehicle to leave the loading space and a second vehicle to enter the space, a space can serve one vehicle every 25 min, or 2.4 vehicles/h.

Using the "minimum design" approach, the number of off-street loading spaces needed by an office building was calculated as follows: number of loading spaces = peak-hour deliveries/2.4. This procedure results in the relationship depicted by the line (Recommended Minimum Design) in Figure 1.

The minimum design approach provides sufficient spaces to serve the average peak-hour demand in a 1-h period. If all trucks arrived at a uniform rate, such a design would function satisfactorily on most days. However, trucks tend to arrive in a random manner, so a lineup of trucks probably will develop during the peak hour. Time spent waiting in a lineup is costly to the truckers, and when the line extends into the street it creates other traffic problems. Hence, the minimum design approach yields a design that may be considered less than optimum.

Economic considerations tend to prohibit provision of sufficient spaces to ensure that a lineup will never develop. However, a desirable design level might provide sufficient off-street spaces so that the demand for facilities does not exceed the available supply of facilities during the average peak hour for at least 75 percent of the time. A multiple-channel lineup theory was used to determine space requirements under these assumed conditions.

If such time is reduced, then the cost of the delivery is also reduced and the efficiency of downtown delivery is improved. However, the provision of a sufficient number of spaces to reduce waiting time also results in a higher probability of having some unused spaces. For example, at the desirable design level depicted in Figure 1, only an average of about 70 percent of the available loading spaces will be used at any one time during the peak hour.

The space requirements estimated in this report are in basic agreement with those proposed by Whitlock and Schoon (13). That research recommendation is midway between the minimum and the desirable level shown in Figure 1.

Retail Department Stores

The level of retail activity in the CBD of most U.S. cities has been declining since World War II. However, retail department stores with floor areas in the the range of 46 468 m^2 (500 000 ft^2) of gross usable space are still operating successfully in downtown Dallas.

Truck-stop generation rates were also utilized to estimate off-street loading requirements for retail department stores in several studies (4,6,7,9,10). These rates ranged from 15.06 to 39.81 daily truck stops/10 000 m^2 gross floor area, i.e., floor area assigned a specific use. The mean value (25.53) derived from these analyses was assumed to represent the average number of truck stops generated on an average day.

Criteria associated with evaluating off-street loading needs of retail department stores include those itemized below.

1. Virtually all truck stops are assumed to occur between 8:00 a.m. and 5:00 p.m., providing 9 h/d of available delivery time.
2. At a typical Dallas department store, approximately 50 percent of the vehicles using the loading space are owned by the store. Retail store management can reduce the magnitude of the peak hour by controlling arrival times of their vehicles. Consequently, the peak hour associated with retail store trucking activity is assumed to be only 10 percent greater than the average nonpeak hour.

3. A 25-min average service time is assumed for truck spaces at retail department stores, even though the variability is much greater than at office buildings. For example, numerous tractor-trailers serve retail stores, and their dwell time may easily exceed 1 h. On the other hand, smaller vehicles, partially as the result of centralized receiving, require less time per stop at a retail store than at an office building (13).

4. Significant seasonal variation in trucking activity is associated with retail stores. Horwood (14) found that the average daily volume of goods handled in the last 12 weeks of the year is about twice that of the annual daily average. Interviews with retailers in Dallas substantiate that such a peak does exist, although it may occur somewhat earlier in the year. Thus, for the last 12 weeks of the year, downtown Dallas department stores were assumed to generate approximately 51.06 stops/10 000 m^2 (4.8 stops/10 000 ft^2).

Retail department stores might consider either (a) design level 1, which provides sufficient spaces during the average peak hour at the "average" time of the year so that demand for loading spaces will not exceed available supply more than 25 percent of the time, or (b) design level 2, which provides sufficient capacity to serve the average condition during the average peak hour at the "peak" time of the year.

Design level 1 addresses operation during the average time of year. If arrival and service rates are not altered during the peak time of year, this design level will result in severe congestion during that 12-week period. At that time, a city may find it advantageous to take strong steps to assure that lining up on city streets does not occur, e.g., possibly implementing strict enforcement of curb regulations during that time period. This approach will not necessarily hinder the operation of the department store, since a store can take several actions to assure that a line will not develop during the peak time of year.

Design level 1 results in a nonlinear relationship between off-street loading spaces required and gross floor area. It was developed using multiple-channel queueing analysis. Due to the nonlinearity of this design level, it closely approximates design level 2 for stores with floor areas of less than 27 800 m^2 (300 000 ft^2), as shown in Figure 2. Using design level 1, about 9 off-street loading spaces would be required for a 46 468-m^2 (500 000-ft^2) department store.

Design level 2 addresses the average condition during the peak 12 weeks of the year. This approach might be considered economically undesirable because some excess capacity will result during the other 40 weeks of the year. Even at this design level, some congestion and lining up can be expected during the peak time of the year. However, the magnitude of this congestion will be less than that which might occur if design level 1 were utilized.

Design level 2 yields a linear relation between gross building floor area and off-street loading space requirements. A design level of 129.12 spaces/500 000 m^2 (12 spaces/500 000 ft^2) results. Observed operation of an off-street loading facility at a downtown Dallas department store suggests that this is a reasonable design level.

PHYSICAL DESIGN OF LOADING SPACES

Providing the required number of loading spaces does not ensure satisfactory operation of these spaces. In several Dallas buildings, the existing off-street loading facilities function in a less than desirable manner because their design is inadequate. In planning the loading space, consideration should be given to vertical clearance, depth of space, width of space, depth of dock, and height of dock.

Type of Delivery Vehicle

The type of vehicle to be accommodated is a major consideration in the design of an off-street loading facility. The following table shows the distribution of delivery vehicles by type of vehicle operating in the Dallas CBD:

Vehicle Type	Percentage of Total Shipments Carried	Cumulative Percentage
Passenger car	18	18
Pickup truck	10	28
Van	27	55
Single-unit truck	40	95
Tractor-trailer truck	3	98
Other	2	100

Except for moving tenants, there is little need for tractor-trailers to deliver goods to office buildings. Many building policies require major tenant moves to occur in the evening or on weekends, during which time the tractor-trailer is able to park at the curb. As a result, it is suggested that off-street loading facilities for office buildings need not be designed to accommodate tractor-trailers. However, it appears that facilities designed to serve retail department stores need to be designed to accommodate the tractor-trailer. Between 25 and 50 percent of the off-street loading spaces at department stores are occupied by tractor-trailers.

Dimensions of Loading Spaces

Table 1 presents the design standards stipulated in the 1974 zoning ordinances of a sample of various cities. Considerable variation exists among the different codes, and some cities do not specify any criteria for certain design parameters.

Loading spaces must have adequate vertical clearance, depth, and width if they are to function properly; thus, it seems appropriate for a city zoning code to specify minimum values for these parameters. Design details of the loading dock are also important factors in the overall functionality of an off-street

Table 1. Minimum dimensions of downtown loading spaces in selected cities.

City	Description	Vertical Clearance (m)	Depth (m)	Width (m)
Chicago	All spaces	4.27	7.62	3.05
Cincinnati	All spaces	NS	7.62	3.05
Dallas	First space	NS	12.20	3.05
	All other spaces	NS	6.10	3.05
Denver	All spaces	4.27	10.67	3.05
Detroit	First office space	NS	10.67	3.66
	Other office spaces	NS	16.77	3.66
	First three retail spaces	NS	10.67	3.66
	Other retail spaces	NS	16.77	3.66
Houston	All spaces	NS	NS	3.66
Jacksonville	All spaces	NS	NS	3.66
Milwaukee	Existing, all spaces	3.66	12.20	3.66
	Proposed, office	4.27	10.67	3.66
	Proposed, retail	4.27	16.77	3.66
New Orleans	All spaces	4.42	10.67	3.66
New York City	Office spaces	3.66	10.06	3.66
	Retail spaces	4.27	10.06	3.66
San Francisco	First space	3.66	7.62	3.05
	All other spaces	4.27	10.67	3.05
Toronto, Canada	All spaces	4.27	9.15	3.66
Range		3.66-4.42	6.10-16.77	3.05-3.66

Notes: NS = not specified.
1 m = 3.28 ft.

loading area; however, significantly different dock designs can function just as well. Accordingly, it appears more appropriate for a city to require a review of the proposed dock design rather than to specify design details in the code. The design criteria suggested herein are based on the standard design vehicles established by the American Association of State Highway Officials (15). The design values presented in this paper should be considered as minimum requirements.

Vertical Clearance

Vertical clearance should be provided to serve the maximum height of vehicles that are expected to regularly use the off-street loading facility. To accommodate the typical single-unit delivery vehicle, an absolute minimum vertical clearance of 3.66 m (12 ft) is needed, but a clearance of 3.96 m (13 ft) is a more desirable standard. To accommodate a tractor-trailer, a minimum vertical clearance of 4.27 m (14 ft) should be provided. Adequate clearance must be provided throughout the off-street area that trucks are required to use, and this clearance should also be considered in relation to changes in grade at driveways.

Depth of Space

Depth of space is also a function of the type of vehicle that is expected to use the space. A 7.62-m (25-ft) space depth is sufficient to serve smaller vehicles such as an automobile, pickup truck, and panel truck. A 10.67-m (35-ft) space can accommodate the single-unit truck, and a 16.77-m (55-ft) space can serve a tractor-trailer.

In designing space depth for an off-street loading facility, a variety of space depths might be provided based on the vehicle distribution expected to use the facility. If all spaces have the same depth, the control in design will be the depth necessary to serve the largest vehicle expected to regularly use the facility.

Width of Space

A minimum width for each space should be stipulated, even though factors such as column spacing may also influence space width. Width of vehicles varies somewhat; smaller vehicles such as automobiles are about 2.13 m (7 ft) wide and trucks 2.44-2.59 m (8-8.5 ft) wide. For two reasons, a desirable space width is one that leaves approximately 1.22 m (4 ft) between parked vehicles. First, many vehicles are side-loading units. If the shipment to be delivered is most accessible from the side of the vehicle, sufficient space should be available to allow convenient unloading. Second, some delivery vehicles during peak periods may find it convenient to stop behind vehicles parked at the dock and deliver their shipment between these vehicles to the dock. Thus, it is desirable to have sufficient space between vehicles to allow movement of a hand-cart.

Therefore, a minimum width of 3.66 m (12 ft) should be provided to serve single-unit and tractor-trailer trucks. A 3.35-m (11-ft) width is adequate to serve smaller vehicles.

Loading Dock Design

An adequate dock depth provides a loading and unloading area as well as space for travel along the loading dock. A minimum dock depth of 4.57 m (15 ft) appears needed. However, a deeper dock area will be required if goods are to be stored on the dock for extended periods of time (16,17,18).

Table 2. Suggested minimal design criteria for off-street loading spaces.

	Type of Vehicle to Be Accommodated		
Design Criterion	Automobile, Pickup, Panel	Single-Unit Truck	Tractor-Trailer Truck
Vertical clearance (m)	–[a]	3.96	4.27
Depth (m)	7.62	10.67	16.77
Width (m)	3.35	3.66	3.66
Dock height (cm)	61-76	89-127	122-132

Notes: 1 m = 3.28 ft; 1 cm = 0.39 in.

[a] Generally not a controlling design feature.

Since vehicle design is not standardized, no dock height can satisfactorily accommodate all vehicles. One design approach might be to provide several different dock heights in the facility, basing the design on the expected distribution of delivery vehicles. Another approach could be to provide one continuous dock height to serve all vehicles, recognizing the need to possibly provide some type of adjustable dock-height equipment. A tractor-trailer requires a dock height of 1.22-1.32 m (4-4.33 ft); a single-unit truck requires one of 1.02-1.27 m (3.33-4.16 ft); and smaller vehicles such as automobiles and pickups require a dock height of about 0.76 m (2.5 ft).

Table 2 suggests minimum design criteria for off-street loading spaces.

CONCLUSION

Provision of an adequate supply of off-street truck-loading facilities is, perhaps, the optimum long-range solution to the truck loading and unloading problem in major downtown areas. Implementation of an adequate zoning ordinance is a major move toward solving this problem. This paper suggests some guidelines that can be used in formulating zoning ordinances to address the issues of space requirements and design. In addition to the ordinance, cities may find it desirable to review plans for off-street loading facilities to ensure that the maneuvering requirements associated with these facilities do not unnecessarily interfere with on-street traffic.

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Abridgment

Determinants of Freight Modal Choice

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In studying the transportation of commodities, the objective of any particular research effort should be kept in mind. A researcher may be interested only in some general notion of the overall demand for freight transportation (e.g., the annual cost of shipping goods), in which case the demand for freight services will be closely tied to the level of national output. However, this procedure starts to collapse when interest centers on the demand for freight services by particular modes (e.g., rail and truck) and becomes rather unworkable. This is true especially from the viewpoint of policy analysis—i.e., when the research effort addresses questions related to the movement of particular goods by certain modes.

Input-output analysis, as well as econometric models, allows an economist or transport planner to forecast disaggregate components of national output (e.g., output by industries). This disaggregation has not been extended to direct modeling of freight demand, because a complete data base on modal characteristics is lacking—especially among unregulated carriers. Individual shipper data are also sparse. Thus, freight forecasting lags behind urban and intercity passenger modal split modeling methodologies. For example, Morton (2) has studied the demand for transport by mode by broad commodity groups, while Nazem (3) has focused on the macro-level approach. In addition, Watson and others (5) and Roberts and others (4) have emphasized individual shipper behavior. Morton found that shipment size and average haul length (AHL) were important determinants of modal choice.

Modes of freight transportation cannot be neatly dichotomized into public and private transport, as is sometimes done in passenger studies. While other researchers have confined their examination of freight haulage to two modes, e.g., Kullman's thesis on rail-truck competition (1), any broad study of freight must deal with more than two modes. If there are n modes for any particular commodity (good f) examined, then

$$\sum_{i=1}^{n} p_{if} = 1 \tag{1}$$

where p_{if} is the probability that a quantity of good f will move by mode i. Dividing both sides of Equation 1 by a nonzero p_{jf}, $i = 1,\ldots,j,\ldots,n$, so that

$$\sum_{i=1}^{n} (p_{if}/p_{jf}) = (1/p_{jf}) \tag{2}$$

Since $p_{jf}/p_{jf} = 1$, then

$$\sum_{i \neq j} (p_{if}/p_{jf}) = (1/p_{jf}) - 1 \tag{3}$$

Assuming strict inequalities, so that $0 < p_{if} < 1$ for all i and f, then the ratios p_{if}/p_{jf} are all positive, $1/p_{jf}$ is greater than one, and p_{jf} is greater than zero.

Because of the first equation, there will be only n-1 modal choices in an n-mode case that can be made freely; therefore, there will be only n-1 equations. While the choice of the base mode, p_{jf}, is arbitrary—and, thus, the results possibly sensitive to the base mode choice—it is desirable that the ranking of modes (in terms of lowest to highest probability of choice) remains invariant to the choice of base mode. If three modes—e.g., rail, truck, and "all else" (including water and air freight)—are being studied, with probabilities p_{rk}, p_{tk}, and p_{ok} of hauling good k, then three ratios could be formed: p_{rk}/p_{ok}, p_{tk}/p_{ok}, and $1/p_{ok}$. Such an approach would waste information, however, in that comparatively good data on a commodity-detail basis are available for rail and truck, whereas poor information is available for the remaining modes. Three alternative ratios could be examined: p_{rk}/p_{ok}, p_{tk}/p_{ok}, and $1/p_{ok}$. Note that as $(p_{rk}/p_{tk})\ (p_{tk}/p_{ok}) = p_{rk}/p_{ok}$, one can still use the "all else" mode as a base. This model can be summarized as follows:

$$\ln(p_{rk}/p_{tk}) = f_{rt}(r_{tk};r_{rk};A_k) \tag{4}$$

$$\ln(p_{tk}/p_{ok}) = f_{to}(r_{tk};r_{rk};A_k) \tag{5}$$

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$$(p_{rk}/p_{ok})(p_{tk}/p_{ok}) = p_{rk}/p_{ok} \tag{6}$$

$$(p_{rk}/p_{ok}) + (p_{tk}/p_{ok}) + 1 = 1/p_{ok} \tag{7}$$

where r_{tk} and r_{rk} are the truck and rail ton-mile rates respectively (derived below), and A_k is a vector of attributes of commodity k. In Equation 5, since rate data for other modes are not readily available, the "all else" rate term has been suppressed.

Data used to estimate the model's equations appeared in the 1972 *Census of Transportation*, the 1972 *Census of Manufactures*, and the 1972 Interstate Commerce Commission's *Freight Commodity Statistics* reports on rail and regulated trucking. The data in the transport census cover only the 48 contiguous states and shipments to Alaska and Hawaii. The transport census covers only manufactured goods, and pipelines are not included in the modal coverage. Still, the transport census covers a wide number of manufactured goods, and eventually 86 products were selected for the model's data that had either "one-to-one" or easily recognizable Standard Transportation Commodity Code-Standard Industrial Classification (STCC-SIC) concordance, at the three-digit level.

While the manufacturing census does not report physical output in any standardized customary units, the transport census does include an estimate by STCC group of intercity tons and ton-miles shipped over 30 miles. While the distance cutoff excludes local and urban goods movements, it may also exclude local intraurban, interplant shipments that are really related more to the local production process than to the transportation process. Value per ton of a commodity was thus calculated as the ratio of the manufacturing census' value-of-shipments number to the transport census' tonnage number. Rates for truck and rail were based on the 1972 *Freight Commodity Statistics* reports for rail and common carrier truck; these reports contain estimates, at the three-digit STCC level, of tonnage and gross revenue for the two modes. One major problem concerns the truck rate: since most trucking is done by private carriers, the calculated rate (revenue divided by tonnage) should be considered as an upwardly biased proxy for the private cost of trucking (the bias is due to common-carrier profit margins). The transportation census contains a breakdown of percentage of tonnage hauled by weight blocks, captured in the variables RLBS and MLBS, described below. Finally, three dummy variables were constructed to reflect production differences of commodities, measured by their value-added from the manufacturing census. (Data in the preceding sources appear only in customary units; thus the model constructed here was calibrated only in customary units. However, 1 lb = 0.45 kg, 1 mile = 1.6 km.)

Thus, the equations contain the following independent variables:

RRTA = rail rate per ton-mile of a commodity;
TRTA = truck-rate per ton-mile;
COSTDF = RRTA-TRTA;
AHL = average length of haul over all modes (in miles);
RLBS = percent of shipments weighing over 90 000 pounds;
MLBS = mean of weights of shipments under 90 000 pounds;
DA = dummy variable, equal to unity if the commodity's value added per ton equals or exceeds \$500/ton but is less than \$1500/ton;
DB = dummy variable, equal to unity if the commodity's value added per ton equals or exceeds \$1500;
DC = dummy variable, equal to unity if over one-half of the goods shipments weigh in excess of 30 000 pounds; and
VALSV = value per ton of the shipment.

Table 1. Ordinary least-squares estimates of modal split equations.

Independent Variable	Equation No. 1	2	3	4	5	6
	Dependent Variable					
	$\ln(p_r/p_t)$	$\ln(p_r/p_t)$	$\ln(p_r/p_o)$	$\ln(p_r/p_o)$	$\ln(p_t/p_o)$	$\ln(p_t/p_o)$
RRTA		-0.015 92		0.020 52		0.030 73
		(0.009 04)		(0.027 25)		(0.029 72)
ln(RRTA)	-0.679 34		-0.491 12		-0.206 82(W)	
	(0.349 83)		(0.926 04)		(1.011 40)	
TRTA				0.022 05		0.023 22(W)
				(0.018 85)		(0.020 57)
ln(TRTA)	0.637 75*		-0.136 91(W)		-0.607 86	
	(0.302 98)		(0.802 03)		(0.875 95)	
MLBS		0.000 04*		0.000 10*		0.000 08
		(0.000 02)		(0.000 04)		(0.000 05)
ln(MLBS)	0.174 72		1.221 59*		1.257 17*	
	(0.221 80)		(0.587 13)		(0.641 24)	
RLBS		3.936 54*		5.068 84*		1.748 71
		(0.825 47)		(2.265 59)		(2.472 54)
ln(RLBS)	0.020 02*		-0.135 01		-0.155 80	
	(0.064 77)		(0.171 46)		(0.187 26)	
VALSV		-0.060 92*		-0.117 10		-0.034 78
		(0.029 40)		(0.080 69)		(0.088 06)
ln(VALSV)	-0.715 92*		0.052 24		0.588 43	
	(0.158 72)		(0.420 16)		(0.458 89)	
AHL		0.449 82		1.173 39*		0.550 60
		(0.230 38)		(0.632 31)		(0.690 07)
ln(AHL)	0.780 94*		1.249 98		0.341 96	
	(0.357 15)		(0.945 42)		(1.032 57)	
COSTDF		0.002 49(W)				
		(0.006 87)				
DA	0.704 95	0.130 09	-1.148 33	0.462 87	-1.437 36	0.220 42
	(0.443 04)	(0.307 41)	(1.172 78)	(0.843 71)	(1.280 87)	(0.920 78)
DB	0.993 86*	0.591 23*	0.634 88	1.408 67*	-0.295 79	0.666 71
	(0.305 66)	(0.245 58)	(0.809 13)	(0.674 03)	(0.883 71)	(0.735 60)
DC	0.825 82*	-0.054 10(W)	1.568 44	0.442 55	0.775 90	0.503 91
	(0.317 95)	(0.342 66)	(0.841 63)	(0.940 46)	(0.919 21)	(1.026 37)
Constant	-3.455 99	-2.595 23	-7.425 14	-3.451 93	-5.499 67	-0.998 64
R^2	0.593 92	0.672 59	0.365 66	0.450 16	0.219 97	0.324 91
F	12.350 76	17.346 82	4.867 64	6.913 64	2.381 33	4.064 15

*Coefficient significant at 95 percent confidence (t-statistics appear in parentheses).

The specifications of the equations are

$$\ln(p_r/p_t) = f(\mathrm{RRTA, TRTA, RLBS, MLBS, VALSV, DA, DB, DC}) \quad (8)$$

$$\ln(p_t/p_o) = g(\mathrm{TRTA, RRTA, AHL, RLBS, MLBS, VALSV, DA, DB, DC}) \quad (9)$$

It is hypothesized that f and g are linear in their independent variables, and that COSTDF replaces one of the rate variables in some cases. Table 1 presents estimates of these equations, along with some logarithmic transformations of the independent variables.

The general form of the equations can also be modified by dropping the variables DA and DB and substituting the following value dummy variables:

DAA = unity if the value of shipments per ton for a commodity is between $1000 and $3000 inclusive, zero otherwise;

DBB = unity if the value of shipments per ton for a commodity is over $3000, zero otherwise.

Table 2. Alternative estimates of modal split equations under new value format.

Independent Variable	Equation No. 1 Dependent Variable $\ln(p_r/p_t)$	Equation No. 2 Dependent Variable $\ln(p_r/p_o)$	Equation No. 3 Dependent Variable $\ln(p_t/p_o)$
RRTA	-0.016 59* (0.009 17)	0.022 35(W) (0.027 32)	0.031 20 (0.029 68)
TRTA		0.018 20 (0.018 88)	0.021 22(W) (0.020 52)
MLBS	0.000 04* (0.000 02)	0.000 09* (0.000 04)	0.000 07 (0.000 05)
RLBS	3.814 42* (0.874 86)	4.892 75* (2.359 51)	1.563 34 (2.563 68)
VALSV	-0.062 50* (0.031 87)	-0.112 76 (0.085 95)	-0.029 52 (0.093 39)
AHL	0.461 81 (0.249 18)	1.140 06 (0.671 82)	0.510 01 (0.730 06)
COSTDF	0.003 99(W) (0.007 00)		
DAA	0.007 27(W) (0.354 50)	0.241 87 (0.955 98)	0.009 61(W) (1.038 70)
DBB	0.368 51(W) (0.252 43)	1.212 13 (0.680 74)	0.505 65(W) (0.739 64)
DC	-0.065 25(W) (0.354 44)	0.518 38 (0.955 81)	0.525 38 (1.038 52)
Constant	-2.321 77	-2.897 55	-0.621 07
R^2	0.656 64	0.443 34	0.322 55
F	16.149 31	6.725 47	4.020 58

*Coefficient significant at 95 percent confidence (t-statistics appear in parentheses).

Table 2 gives the parameter estimates of the modified equations.

Table 3 gives the results, in summary form, of those equations with multiple correlation coefficients ("R-squares") above 0.4. The determination of the correctness of sign was based on a priori speculation as to the sign of each particular coefficient. What is most apparent is that rate variables do not play much of a role in this model; rather, value of shipment, weight, and, to a lesser extent, average haul length variables are the major determinants of modal choice.

This research implies that, in order to forecast freight commodity flows accurately, it is necessary to take individual commodity characteristics such as shipment size and value into account. The type of mode chosen by a shipper will depend greatly on the commodity to be transported; in turn, this will help determine modal choice. Input-output models provide commodity-group output forecasts that can be used as a starting point to forecast demand for transportation by mode at a commodity level; an appropriate modal split algorithm can—after converting value of output to tons—estimate the tonnage carried by each mode. This methodology is preferable to more macro-related methodologies when research is focusing, for example, on the effects of energy or regulatory policies; it may be that in many cases government actions will not alter shipper choice because of a shipper's perception of transport.

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Table 3. Summary of best regression results.

Equation (Table, Number)	Structural Specification	Price Variable	Value Variable	Weight Variable	Haul Length
1, 1	Rail-truck ratio dependent variable; included logarithms of truck and rail rates and production dummies (DA, DB); non-dummies in logarithms	Truck rate significant; rail rate of insignificantly correct sign	Value variable VALSV significant	Weight variables RLBS and DC significant	Average haul length (AHL) significant
1, 2	Rail-truck ratio dependent variable; COSTDF used in place of truck rate; independent variables not transformed into logarithms	COSTDF of insignificantly wrong sign; rail rate insignificant	Value variable VALSV significantly negative	Weight variables RLBS and MLBS significant	Insignificant
1, 4	Rail-all else ratio dependent variable; truck and rail rates used; all independent variables except dummies in logarithms	Both rail and truck rates insignificant	VALSV is insignificant	Both RLBS and MLBS significant	Significant
2, 1	Rail-truck ratio dependent variable; COSTDF and rail rate used; value of shipment dummies used	Rail rate significant; COSTDF of insignificantly wrong sign	RLBS and MLBS have significantly correct signs; DC has insignificant wrong sign	VALSV of significant correct sign; DAA, DBB, of insignificantly wrong sign	Insignificant
2, 2	Rail-all else ratio as dependent variable; rail and truck rates used, along with value dummies	Rail rate insignificantly wrong; truck rate insignificant	MLBS, RLBS significant	VALSV insignificant	Insignificant

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Estimating Effects of Railroad Abandonment

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Estimates were developed of the potential for rail-service termination and of the probable transport-related effects that such loss of rail service would have on the freight-transport system, transport costs of affected rail users, resulting public- and private-sector investment requirements, and energy consumption. All estimates were developed for lines on which service either had been recently terminated or might be terminated in the future. A survey was conducted of a sample of users of these lines. Estimates of the overall effects of abandonment were developed by a computer program from an analysis of survey responses and from waybill data for shipments originating or terminating on the lines under study. About 80 percent of present rail shipments to or from facilities that lose rail service would continue to be made to or from these facilities by another mode, with most of these made entirely by truck or by a combination of truck and rail. About half of the remaining shipments would continue to be made to or from other locations in the general area. The average increase in transport-related expenditures of affected rail users would be about 17 percent of present railroad charges. It was also estimated that abandonment of the lightest density lines under study would generally result in a small reduction in fuel consumption, while abandonment of uneconomic lines with more moderate traffic densities would result in increased fuel consumption.

The Railroad Revitalization and Regulatory Reform Act of 1976 (4R Act) and other recently enacted legislation contain provisions that can result in increased rates of abandonment of unprofitable branch lines by railroads and that will permit subsidies for continued service on many of these lines. The purpose of this legislation, of course, is to improve the financial health of the currently ailing railroad industry. However, any increase in the rate at which branch-line service is terminated can be expected to have side effects on the rest of the transport industry, on the present users of affected lines, and on the local economies of the predominantly rural areas served by these lines.

This paper presents the methodology used in a recently completed study (1) designed to produce information about the extent of some of these effects. In particular, estimates were developed of the potential effects of railroad abandonment on traffic on the remainder of the freight transport system, transport costs of affected rail users, resulting public- and private-sector investment requirements, and energy consumption. Some of the major results of the study are presented here. Additional data may be found in Weinblatt and others (2) and in the complete report (1).

METHOD OF ANALYSIS

For this study, four sets of lines, which had either recently lost rail service or could lose service in the future, were identified:

1. Excluded lines: 8500 km (5282 miles) of line in the Northeast excluded from the Final System Plan (FSP) for Consolidated Rail Corporation (Conrail) (3);
2. Abandoned lines: approximately 4200 km (2600 miles) of line in the Northeast excluded from FSP on which service was discontinued on April 1, 1976;
3. Lines with petitions pending (PP): 9752 km (6060 miles) of non-Conrail lines located throughout the country on which abandonment petitions were pending as of July 23, 1976; and
4. Apparently uneconomic (AU) lines: 48 900 km (30 400 miles) of non-Conrail lines located throughout the country that appeared to be uneconomic on the basis of a computer analysis of traffic data.

For each of the four sets of study lines, estimates of the annual volume of shipments originating or terminating on these lines were obtained for seven regions and 16 commodity groups. For the abandoned and excluded lines, shipment data were acquired from the United States Railway Association waybill files for 1973; for lines with petitions pending and uneconomic lines, data were obtained from the Federal Railroad Administration One-Percent Waybill Sample for 1972, 1973, and 1974. Kilometer and shipment data for the PP and AU lines have been detailed in Weinblatt (4), along with a description of the procedure used in determining the apparently uneconomic lines. Preliminary estimates of the volume of shipments generated by the portions of these two sets of lines in 31 southern and western states were also included in the Transportation Secretary's Report to Congress, mandated under section 904 of the 4R Act (5,6).

Due to space limitations, the results in the latter part of this paper will be presented only for a fifth set of lines, consisting of the apparently uneconomic lines plus those excluded lines that had not already been abandoned. Thus, this fifth set consists of those lines in service in the summer of 1976 that could lose service in the next few years.

**Mr. Weinblatt was with CONSAD Research Corporation, Pittsburgh, Pennsylvania, when this research was performed.*

The 53 000 km (33 000 miles) of line in this set represent about 16.5 percent of the nation's total railroad system (7). However, only about 2.5 percent of the nation's railroad traffic (8) originates on these lines, and only about 1.1 percent of all traffic terminates on them.

Rail-User Survey

Users of lines in any of the four sets studied were selected by quota sampling in order to obtain appropriate representation of shippers and receivers of commodities in each of the 16 commodity groups. A sample of 364 rail users was selected for the survey using telephone and mail methods. Usable responses to an eight-page questionnaire were obtained from 310 affected or potentially affected facilities. This information included

1. Present use of rail and of alternate modes (commodities, annual volumes, origins, and destinations),
2. Transport capabilities (equipment owned, availability of rail siding),
3. Size (annual sales volume, employment), and
4. Expected effect of abandonment on operation (volume, modal usage, new or modified facilities and equipment).

Survey Analysis

Analysis of the effects of abandonment on each rail user began with the grouping of similar shipments and the estimation of the cost to the rail user of the transport alternatives for each group. Five alternatives were considered: transshipment by rail and truck; truck (directly from present origin to present destination); barge (with transshipment by truck and, possibly, rail); trailer-on-flat-car (TOFC); and truck (to a closer market or from a closer source of supply). For each group of shipments that could be affected by future abandonments, cost estimates were developed for those alternatives that appeared to be realistic possibilities. These rail-user costs consist of transport and trans-loading costs (or charges) as well as amortization of investment costs required for new or modified facilities and equipment.

Rail-user transport costs used in this analysis were derived from a review of several retrospective studies of the effects of previous abandonments (9, 14) and approximately 20 other sources (for a complete list, see 1, pp. 38-41). Charges for rail and barge movements were estimated on an individual basis from data in the 1974 *Carload Waybill Statistics* (8), in Baumel, Miller, and Drinka (15), and in Kearney (16). Average rail-user costs for other means of transport and for transloading are summarized in the following table (1 Mg·km = 0.685 ton-miles; 1 Mg = 1.102 tons):

Mode	Cost (cents/ Mg·km)	Mode	Cost (dollars/ Mg)
TOFC	2.40	Transloading	
Trucking		Bulk commodities	1.65
Direct	3.42		
Rail access	5.48	Non-bulk commodities	3.86
TOFC access	4.79		
Barge access	4.79		

On the basis of these cost estimates and other available information, it was determined which transport alternative or alternatives would most likely be used for each group of similar shipments if present rail service were to be discontinued. This determination was based on several factors, including alternatives already in use for similar shipments, handling characteristics, likely availability of equipment for transshipping, estimated cost of the alternatives, value of the commodity, and the alternative which the rail user thought would be selected. For the 15 surveyed rail users who had already lost service as a result of exclusion from the FSP, the transport alternative that was in use or that would eventually be used was already known and was obtained directly from the survey. Information from these respondents was used to aid in the analysis of other surveyed rail users.

Subsequent steps in the analysis of the effects on individual rail users were performed similarly. These steps involved the

1. Probability of relocating part or all of the affected facilities and the expected cost of such relocation,
2. Probability of a facility being closed or of certain lines of business being terminated, and
3. Expected decline in business volume at the affected location.

These steps included a comparison of the estimated sales volume of the affected products with the expected increase in transport costs for continued operation at the affected facility, as well as an evaluation of the ability of the firm to pass these increased costs along to its customers or suppliers.

Expansion of Survey Results

Estimates of the overall effects of abandonment associated with each set of potentially affected shipments were developed by applying the results of the survey analysis to the waybill data for the shipments and by incorporating supplementary data from other sources as appropriate. Supplementary data values for transport costs and fuel consumption are discussed in subsequent sections of this paper.

The general procedure for estimating the overall effects of abandonment from this information is summarized as follows:

1. Obtain the total number of affected megagrams or megagram-kilometers of each commodity group in each region;
2. Multiply by one or more response factors obtained from the survey results (these factors are usually a function of the commodity group);
3. Sum, in certain instances, over two or more responses obtained in step 2 above;
4. Multiply, in some instances, by a supplementary parameter value (e.g., diesel fuel consumed per megagram-kilometer for each mode); and
5. Sum over all commodity groups to produce results by region, or over all regions to produce results by commodity group.

RESULTS

Transport Alternatives

Table 1 shows estimates of how abandonment would affect shipments that presently originate or terminate on the 53 000 km (33 000 miles) of line that could lose service. About 72 percent of these shipments are expected to continue to be made between the present origin and destination. Most of this traffic is expected either to be shipped by truck directly from origin to destination or to move by conventional rail service with trucks used for transport between the affected rail users and another rail line. About 1.5 percent of affected shipments are expected

Table 1. Total traffic potentially affected by modal conversion.

Category	Volume of Shipments (Mg 000 000s)	Percentage of Total
Change in transport mode		
1. Rail/truck	14.7	31.6
2. Truck	17.5	37.7
3. Barge/truck	0.7	1.5
4. TOFC	0.8	1.6
Change in origin or destination		
5. Change of supplier or market	3.6	7.8
6. Readjustment within area	4.8	10.3
7. Loss from area	4.3	9.3
Total	46.6	

Notes: 1 Mg = 1.102 tons.
Detail may not add to totals due to rounding.

to be transported by TOFC and a similar amount by barge (with trucks used for transport between the rail users and barge-loading points).

Another 8 percent of affected shipments would continue to be made to or from affected facilities but would be made (by truck) to a closer market or from a closer supplier.

Approximately 20 percent of affected shipments would no longer be made to an affected facility (see response categories 6 and 7 in Table 1). Such shipments would be the result of lost business volume, partial or complete relocation of an affected facility, termination of a line of business, or the closing of an affected facility. Of these shipments, however, about half will continue to be made to other locations within commuting distance of the affected facilities, including locations to which an affected rail user might relocate. Thus, it is estimated that about 10 percent of affected shipments would no longer be made to or from the areas presently served by these lines.

Although seven response alternatives are shown in Table 1, analysis of the transport implications of the last two alternatives was generally beyond the scope of this study. Therefore, unless otherwise stated, subsequent results do not reflect data for the 20 percent of present shipments that would no longer be made to or from an affected facility.

Effect on Modal Usage

The following table shows estimates of the expected change in use of the four transport modes under consideration as a result of adoption of the transport alternatives summarized in Table 1:

Mode	Billions of Mg·km
Rail	
Conventional	−9.01
TOFC	+1.22
Truck	
Direct	+6.47
Rail access	+0.38
Barge access	+0.02
TOFC access	+0.05
Barge	+0.42
Total rail shipments potentially affected, Mg·km	37.2

The figures in the above table represent changes in megagram-kilometers (1 mg·km = 0.685 ton-mile) carried by the specified mode and reflect differences in circuity among modes.

Fuel Consumption

Overall, railroads represent a fuel-efficient mode for hauling freight. However, their overall efficiency is a result of combining very fuel-efficient line-haul operations with less efficient distribution and collection service. Fuel efficiency of the latter service is particularly low on the branch lines of least density. Abandonment of such lines, combined with the use of trucks for pickup and delivery services, will result in reduced fuel consumption. However, to the extent that abandonment results in the use of trucks for direct service from origin to destination, fuel consumption will be increased. Use of TOFC as an alternate mode will also generally result in increased fuel consumption, while bimodal movement by truck and barge will normally result in a fuel saving.

Estimates of the overall effects of abandoning the study lines were developed from the above estimates of change in modal usage and from the estimates of fuel consumption by mode and type of service shown in Table 2. The results indicate that abandonment of all 53 000 km (33 000 miles) of line would result in a 5 percent increase in fuel consumption. In terms of diesel fuel, this increase would be about 2200 m^3 (8 million gal) annually.

Because of the relative fuel inefficiency of light-density operations, present fuel consumption per megagram-kilometer for shipments generated by these lines is somewhat higher than the national average for railroad operations. This is particularly true for the lines with the lightest traffic densities. Indeed, if only the lines with petitions pending were abandoned, an 11 percent saving in fuel consumption would result.

Transport Costs

Estimates of the change in rail-user expenditures for shipments that would continue to be made to or from an affected facility were derived from the estimated changes in modal usage, waybill data for railroad charges of potentially affected movements (adjusted to 1976 dollars using the U.S. Bureau of Labor Statistics' Railroad Freight Price Index), the average costs to rail users noted earlier in this paper, and average barge transport charges of 0.52 cents/Mg·km (0.76 cents/ton-mile) obtained from the survey analysis.

Increased transport costs are estimated to average about $3.00/Mg ($2.70/ton), which represents 17 percent of the average railroad charges currently in-

Table 2. Fuel consumption data by mode and type of service.

Mode[a]	Approximate Energy Consumption per Net Mg·km (J/Mg·km)	Consumption of Diesel Fuel (m^3/Mg·km)
Rail		
General	0.97	1.95
TOFC[b]	1.11	2.23
Local service[c]	-	6.0[d]
Truck		
Rail access	3.87	7.7
All other	2.63	5.3
Barge	0.69	1.39

Notes: 1 J/Mg·km = 0.001 384 Btu/ton-mile, 1 m^3/Mg·km = 386 gal/ton-mile,
1 m^3/km = 425 gal/mile.

[a] Except where noted, data obtained from Leilich, Prokopy, and Ruina (17).

[b] See Rice (18).

[c] Estimated by linear regression (1, pp. 51-52) on Harbridge House estimates of local-service fuel consumption on 10 abandonable lines in Wisconsin, New Hampshire, and Massachusetts (19, 20).

[d] Plus 183 m^3/km annually.

curred by these shipments. Except for increased handling (transloading) costs, these estimates do not include any changes in the nontransport components of operating costs; for many medium- and higher-valued commodities, reduced inventory costs will do much to balance the increased expenses for direct trucking. No estimate of increased expenditures was made for shipments that would no longer be made to or from an affected facility.

Capital Investment

Estimates of capital investment and related effects that would result from loss of rail service were derived from the results of the analysis of the rail-user surveys and supplemented by data on motor-carrier capital requirements (1, pp. 42-45; 2) and on highway construction and maintenance costs (1, pp. 45-49; 22, 23).

If all 53 000 km (33 000 miles) of line were to be abandoned, it is estimated that approximately 320 firms would relocate part or all of their facilities at a total cost of $130 million (an average of about $400 000/facility). Another $120 million would be required by rail users to purchase vehicles and other equipment and to modify existing facilities. Motor carriers and firms that either supply or purchase from affected rail users would be expected to invest $320 million in vehicles and in expanding related facilities. Annual costs for road and bridge construction would increase by an estinated $5.8 million, and those for road and bridge maintenance by $6.5 million.

Abandonment and Subsidy Costs

From the estimates generated during this study, it is possible to develop further estimates indicating that the cost of subsidizing continued operation of all 53 000 km (33 000 miles) of line will be appreciably higher than the total private- and public-sector costs of abandoning these lines (see 1, pp. 73-78). Subsidy costs, however, will tend to be greatest (per carload or per megagram) for the lines with the lightest traffic densities, while the benefits of subsidy (i.e., avoidance of abandonment costs) will tend to be greatest for the abandonable lines with the heaviest densities. Thus, there are undoubtedly some lines for which the transport-related costs of abandonment would exceed the cost of subsidization. Discrimination among the lines in question can only be made after detailed and specific studies.

This study has focused on the transportation economics of shipments on light-density lines rather than on social, economic, or environmental impacts on individual communities. Consideration of these factors would increase the number of lines for which the benefits of subsidy would exceed the cost of subsidy. However, it would still appear that, for most uneconomic lines, an assistance program enabling rail users and local communities to adjust to the loss of rail service would be more cost-effective than continued operation under subsidy.

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Abridgment

Use of Mobile Communications in the Trucking Industry

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Mobile radio use has become a widely adopted component of modern transportation systems. Communication and transportation may serve as substitutes for or complements to transportation systems. As a substitute, communication can often replace a trip by accomplishing the trip's objective without direct personal contact. The telecommunications industry is developing extensive technology for information handling and transmitting. Thus, when the purpose of a trip is to move information rather than goods or persons, electronic communication may be substituted. Transportation and communication can also be complementary. As in most of the areas to be described in this paper, communication is used to increase the efficiency of vehicle operations. Routing and scheduling changes can reduce mileage, increase load factors, and bypass inclement weather or delaying traffic conditions.

However, the difference between the substitutive and complementary relationships of communication and transportation is not always clear-cut. For example, through the use of mobile communication, a freight vehicle can be dispatched to make a nearby pickup or delivery that was not requested in the original dispatch.

DEFINITION

Mobile communication has been defined as voice or signalling communications services between base stations and mobile units, either hand-carried or vehicular. This definition can be expanded slightly by adding that information transmission can occur between humans, between machines, or between humans and machines. The use of electronic signalling for automated control purposes, often encountered in the transportation area, could thus be included. Also included in this definition are mobile communications in the area of safety and special radio services. This area covers aviation; marine and land mobile radio use by state and local governments (e.g., police, fire, forestry, highway departments); industrial (e.g., in-plant manufacturing uses, construction site communications, service and supply vehicle links); land transportation (e.g., railroads, passenger buses, delivery trucks, taxis, automobile emergencies); disaster communications; and other experimental, hobby, and personal convenience uses.

APPLICATION

Any communication between vehicles or between vehicles and fixed stations by visual, electronic, or other signals generated or received by devices within the vehicles can be considered mobile communication. Extensive use of two-way radio communication has significantly increased efficiency and service quality. A reduction in the number of pickups and deliveries, increased shipment requests, and reductions in fuel consumption or the number of vehicles required have all been noted by mobile communications users in the transportation sector.

REGULATION

Land mobile radio use is controlled by the Federal Communications Commission (FCC) as part of the land transportation radio service sector of the Safety and Special Radio Services Bureau. Motor freight and passenger carriers, taxi operators, railroad radio users, and automobile emergency systems—including highway maintenance vehicles—are included in this sector governed under FCC Rules and Regulations (part 93).

Applications for broadcast frequencies are made to an officer of the FCC who coordinates them with existing users and other applicants before forwarding them for commission approval. The radio spectrum available for land transportation users is broken down for different services (e.g., rail, freight, passenger, automobile emergency). A further breakdown is made to ensure the compatibility of signal characteristics and message types.

The use of citizen-band radio by trucking companies is greatest where the spectrum is overcrowded. It is rare to find citizen-band radio used for dispatching in low-density urban or rural areas. Furthermore, most companies have one allocated frequency—and only a few have two or more (in each separate area of operation)—but frequencies must be shared with other users in crowded urban areas. Loading is generally high, i.e., 20-200 units/frequency, although this is low by police or fire standards. In all, there are 6000 licenses in the industrial radio services sector operating a total of 75 000-80 000 vehicles.

ASSESSING NEW TECHNOLOGIES

With the allocation of the 900 MHz band to land mobile radio use, as specified in FCC docket 18262, two new mobile communications technologies have been developed to promote efficient use of this spectrum. These are known as the multichannel trunked system and the cellular system.

In the multichannel trunked system with automatic control (MCTS), access to the several channels assigned to this system is controlled by a central computer unit. All users must request permission to transmit.

In a cellular system, a large service area is broken up into cells; within each cell is operated a subsystem functionally similar to that of the multichannel trunked system. The cells may be from 1.6 km (1 mile) to about 32 km (20 miles) in diameter, and the MCTS transmitters in adjacent cells operate on different sets of frequencies. The major purpose of the cellular system is to increase mobile communication capacity within a given spectrum allocation. Short-range transmitters and small cell size permit reuse of allocated frequencies in cells separated by a specified distance from the cell originally using those frequencies. Moreover, small cell sizes are naturally compatible with the limited range and unfavorable propagation characteristic of the frequencies now being made available for mobile communications. The major advantage of the cellular system is its vast potential capacity; it can accommodate millions of users. The capacity is not only proportional to the number of channels assigned, but is also inversely proportional to cell size. As cell size is reduced, the number of cells in a given service area is increased, thus increasing frequency reuse. Additional advantages are privacy and virtually unlimited effective range.

COMMUNICATIONS AND THE TRUCKING INDUSTRY

The freight transportation industry is very diverse and at the same time highly specialized. That is, many types of operations exist, although a number of firms will concentrate on a specific type of operation. A company can be considered a local or a long-haul carrier. In combination, these distinctions permit the development of the spiderweb network that permits complete coverage of a region. Local carriers are allotted a region to serve, and generally are centered around one or a few major cities. Each local carrier is responsible for the pickup and delivery of goods within its region.

Long-haul carriers link major service areas, transporting goods between cities for subsequent distribution locally. Terminals are located in each local region, and direct service between these terminals becomes the function of these over-the-road operations.

Routing arrangement also characterizes the diversity of the industry. These types of operations are of major importance in describing the communications needs of a carrier. The Interstate Commerce Commission recognizes five distinct types of routing: regular route/scheduled service; regular route/nonscheduled service; irregular route/radial service; irregular route/nonradial service; and local cartage service.

Carriers can also be classified according to the following economic criteria:

1. Class 1 carrier, annual gross of a firm in excess of $3 000 000;
2. Class 2 carrier, annual gross between $500 000 and $3 000 000; and
3. Class 3 carrier, annual gross under $500 000.

In the United States in 1970, there were 3632 class 1 and 2 carriers and 11 468 class 3 carriers. Because classes 1 and 2 employ a much larger number of vehicles, however, the difference in terms of total equipment is much smaller. Approximately 50 percent (about 1800 companies) of the class 1 and class 2 carriers use radio equipment, whereas only 5-8 percent of the class 3 firms employ mobile technology (about 700 companies). Two factors seem to be responsible for this: the capital expenditure necessary to obtain radio equipment and the reduced problem of communication when only one or a few trucks are involved. A stratification of the industry is completed by considering two other classifications: by type of "contract arrangement" that refers to the ownership of the cargo being transported and by type of commodity transported. The basic distinction is between for-hire carriers (providing freight movement for other businesses and industries) and private carriers (fleets owned by a business or industry that transport the industry's cargo).

The most important need of the long-haul trucker is one of control, especially in cases where many terminals are maintained and a large vehicle fleet is maintained. Control of transferred cargo as well as knowledge of vehicle arrival time at each terminal (for more efficient loading) is essential. Because of the long time that a truck may be out of communication with terminals, control could also be used to aid in emergency situations and to monitor the performance of the driver.

Local service, typically serving irregular routes, relies more on communications for relaying new assignments to drivers. In an ideal situation, a truck coordinates several successive pickups and deliveries before returning to a terminal. To accomplish this, some form of communication with the driver is needed.

To meet these communication needs, a wide variety of systems are available and in use. These include various conventional telephone arrangements, on-line data transmitting and teletype systems, and mobile technologies such as two-way radios and digital equipment.

EFFICIENCIES AND IMPACTS OF COMMUNICATIONS TECHNOLOGY

The use of mobile radio has two kinds of economic benefit: increased revenue and decreased cost. Immediate relay of incoming requests to an available vehicle enables a larger number of customers to be served per day (increased revenue). Not only can more customer requests be handled, but fewer trucks are needed to service a particular area if they are radio-equipped. Four radio-equipped trucks may be able to perform the task of five trucks without radio equipment. Fewer trucks or truck-hours mean that a company can, for example, decrease driver wages and fuel consumption.

Besides economic savings, there are a number of more subtle impacts. Many customers prefer to do business with mobile radio users because of the greater speed and quality of service provided. In cases where trucks are in the vicinity when a customer phones in a request, immediate contact with the driver via the terminal dispatcher can provide service in a matter of minutes. Any questions arising during business transactions that cannot be answered by the driver also can be clarified immediately.

A certain degree of safety is also provided through the use of radio equipment. In cases of breakdown, accident, or other emergency, the driver is able to get aid through the local terminal or from other company vehicles in the area, if mobile-to-mobile capabilities exist. Less reliance on outside help results in greater security for driver and cargo. Communications can reduce the danger of hijacking.

POTENTIAL MARKET FOR NEW TECHNOLOGY

A market for new technology in the trucking industry will depend on one of the following three abilities of a cellular or multichannel system:

1. The ability to decrease congestion and hence transmission delays,
2. The ability to provide dispatching service at a lower cost than present mobile equipment, and
3. Capabilities not now present in dispatch and communications equipment that would aid trucking firms.

Radio users interviewed for this study did not view radio congestion as a major problem. Yet in metropolitan areas, where radio channels are shared by a number of users, congestion of the airwaves can mean inefficiency in the trucking industry as in any other type of dispatch service.

HIJACKING AND MOBILE COMMUNICATIONS

The U.S. Department of Transportation noted that the total cost of cargo theft and pilferage exceeds $1 billion/year—with the trucking industry experiencing the largest percentage of that total. Theft usually occurs during loading and unloading, in the terminal yard (about 85 percent of stolen cargo goes out the front gates of transportation facilities during normal operating hours and in the possession of persons and in vehicles authorized to be on premises for legitimate reasons), or in transit between terminals.

Hijacking has recently become more prevalent. Increased terminal security has reduced the first two types of loss, but the problem has moved to the road.

CONCLUSIONS

This paper has attempted to identify the significant role that mobile communications plays in the operation of pickup and delivery and over-the-road service in the trucking industry. A number of specific instances of operational and safety improvements due to the use of communications devices have been identified. Very little doubt remains that improved mobile communications technologies, such as the ones briefly described in this paper, and a more widespread adoption of available and future devices will further increase the performance of the trucking industry.

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Estimating Service-Differentiated Transport Demand Functions

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This paper develops a methodology for estimating the demand for freight transport based on a model of the shipper's decision-making process. Conditions of optimality are used to specify a choice model—subject to some assumptions about the shipper's response to the risks incurred by using the transport system. This model is expanded to allow for testing for imperfection in the goods markets. If such imperfection exists, a technique is proposed that involves generating a posterior on shipment size, conditioned on alternative choice from a prior on shipment size and the estimated choice model. The resulting expectation of the posterior, when used in combination with industry supply functions, produces demand equations. Finally, market equilibria—where demand equals supply—are computed.

Estimating the demand for freight transportation has been a favorite pastime of many transport economists (1-12). Approaches have varied from gravity models to logit analysis (13). A major advantage of a gravity model is that it actually predicts flows. Its major disadvantage is that it is not based on any economic theory and thus is generally not sensitive to microeconomic parameters such as market prices, transport rates, and service levels. An advantage of a choice model, such as probit and logit analysis, has been its responsiveness to microeconomic parameters, although its estimation has usually been performed without regard to microeconomic theory (5); notable exceptions to this are found in Allen (1) and Beuthe (3). The estimated choice probabilities are then used to separate some given total quantity to obtain estimates of shipment size for each alternative. This method is clearly limited because the total amount shipped depends on the firm's decisions regarding alternatives and shipment size.

This paper develops a consistent methodology for estimating demand equations by starting from a microeconomic model of a shipping firm, estimating a choice model dependent on both alternative and shipment size, and then producing demand equations that reflect choice of market and mode, prices at the market, transport rates for the different modes, and service characteristics of the modes. This paper also presents a theoretical analysis of the shipping firm, develops the basic approach for deriving transport demand, estimates logit models for market-mode choice, and reports the results of the demand estimation and the estimated market equilibria.

FIRM TRANSPORT DEMAND AND ANALYSIS

Theory

Consider a typical shipper who can sell a product in various markets and can use several alternative transport modes. Assume that the firm is competitive in the sense that it takes market prices and transport rates as given; the firm's location is fixed in space.

In the following analysis this notation is used:

P_j = price of the product in market j, $j=1,\ldots,J$
t_{jm} = transport rate to market j by mode m, $j=1,\ldots,J$ and $m=1,\ldots,M$
q_{jm} = quantity shipped to market j by mode m by the firm
$H_{jm}(q_{jm})$ = service-induced transport cost of shipping q_{jm}
$C(q)$ = cost to firm of producing $q = \sum\sum_{jm} q_{jm}$

Notice that the alternative of not selling in any market and merely holding inventories can be included by identifying one of the market-mode pairs with not selling and not shipping.

Modes are differentiated by their service attributes such as speed and reliability. These attributes induce certain costs that are central to the theory of transport demand as a derived demand. Induced costs and how they relate to service attributes include the following:

1. Equipment availability costs. Uncertainty as to the availability of transport equipment when it is needed induces costs. For example, inventory costs are incurred when a shipment must be placed in a holding position while waiting for the arrival of transport equipment. Penalty costs may be levied on a shipper who cannot make delivery as scheduled. To the extent that late arrival of equipment exacerbates on-time delivery, these penalty costs can be associated with equipment availability. The opportunity costs that are incurred when a shipment is tied up because equipment is not readily available is another category of availability costs. Thus, availability is a service attribute that imposes costs on the shipper.
2. Transit costs. Interest and inventory carrying costs are incurred on the value of a shipment during transit. Furthermore, variance in scheduled transit time increases the risk of incurring penalties due to late delivery of goods and loss of goodwill. Thus, transit time on each mode is a service attribute that induces costs of using a particular mode.
3. Loading and handling costs. These costs will vary by mode when different combinations of labor and capital inputs are required. For example, special facilities may be needed to load rail cars vis-à-vis trucks.

An important aspect of transport service is reliability. In the case of physical reliability, there are risks associated with loss and damage. In the case of schedule reliability, there are risks associated with the ability of the shipper to deliver a shipment on a promised date. These risks are attributable in part to uncertainty in equipment availability and transit time variance. Thus, reliability introduces the notion of risk into the shipper's decision as to where to ship and by what mode.

In Daughety and Inaba (14) the selection of market and mode was treated as a portfolio problem of investment in risky assets. Under the assumption of risk-aversion the service-induced cost function $H_{jm}(q_{jm})$ can be expected to be strictly convex in q_{jm}. Now, consider the firm's profit function:

$$\Pi(q_{11},\ldots,q_{JM}) = \sum_j \sum_m [P_j q_{jm} - t_{jm} q_{jm} - H_{jm}(q_{jm})] - C(q)$$

The shipper chooses nonnegative q_{jm}'s so as to maximize $\Pi(q_{11},\ldots,q_{JM})$. The resulting q_{jm}'s are functions of prices P_j, rates t_{jm}, and the parameters for the functions $H_{jm}(\cdot)$ and $C(\cdot)$. These constitute the firm's derived demand for transportation. The first-order conditions are

$$P_j - t_{jm} - H'_{jm}(q_{jm}) - C'(q) = 0$$

$$q = \sum_j \sum_{m q_{jm}} \tag{1}$$

To clarify the relationships among the modal demand functions, the conditional (inverse) demand function for alternative η (i.e., mode m and market j; η = j,m) is defined as

$$r_\eta(q_\eta) = P_j - C'(q_\eta) - H'_\eta(q_\eta)$$

(The range of η is 1 to JM. In the sequel, lower-case Greek letters, such as ν, τ, etc., are used to represent market-mode alternatives.) Note that this is simply the left side (without t_η) of Equation 1 evaluated for $q = q_\eta$. Thus, if the only alternative available to the shipper were η (ship to j by m), then $r_\eta(q_\eta)$ is the maximum per unit rate that the shipper would be willing to pay to ship q_η on mode m to market j. Thus, it is a demand price for service. It is not the demand function for alternative η service since it is conditioned on being the only available alternative. It will be shown later that choice models give rise to $r_\eta(q_\eta)$, while regression models give rise to direct estimation of the demand function implicit in Equation 1.

If $r_\eta(q_\eta)$ is inverted, $r_\eta^{-1}(t_\eta)$ results. Summing over all firms produces $R_\eta^{-1}(t_\eta)$, the maximum price shippers would be willing to pay to ship a total of Q on alternative η, given that alternative η is the only alternative used by all shippers.

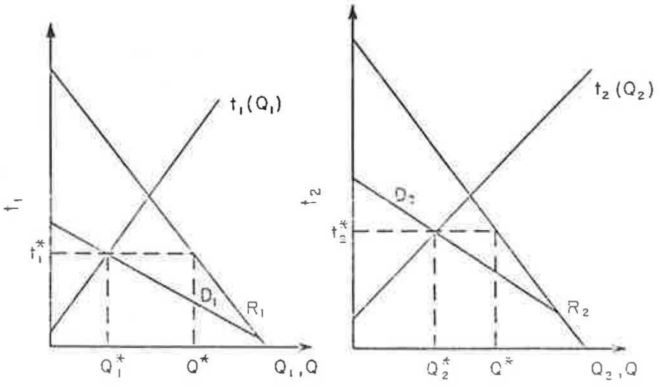
Let Q_η be the amount of service provided in alternative η. Thus, an inverse supply function $t_\eta(Q_\eta)$ is assumed, which represents rates as a function of quantities shipped. The demand for alternative η service is the set of ordered pairs (p_η, Q_η) that belong to

$$D_\eta = \left\{(p_\eta, Q_\eta) \epsilon R^2_+ \mid p_\eta \equiv R_\eta\left(\sum_\nu Q_\nu\right), t_\tau(Q_\tau) = R_\tau\left(\sum_\nu Q_\nu\right) \tau \neq \eta\right\}$$

In other words, demand for alternative η service is the set of nonnegative demand prices (p_η) and demand quantities (Q_η) so that Q_η is the residual demand left over after accounting for all other alternatives, based on a total flow $Q = \sum_\nu Q_\nu$ on all alternatives. For given Q, the $R_\nu(Q)$ is computed for each alternative. This calls forth Q_ν service $[=t_\nu^{-1}(R_\nu(Q))]$. Thus, $Q_\eta = \max(0, Q - \sum_{\nu \neq \eta} Q_\nu)$ is the residual demand quantity, and $p_\eta = R_\eta(Q)$ is the demand price. Varying Q results in tracing out the demand curve for alternative η. This is shown for a two-alternative case in Figure 1. Where unconditional demand (D_η) equals supply (t_η), the equilibrium for the transport market, which equilibrates the goods markets, exists.

The above analysis shows how demand for transport arises from a basic model of the shipper and that, in order to find demand, goods market characteristics

Figure 1. Market equilibrium using residual demand curves.



and service characteristics must be included as well as rates for service. It should be obvious that changes in, for example, service characteristics of one mode affect [via the $R_\eta(\cdot)$ function] the demand for alternative modes and, in this case, market selection as well.

Developing Estimation Models

The use of the first-order conditions does not stop with the theoretical analysis of demand. This section will show that not only can conditions of optimality be used to specify the form of the model to be estimated, but also that they provide a set of conditions indicating the applicability of various techniques (i.e., regression versus quantal choice) to the estimation problem itself.

As mentioned earlier, it can be shown that, under the assumption of risk-aversion on the part of the shipper, the service-induced cost functions $H_\eta(\cdot)$ will be strictly convex and monotonic. Consider the functions:

$$V_\eta(\cdot) \equiv P_j - t_\eta - H'_\eta(\cdot)$$

These functions reflect the marginal value of distribution of the good by alternative η. A restatement of Equation 1 is

$$V_\eta(q_\eta) = C'(\sum_\nu q_\nu) \quad \forall \qquad (2)$$

Since the service-induced cost functions are strictly convex and monotonic, the $V_\eta(\cdot)$ functions are downward sloping. Figure 2 illustrates the optimal solution, assuming four alternatives. As can be seen, the optimal solution is to use more than one alternative, in other words, to pick a portfolio of alternatives. Thus, except under special conditions, the shipper will not choose just one alternative; rather, the shipper will choose a mix. Thus, quantal choice models, wherein only one alternative is chosen, are not appropriate. Again, this is due to the risk-aversion of the shipper—a very reasonable assumption. In this case, the appropriate approach is regression analysis on a system of equations. This is unfortunate; because both $C(\cdot)$ and $H_\eta(\cdot)$ are unknown, this approach will be very data intensive.

H_η is strictly convex in general. However, for firms such as those being examined here (country elevators), a linear approximation to the risk function is not too inaccurate (4) because elevators typically ship only a fraction of their holdings at a time. Thus, in terms of wealth put at risk, these firms are relatively (compared to terminal elevators) close to the origin of the risk function and, thus, a linear approximation to the unknown function is appropriate. This is not necessarily true for very large shippers with a multilevel, coordinated decision-making process such as terminal operators.

If we now approximate $H_\eta(\cdot)$ by a linear function, then $V_\eta(\cdot)$ is a constant since $H_\eta'(\cdot)$ will be a constant. The result is shown in Figure 3. The optimal solution is to pick the maximum V_η and use only that alternative. Now, rather than using regression techniques on a system of equations, we instead should use quantal choice. For if we take the total marginal return to be the sum of a measured, nonstochastic term (V_η) and a random variable (ϵ_η), then we pose the choice problem as picking the alternative with highest marginal return, i.e., we want to pick alternative η if

$$V_\eta + \epsilon_\eta > V_\nu + \epsilon_\nu \qquad \nu \neq \eta$$

Define the choice variable y that takes the value y=n, if the shipper chooses the η-th alternative. Here the alternatives are defined as market-mode pairs. Let x_η be a vector of observable characteristics of the shipper and let w be a vector of unobservable variables. Assume that the shipper's decision depends on the x_η's, z, and w. Thus, probability distribution of y is determined by the vector $x = (x_\eta)$, z, and the unknown parameters that characterize the distribution of w. Then the most general choice model [see (15)] can be mathematically represented by

$$\text{Prob}\{y = \eta \mid x,z\} = \exp F_\eta(x,z,w) \Big/ \sum_\eta \exp F_\eta(x,z,w) \qquad (3)$$

Figure 2. Assuming four alternatives, shipper will choose a mix as is shown by downward-sloping curves. Risk here is strictly convex.

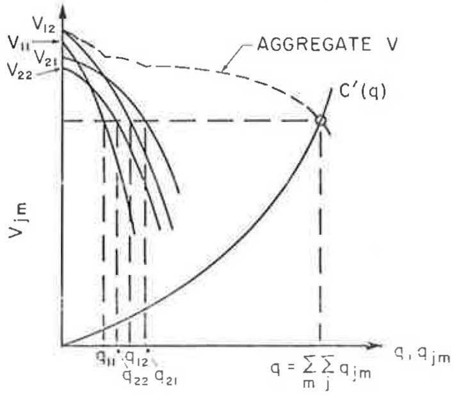
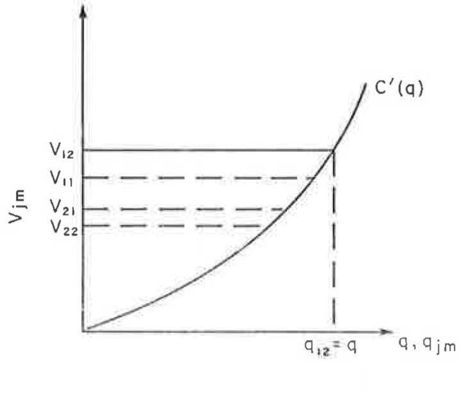


Figure 3. Linear risk for shipper is indicated; thus the optimal solution is to choose only one alternative.



where F_η is some function. Considerable effort has been expended on Equation 3 in recent years by Amemiya (15), Domencich and McFadden (16,17), and Nerlove and Press (18). McFadden has shown that if the ϵ_η's are independent with distribution $[-\exp(-\epsilon_\eta - \alpha_\eta)]$ where α_η is a parameter, then, letting $F_\nu\ (x,z,w) = V_\nu - a_\nu$, we have

$$\mathrm{PR}\{V_\eta + \alpha_\eta > V_\nu + \alpha_\nu\ \nu \neq \eta\} = \Pr\{y = \eta \mid x,z\}$$

$$= \exp(V_\eta - \alpha_\eta) \Big/ \sum_\nu \exp(V_\nu - \alpha_\nu)$$

Therefore, if we approximate H_η with a linear function, which reflects the fact that country elevators typically make small shipments (relative to their total wealth), then a choice model can be used. We have chosen to use a logit representation of the choice problem both because of the McFadden results and computational ease as well as its closeness to alternative choice models (16,17). The models used were

$$\Pr\{y = \eta \mid V\} = \mathrm{Prob}\{V_\nu + \epsilon_\nu < V_\nu + \epsilon_\nu\ \forall_{\nu \neq \eta}\} \tag{4}$$

and

$$\Pr\{y = \eta \mid q,V\} = \mathrm{Prob}\{V_\nu q + \epsilon_\nu < V_\eta q + \epsilon_\eta\ \forall_{\nu \neq \eta}\} \tag{5}$$

where unsubscripted V stands for the vector (x,z). The reason for the second model is that, if it outperforms Equation 4, there is an indication of imperfection in the goods market. As one might expect, this is what occurred.

ESTIMATING THE CHOICE MODEL

This section deals with modeling a specific type of shipper—a country elevator that ships corn to various markets. In general, such characteristics as loss and damage and schedule reliability are not critical to such shippers, although other service characteristics are important. Specifically, we include a measure of equipment delay, i.e., availability (4). The measure that enters the shipper's profit function provides an approximate cost associated with using a mode. After estimating the two choice models, we will then show how demand functions can be derived. The analysis was performed in customary units rather than SI units.

Measuring Availability

Shippers form expectations about various service parameters. Miklius and Casavant (19) found that such expectations may not reflect reality. Nevertheless, shippers act on their expectations. In this case, grain elevator operators evaluate the availability of transport equipment, i.e., how much equipment delay they expect to experience in ordering and obtaining transportation vehicles (trucks, rail cars, barges) to fulfill commitments. Delays are often expected during the harvest period when transportation use is at its peak and resources are scarce. Then the availability of a piece of equipment can be critical. A number of different types of contracts with various provisions for delivery times exist and are used (20). In all cases, however, elevator operators require a high degree of confidence in the availability of equipment to make deliveries. Thus, opportunities may be foregone or responses to bids altered due to expectations about the availability of transport equipment.

Daughety and Inaba (4) showed how data collected by questionnaire could be used to construct an availability measure. The authors defined the α-expected delay to be n days where n is the value so that $\Pr\{T \leq n\} = \alpha$ with T the number of days' delay in equipment arrival. The following table shows the 0.95-expected delay times and costs for two groups of shippers: SCR shippers (those who used only truck or single-car rail) and MCR shippers (those who used truck and single- and multiple-car rail).

Shipper	Days	Cost per Bushel ($)
Small (Truck, SCR)	7.8	0.0042
Large (Truck, SCR, MCR)	13.5	0.0072

The costs are found by evaluating the delays at the average inventory holding of 1.6¢/bushel/month. This table will not be discussed further other than to note that bigger shippers get poorer service in part because the railroads are unable to adjust their rates (4).

Specification of Model for Estimation

The behavioral model of the country elevator takes risk as linear and thus only one market and one mode are chosen to maximize the elevator's choice function (i.e., net price or net profits). Therefore, the logit technique is appropriate.

The observable part of the choice index consists of three types of exogenous variables or attributes: market variables, market-mode variables, and shipper-mode variables. Let P(n), t(n), A(n) be the vectors of exogenous variables observed by the n-th shipper where

$P_j(n)$ = the price at the j-th market,
$t_{jm}(n)$ = the transport rate of shipping to the j-th market by the m-th mode, and
$A_m(n)$ = the perceived availability cost per bushel of shipping by the m-th mode.

Following the theoretical considerations presented earlier in this paper, the choice index of the country elevator can be either net price or profits = net price x quantity. Therefore, the logit models used in this study are

1. The net-price model

$$\Pr\{y = (j,m) \mid P(n), t(n), A(n)\} = \exp[\alpha_{j1} P_j(n) + \alpha_{jm2} t_{jm}(n) + \alpha_{m3} A_m(n)] \Big/ \sum_{\ell} \sum_{k} \exp[\alpha_{\ell 1} P_\ell(n) + \alpha_{\ell k2} t_{\ell k}(n) + \alpha_{k3} A_k(n)] \tag{6}$$

2. The net-profit model

$$\Pr\{y = \eta \mid q(n), P(n), t(n), A(n)\} = \exp[\alpha_{j1} P_j(n) q(n) + \alpha_{jm2} t_{jm}(n) q(n) + \alpha_{m3} A_m(n) q(n)] \Big/ \sum_{\ell} \sum_{k} \exp[\alpha_{\ell 1} P_\ell(n) q(n) + \alpha_{\ell k2} t_{\ell k}(n) q(n) + \alpha_{k3} A_k(n) q(n)] \tag{7}$$

For SCR shippers, the availability cost for rail is $0.0042/bushel, whereas for MCR shippers, this variable has the value $0.0072/bushel. Since trucks are generally readily available (4), the availability cost is zero for all shippers in the sample.

Data and Estimated Choice Probabilities

In 1976, a survey was circulated to elevator firms in Indiana, Illinois, and Iowa. The survey asked for firm-level information (ownership structure, capacity, modes used, markets traded with, monthly storage charge, and accessibility to transport system), subjective assessments (the distribution of delay times in receiving equipment of various modes), and randomly selected shipment examples for specified times of the year and for specified crops. The individual shipment records contained information on quantity shipped, mode, contract price, transit time, transport rate, who paid the transport, destination, expected travel time, date of contract commitment, and shipment due date. For this study, only price, quantity, transport rate, whether the shipper paid the transport rate, destination, mode, and the distribution of delay times were used. Generally, no records are kept that indicate forgone opportunities. Thus, it was necessary to construct alternatives for each shipper.

Two major market areas were specified: river and local. River covers midwest and mideast destination points on the Missouri, Mississippi, Illinois, and Ohio rivers, as well as Chicago. All other midwest and mideast traffic is typically local. Shipments to the coasts were excluded. Obviously, such labels are somewhat arbitrary. The aggregation of the destinations into market areas was made on the basis of the type of activity associated with the area as well as the relative distance of a specific location to the alternative areas.

Two modes were examined: truck and single-car rail. All data were gathered for the week of October 19, 1975. This week is well into the harvest season for corn, the selected crop. Answers from those elevator firms that only used trucks to make shipments were used only to compute some average values. Since these elevator firms had eliminated other modes from their choice set, we could not include them in the overall choice analysis. An examination of why such firms choose not to even consider other modes will not be considered here.

As is well known, prices at the different markets reflect, to some extent, the commodity futures trading activity in the crop. Corn is traded at the Chicago Board of Trade. Prices did not vary greatly (σ = 0.234). Thus it was felt that the average regional prices from the data base would provide reasonable surrogates for the actual prices at the alternative markets. The regional prices per bushel were \$2.663 (river) and \$2.605 (local).

Actual transport rates were not obtained for alternatives not chosen. Rates were predicted from data collected on shipment sizes, rate paid, and distance shipped. Finally, availability costs per bushel were zero for truck, \$0.0042 for single-car rail when used by shippers who only use single-car rail at most, and \$0.0072 for single-car rail when used by shippers who also can use multiple-car rail.

Table 1 displays the estimated values of the coefficients for both of our logit models. Two models (truck and single-car rail) and two markets (river and local) result in four alternatives: truck to the river (TR), truck-local (TL), single-car to the river (SR), and single-car local (SL).

Table 1. Net-price and net-profit probability models.

	Model			
	Net-Price		Net-Profit	
Factor	River	Local	River	Local
Price	2.626 (1.046)	3.176 (1.193)	0.0014 (3.412)	0.0013 (2.945)
Truck	-33.21 (-3.889)	-64.63 (-4.491)	-0.0096 (-3.925)	-0.0128 (-3.297)
Rail	-16.74 (-3.547)	-25.29 (-3.410)	-0.0048 (-3.635)	0.0016 (-3.060)
Availability	-457.5 (-2.394)		-0.0669 (-1.951)	

Note: Asymptotic t-values for coefficients are shown in parentheses.

The first model predicted the correct choice 90 percent of the time and had a likelihood ratio index of 0.865, while the values for the second model were 82 percent and 0.4028 respectively. The likelihood ratio index gives a weak measure of the explanatory power of the model and is defined as one minus the ratio of the log-likelihood at zero, [For a discussion of this measure and its relationship to other goodness-of-fit measures, see Domencich and McFadden (16).] Asymptotic t-values for the coefficients are shown in parentheses. It is interesting to note that the first model has better summary statistics, whereas the price variables are not very significant. The theory expressed earlier suggests that, if elevators are competitive and have approximately linear service-induced transport cost functions, then the net-price model should be a good representation of market-mode choice. However, as Table 1 shows, a comparison of the t-values on the price variables suggests this is not true. The fact that market prices in the net-price model are insignificant is inconsistent with the theory, the remarks made by elevator operators, and the fact that organized futures markets exist to amplify and communicate information on market prices. On the other hand, when net price is multiplied by quantity, the market price variables in the net-profit model become significant.

Discussions with country elevator operators clarified the matter. In general, elevators face two types of buyers. One type—generally the larger buyers—accepts virtually any shipment size in response to its posted bids. These buyers reflect a perfectly elastic demand for grain. The second type of buyers poses downward-sloping demand curves. They issue a bid for grain and, as with the first type of buyer, the country elevator operator responds with an amount to ship. This is then negotiated, along with the bid price itself, either until a mutually satisfactory bid price and quantity are found or until negotiations break down. Clearly, the buyers are seeking points on their demand curve, while the elevators are attempting to stay on their supply (marginal cost) curve. The result is either a cobwebbing-in to a negotiated solution (intersection) or divergence (no contract).

The existence of such transactions is easily confirmed; their extent in the market, however, is unknown. A test for their effect on shipper choice is the estimation of Equation 7, the net-profit model. The t-values on revenues (price times quantity) are very significant, indicating that market imperfection in terms of bid negotiation is extensive and invalidates the use of Equation 6, the net-price model. The analysis in the rest of the paper is based on Equation 7.

Demand Functions and Choice Probabilities

Two ways to predict demand have already been noted. The first was through aggregating individual demand functions. If we had been able to use regression, we could now do this. It is also impossible to directly find the demand function using quantal techniques. An individual demand function would be represented as

$$E(Q_\eta \mid V) = \int_{-\infty}^{\infty} q \, dPr\{y = \eta, q \leq Q \mid V\}$$

where V is a vector of observed parameter values. By varying t_η, for example, we could trace out the demand for transportation for alternative η. Unfortunately, we do not have an estimate of $PR\{y=\eta, q \leq Q \mid V\}$. This can be seen by the following:

$$\Pr\{y=\eta, q \leqslant Q \mid V\} = \Pr\{q \leqslant Q \mid y=\eta, V\} \cdot \Pr\{y=\eta \mid V\} \qquad (8)$$

$$\Pr\{y=\eta, q \leqslant Q \mid V\} = \int_{-\infty}^{Q} \Pr\{y=\eta \mid q \epsilon d\bar{Q}, V\} \cdot \Pr\{q \epsilon d\bar{Q} \mid V\} \qquad (9)$$

Equation 8 cannot be estimated because it requires the net-price model, the applicability of which is precluded by market imperfections. Moreover, Equation 9 requires additional estimates of the firm's choice behavior, i.e., $\Pr\{q \leq Q | V\}$.

However, aggregate demand functions for each market-mode pair can be estimated from the net-profit model by using the method presented in the section on firm and transport demand theory. Let $h(q|\eta,V)$ be the posterior density on shipment size given that the firm chooses alternative η and observes the vector V of parameter values. Let f(q) be the prior density on shipment size. Then by Bayes' theorem

$$h(q|\eta, V) = [\Pr\{y=\eta|q, V\} \cdot f(q)] \Big/ \int_{-\infty}^{\infty} [\Pr\{y=\eta|q, V\} \cdot f(q)dq]$$

where $\Pr\{y=\eta|q,V\}$ is, of course, the selection probability of the net-profit model. Then

$$E(Q|\eta, V) = \int_{-\infty}^{\infty} qh(q|\eta, V)dq$$

gives the expected quantity shipped given η and V. Notice that if we only alter t_η (in V) and trace out the expected shipments, we will trace out $r_\eta^{-1}(t_\eta)$, the conditional demand for alternative η service discussed earlier. Using the procedure outlined, we can thus estimate $R_\eta(Q)$ functions and, given supply functions, we can estimate demand functions for each market-mode pair.

DEMAND FUNCTION ESTIMATION RESULTS

Prior Density on Shipment Size

The prior on shipment size, f(q), was taken to be normally distributed, based on an elementary central limit theorem argument. Two priors were used, i.e., one for small shippers and one for large shippers. The means and standard deviations for the priors are shown in the following table:

Shipper Size	Mean	Standard Deviation
Small	4 075	5 912
Large	11 835	23 484

Individual $r_\eta(q_\eta)$ and Market Level $R_\eta(Q)$

Using the priors shown above, $E(Q|\eta,V)$ was computed for both types of shipper, for all four alternatives, and for various values of t_η. Table 2 displays coefficients for linear regressions that were fitted to the computed values.

The regressions in Table 2 represent inverses of $r_\eta(q_\eta)$. As can be observed, all are downward sloping except small shippers, alternative (SL), which is constant. The computed shipments were then aggregated and scaled upward to represent the region (2500 elevators). Table 3 displays the inverses of $R_\eta(Q)$.

Supply

Demand for modal service is a residual demand, and supply functions must be estimated before demand curves are derived. In this study, rate functions are used as surrogates for supply curves. These approximations had to be used because supply functions for truck and rail for the region do not exist in the literature, and limitations of cost data precluded estimation of supply curves in the traditional manner.

Rate functions were estimated for the four market-mode alternatives by regressing rates on the amounts shipped by alternative. Assuming that the sample rates and quantities shipped are representative of the typical transport firm, an estimate of the aggregate amount shipped on an alternative mode was obtained by multiplying the sample quantities by an estimate of the number of typical firms providing the service. The procedure to estimate the number of typical firms providing service to each market-mode alternative is described here.

Assume that a typical firm is represented by the amount of service supplied during the period svq, where s is the number of shipments per vehicle during the period, v is the number of vehicles per firm, and q is the load per vehicle. Then the amount that a typical firm can carry on one shipment is Q = vq. If N is the number of firms providing service on an alternative, the quantity of service provided during the period must be T = Nsvq = NsQ.

Estimates of T,s,q, and Q yield estimates of N, the number of typical firms, and v, the number of vehicles per firm. To estimate the T's, the sample totals of the quantity shipped on each alternative were scaled up to the projected total shipments by alternative for the region. Estimates of s were obtained from the data on actual transit times reported

Table 2. Regression of $E(Q|\eta,V)$ on t_η.

Alternative	t_η	Constant	R^2
Small shipper:			
TR	-72 875	13 988	0.97
	(16.3)	(25.5)	
TL	-51 072	7 748	0.86
	(-7.2)	(10.5)	
SR	-32 468	10 682	0.97
	(-16.9)	(25.2)	
SL	51.6	7 757	-
	(0.2)	(145.8)	
Large shipper:			
TR	-314 030	55 439	0.75
	(-5.0)	(7.2)	
TL	-241 000	30 515	0.53
	(-3.2)	(3.9)	
SR	-44 697	13 359	0.91
	(-9.2)	(12.4)	
SL	-197 440	62 839	0.99
	(-28.6)	(41.1)	

Notes: TR = truck-to-river; TL = truck-local; SR = single-car to river; SL = single-car local.
Asymptotic t-values for coefficients are shown in parentheses.

Table 3. Inverses of $R_\eta(Q)$.

Alternative	t_η	Constant	R^2
TR	$-6.2116 \cdot 10^8$	$1.1042 \cdot 10^8$	0.78
	(-5.4)	(7.8)	
TL	$-4.734 \cdot 10^8$	$6.0812 \cdot 10^7$	0.56
	(-3.3)	(4.1)	
SR	$-1.0348 \cdot 10^8$	$3.1579 \cdot 10^7$	0.93
	(-10.2)	(14.1)	
SL	$-3.5937 \cdot 10^8$	$1.1966 \cdot 10^8$	0.99
	(-28.7)	(43.1)	

Notes: TR = truck-to-river; TL = truck-local; SR = single-car to river; SL = single-car local.
Asymptotic t-values for coefficients are shown in parentheses.

in the survey. The average shipment sizes were used as estimates of the Q's. Finally, average load capacities for truck and rail hopper cars were used to approximate the q's. Our procedure yielded these estimates: the number of typical firms providing truck service to the river and local was 427 and 128 respectively; the number of typical firms providing rail service to the river and local was 416 and 416 respectively; the number of vehicles per firm was 6 and 11 trucks, 1 and 3 rail cars respectively.

Clearly, our procedure suffers from the fact that vehicles are switched and reallocated among markets on a daily basis. Consequently, our definition of a typical firm as a grouping of transport vehicles providing service sufficient to carry the average load departs considerably from the actual. However, within this constraint, the implied industry supply functions as approximated by rate functions are shown in the following table:

Alternative	Prediction Equation	R^2
TR	$t_1 = 0.189\,065q^{-0.031\,893}$	0.69
TL	$t_2 = 3.284 \cdot 10^{-8}q + 0.0531$	0.27
SR	$t_3 = 1.0474 \cdot 10^{-8}q + 0.2087$	0.39
SL	$t_4 = 1.0474 \cdot 10^{-8}q + 0.1828$	0.39

These were found by estimating individual rate functions and then scaling up to reflect the implied size of each alternative "industry."

As shown, all functions are linear except for the first alternative, which was log-linear. Rates are predicted as a function of shipment size (in bushels × 10^{-7}). Again, the reader is cautioned that these are not aggregate marginal cost functions. They are simply observed relationships between rates and shipment size, scaled up by estimated number of firms.

In general, alternative one reflects an essentially horizontal supply function, while the second alternative is upward sloping. This probably reflects the fact that local movements entail search costs for the next load; movements to the river provide lower search costs due to higher concentrations of firms. The fact that the rail-rate functions slope upward does not conflict with the regulation of rails. Rates are regulated on a point-to-point basis, while the rate functions are aggregations over a three-state region.

Demand Functions and Resulting Equilibria

Elements of D_η ($=1,\ldots,4$) were computed and then fit with a linear equation to summarize their trend. These equations are displayed below:

Alternative	t_η	Constant	R^2
TR	$-7.0341 \cdot 10^8$	$1.1477 \cdot 10^8$	0.99
TL	$-5.4795 \cdot 10^8$	$5.8201 \cdot 10^7$	0.98
SR	$-1.3673 \cdot 10^8$	$2.526 \cdot 10^7$	0.99
SL	$-3.3604 \cdot 10^8$	$1.1122 \cdot 10^8$	0.93

Caution is again suggested in using these results. The high linearity is simply due to the use of linear functions to derive the demand curves. Future work must rely on more sophisticated statistical and numerical techniques. Nevertheless, the following approximate equilibria were computed:

Alternative	t_η (\$)	q (bushels)
TR	0.108	38 500 000
TL	0.103	1 500 000
SR	-	-
SL	0.289	14 000 000

For the third alternative, demand was slightly below supply and thus the model predicts no market for services. This corresponds reasonably well with the observation that, for the movements used to estimate the logit function (78 elevators), single-car-to-the-river accounted for only 6 percent of the total quantity moved. Statistical and numerical error probably account for the result indicated in the preceding table.

The estimates for the first and fourth alternatives seem slightly high (it was generally expected that total flows would be in the neighborhood of 25 to 35 million bushels). This is also reflected in the fact that total shipments ($\sum_\eta q_\eta$) do not equal implied total shipments from $R_\eta^{-1}(t_\eta)$. This is clearly a result of the heavy reliance on the estimated linear relationships among the variables and the size of the sample used. However, relative magnitudes are generally reflective of the data observed.

SUMMARY

In this paper we have developed a technique for estimating demand for transport service that is sensitive to transport rates, market prices, and service levels. We estimated own-demand functions; clearly a variety of cross-demand functions could similarly be derived as well as demand functions parameterized on perceived service level.

The approach was based on a model of a shipper's decision-making process. Conditions of optimality were used to specify a choice model subject to some assumptions about the shipper's response to the risks incurred by using the transport system. This model was expanded to allow for testing for imperfection in the goods markets. In the presence of such imperfection we proposed a technique that required generating a posterior on shipment size, conditioned on alternative choice from a prior on shipment size and the estimated choice model. The resulting expectation of the posterior, when used in combination with industry supply functions, produced demand equations. Finally, market equilibria—where demand was equal to supply—were computed.

Improvements must occur in at least two areas. First, industry supply curves based on cost analysis must be used rather than the rate functions used herein. Second, a larger sample of elevator firms is called for. Both of these problems are presently under development.

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Effect of Increased Motor-Carrier Sizes and Weights on Railroad Revenues

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Railroad net revenue is directly related to motor-carrier rates and costs on all traffic for which motor carriage can be substituted easily for rail service. Increases in maximum lawful truck sizes and weights will lead to lower motor-carrier costs. Competition and regulatory pressure will translate these lower costs into lower rates. Railroads will have to either match the lower rates or lose traffic to the competing mode. In either instance, railroad revenue will decline as a result of the increased truck sizes and weights. The amount of loss depends on the reduction in motor-carrier costs and rates brought about by the increase in capacity, and by the proportion of existing rail traffic that will move by motor carrier if the relative rates of the two modes change. If motor-carrier capacity increases from 33 249 kg to 40 834 kg (from 73 280 lb to 90 000 lb), costs of operation and rates are estimated to decline by 16.8 percent. Potential for diversion from rail to truck was estimated by examining market shares of each commodity in each distance grouping. Available market share data suggest that railroads compete with motor carriers for traffic accounting for approximately 75 percent of rail revenue. Thus, a 16.8 percent decline in motor-carrier costs and rates would force railroads to make competitive adjustments that would cost the industry up to $2 billion.

An increase in motor-carrier size and weight limits will lower the cost of carrying goods by motor carrier, thus increasing the attractiveness of motor carriage over rail carriage. Lower motor-carrier costs would permit for-hire motor carriers to reduce rates to attract traffic from railroads and would lower the costs of private carriage. Where shippers view railroads and motor carriers as alternative means of shipping goods, a change in the cost of moving by one mode rather than another will encourage substantial diversion of traffic to the mode offering service at reduced cost. The mode affected by the diversion can either lose the traffic or lower rates to maintain its share of market. The amount of diversion that will result from a given change in relative prices is a function of the elasticity of substitution between the two modes, i.e., the degree to which shippers will change modes in response to a change in price. Elasticity of substitution will vary among commodities and over different distances for the movement of a single commodity.

The 1972 Census of Transportation (1) provides information about the share of market by mode for each 3-digit commodity code by distance block. Thus, one can infer the susceptibility of each commodity to diversion from the existing market share data. Where motor carriers already have a significant share of the market, they can be expected to substantially increase their market share if cost of shipping by motor declines relative to the cost of shipping by rail. In such cases, railroads must either choose to leave rates unchanged and lose the contribution to overhead such traffic previously provided, or reduce rates to hold onto traffic and incur a revenue loss equal to the reduced contribution to overhead. The sum of the reduction in contribution to overhead from lost traffic and from rate reductions equals the revenue loss resulting from the change in motor-carrier costs.

EFFECT OF CHANGES ON COSTS AND RATES

Motor-carrier net revenue is a function of revenue per 45.3 kg (100 lb) of freight carried, amount of freight carried, and costs of operating the tractor and trailer(s) over the route. Thus,

$$NR_1 = R_1(CAP) - TC \qquad (1)$$

If heavier loadings are permitted, then at constant rates R_1, revenue increases by the amount of additional freight times the rate per 45.3 kg (100 lb), less any additional costs in operating the tractor and trailer(s). Thus,

$$NR_2 = R_1(CAP) + R_1(\Delta CAP) - (TC + \Delta TC)$$

and

$$NR = R_1[(\Delta CAP) - \Delta TC] \qquad (2)$$

where

NR = Net Revenue,
TC = Total Cost,
CAP = Capacity of trailer(s) expressed in 45.3 kg (100 lb) and as constrained by law, and
R = Motor-carrier rate per 45.3 kg (100 lb).

As long as $R_1(\Delta CAP) > \Delta TC$ cost per 45.3 kg (100 lb) falls. For an unregulated carrier, competition will force down motor rates to levels approaching cost (including fair return). Regulated carriers are supposed to be regulated in such a manner that they only earn cost plus a fair return. Private carriers examine their cost of carriage when determining whether to use their own fleet or ship by common carrier. If competition, regulation, or cost per 45.3 kg (100 lb) determines charges against which railroad rates are compared when deciding which mode to use, then one can expect rates to fall as needed to hold net revenue at the break-even level (the break-even level permits a firm to earn a market rate of return). Competitive pressure will force motor-carrier rates and costs down to a level where net revenue is increased by enough to cover any increase in capital costs. Thus, a new rate level (cost level for private trucking) will emerge equal to the old level plus any additional costs of the increased size:

$$R_2 = [R_1(CAP) + \Delta TC]/(CAP + \Delta CAP) \qquad (3)$$

The rate level falls proportionately with the increase in capacity except as countered by increases in costs resulting from operating at the additional capacity limits.

SUBSTITUTING MOTOR SERVICE FOR RAIL SERVICE

The level of revenue loss to railroads resulting from declining motor-carrier costs is, to a large extent, a function of how aggressively motor carriers seek to attract traffic previously moving by rail. If the history of diversion of commodities from rail to truck in the post-World War II period is prologue, the motor carriers will take advantage of reductions in costs brought about by changes in capacity constraints to attract traffic from railroads. If railroads continue to act as they have in the past, they will lower rates as necessary to try to retain traffic unless the rate reduction would result in out-of-pocket losses. Since railroad rates are typically lower than truck rates because rail service is generally perceived to be inferior to truck service for most commodities, a reduction in motor-carrier rates must bring forth a corresponding reduction in railroad rates that at least maintains the relative rate differential in order to maintain market share.

Ideally, one would like to measure the effect of relative rate changes on modal choice in each market by examining the change in modal traffic distribution that occurs as motor-carrier rates and private-carrier costs fall. The greater the opportunity to substitute one mode for the other, the larger the effect of a change in truck rates on diversion, and thus, the greater the rail rate reduction needed to hold traffic. Unfortunately, the specific data required for such an analysis are not normally available. Examination of market share data, however, can be used to infer the elasticity of substitution between truck and rail.

The inherent assumption in such an approach is that whenever a considerable portion of a commodity is already moving by motor carrier in a given distance block, a 16.8 percent reduction in motor rates is likely to trigger a substantial diversion of existing rail traffic to truck. The only alternative thesis would be that the service provided by the two modes is different and that changes in relative prices will not affect the distribution of traffic. The trend of market share data, shown in the Census of Transportation and in the Fresh Fruit and Vegetable Unload Data (2), supports the view that the services are close substitutes. In particular, the evidence shows that traffic has been shifting from rail to motor carrier whenever motor-carrier rates or costs fell relative to rail rates. Additional evidence of the pervasive nature of competition is found in the numerous hold downs found in railroad general rate increases and the scaling down or cancelling of rate increases by railroads on the grounds that competition would not permit it (3).

Similar evidence is available on a more geographically specific basis for grain movements moving through the Minneapolis-St. Paul area. Again, the market share of motor carriers has been rising over the past decade as motor-carrier rates fell relative to rail rates. Examination of available market share data collected on a monthly basis demonstrates that there is a high cross elasticity of demand between rail and motor services. Rail market share is largest in those months when truck rates are highest (usually during harvest or large international grain sale periods); it drops off sharply as motor-carrier rates fall. The variation in demand for rail services is extremely sharp, as truck prices move from levels below to levels above rail rates. Available market share data on produce demonstrates that the cross elasticity of substitution for transportation of agricultural products is very high (2). The general increase data provide similar support for the thesis that there is a high cross elasticity of demand for a broad set of manufactured products. The evidence on cross elasticity of demand, in turn, supports the thesis that rail rate reductions implemented to match motor-carrier rate reductions will generally minimize revenue loss as long as the resulting rail rate is above long-range incremental cost.

The evidence of high cross elasticity of demand for most manufactured and agricultural products must be measured for each commodity. Any commodity already moving by motor carrier to a significant extent is likely to exhibit high sensitivity in choice of mode to changes in relative rates. Commodities still moving completely by rail may be divertible to motor carriers as motor-carrier rates decline by 16.8 percent relative to rail rates. We have, however, followed the conservative approach of assuming that traffic currently moving primarily by rail will continue to move by that mode even if motor-carrier rates fall. To the extent the assumption is in error, estimates of diversion, and consequently of rail revenue loss, are understated. The higher the share is of a commodity already moving by motor carrier in a given distance block, the higher the amount of diversion that will occur as a result of a relative decline in motor-carrier rates. A 16.8 percent decline in motor rates will force explicit reevaluation of modal choice throughout the shipping community. Even when relatively major changes in packaging or in design of shipping and receiving facilities become necessary to shift modes, they are likely to be considered by shippers when relative changes in rates of this order of magnitude emerge.

For purposes of this analysis, we assume railroads will drop rates to meet truck competition for traffic currently carried by rail as long as the resulting rail rate remains above the long-range variable cost of moving the traffic involved. Motor carriers will seek to divert traffic from railroads by lowering rates as long as they can earn a market rate of return on both existing and new traffic. Specifically, market and regulatory pressures will cause motor carriers to continue to lower rates until diversion is maximized (because rail will not cut their rates further to hold onto traffic) or until competition for rail traffic or for other motor-carrier traffic forces rates to reach level R_2, the level that leaves them with the same rate of return they earned under the old capacity constraints. Whether railroad competition, intramodal truck competition, or competition with private truckers would force rates to level R_2 is a question that need not be answered for purposes of calculating the revenue loss to railroads resulting from changing size or weight constraints for motor carriers. The cost to railroads will be the same regardless of the source of downward pressure on rail rates.

Not all traffic moves at railroad rates sufficiently close to truck rates that a change in truck cost resulting from a capacity increase will make a truck movement competitive with railroad movement. Some traffic moves by railroad because rail rates are such that even substantial reductions in motor-carrier costs would not result in rates competitive with those of the railroads. Movements over any distance of coal, ores, and gravel are often cited as examples of commodities that fall into this class. Finally, for many commodities, trucks are thought to be competitive over shorter distances, but not competitive over longer distances as railroad average costs per kilometer tend to drop, while corresponding average truck costs remain relatively constant. Both the ability to move by each mode and the effect of distance on modal choice are tested for each major commodity group in order to determine how much rail traffic is divertible to motor carriers.

Other traffic moves by railroad for reasons unrelated to the relative level of long-term costs (at least within the range of change contemplated here). For example, a shipper who relies on private trucking for the majority of a firm's shipments may use rail services to handle some traffic during peak shipping periods. In this manner, the shipper can keep the firm's private truck fleet fully utilized. The shipper will use rail carriers for peak load movements whenever the rail rates are lower than the cost of maintaining a partially utilized truck fleet. Those shipping primarily in unregulated trucks may find times when truck rates rise above the rail rates in response to short-term changes in market conditions unrelated to costs of providing service. At such times, these shippers will shift to rail transportation for brief periods. Finally, some traffic moves by rail even at rates higher than motor-carrier rates because of preference of the consignor, consignee, or both. A firm set up to handle all incoming shipments by rail may demand rail service even when, on occasion, rail rates are higher than motor-carrier rates simply because of the inconvenience associated with receiving an occasional shipment by truck.

INCREASING MOTOR-CARRIER CAPACITY AND COSTS

Federal law permits motor carriers to carry up to 36 288 kg (80 000 lb) unless constrained by a lower limit set by any state through which the carrier moves. Many states have imposed such lower limits. Since lower state limits not only constrain movements originating or terminating in a state but also movements going through the state, it is impossible to say what traffic is subject to which weight constraint. More important, the market share data available from the 1972 Census of Transportation (1) reflect the effect of the old 33 249-kg (73 280-lb) weight limit on relative market share. Thus, for the purpose of evaluating the effect of an increase in size and capacity to 40 834 kg (90 000 lb), the analysis is based on a 33 249-kg (73 280-lb) weight limit. Some have asserted that the railroads are already suffering diversion on reduced revenues as a result of the increase to 36 288 kg (80 000 lb); however, no quantification of the effect of the change on rail traffic or revenue has yet appeared.

When weight limits are increased, motor-carrier costs rise by less than net cargo weight and revenue (assuming constant tariff rates). This occurs because some components of motor-carrier costs do not vary in direct proportion to gross vehicle weight. Cost components such as driver wages and certain taxes are independent of vehicle weight. On the other hand, tire cost is a direct function of weight and will increase 1 percent for every 1 percent increase in weight. Maintenance and fuel cost are essentially directly proportional to engine power output. Engine power output at 88 km/h (55 mph) is, in turn, about 50 percent dependent on weight and 50 percent dependent on aerodynamic drag. Thus, holding speed and vehicle frontal area constant, maintenance and fuel costs increase only 0.5 percent for each 1 percent increase in gross vehicle weight. The relationships of vehicle purchase price (and, thus, depreciation and financing costs) and of insurance costs to gross vehicle weight are less clear. An estimate of a 0.5 percent increase in cost for a 1 percent increase in gross vehicle weight seems reasonable. [Doubling this estimate to 1 percent—a directly proportional relationship—or decreasing it to 0 percent (no relationship) produces only a 1 percent change in total operating cost.]

When applied to an increase in gross weight from 33 249 kg (73 280 lb) to 40 834 kg (90 000 lb), these parameters, applied to motor-carrier operating costs, define a 16.8 percent decrease in cost per ton of cargo. If rail-competitive truckload rates reflect cost (and competition from private carriage and rail rates probably force them to this level), railroad rates would have to decline by at least this same 16.8 percent on truck-competitive traffic to hold that traffic on rail. To the extent rail rates are lower than motor rates to reflect a quality of service differential, a further decline may be required.

DETERMINING EXPECTED DIVERSION

Market share information by commodity and distance block is available in the 1972 Census of Transportation (1) from which inferences may be made about the intermodal cross elasticity of demand. The evidence presented here suggests that the higher the motor-carrier share of the market, the higher the cross elasticity of demand and the greater the rate adjustment a railroad must make to hold onto its traffic. In those markets where railroads have a large proportion of the market, a less than proportionate rate reduction is needed to hold onto market share. Alternatively, if the rate reduction does not occur, the expected amount of diversion to motor carriers is smaller. As the motor-carrier existing market share rises, the substitution prospect of motor service for rail service is demonstrably greater, and motor-carrier rate reductions must be more nearly matched by railroads if they are to hold market share.

Motor-carrier service is generally considered to be superior to rail service. Thus, shippers will pay a premium and continue to use motor service. Since the value of the service differential is different for different shippers (higher for the shipper not located on a railroad line than for the shipper located on a frequently served industrial siding), the effect of a given change in relative rates on different shippers will be different. Basically, the service differential almost always favors the motor carrier. Thus, the resulting estimate of the cost of motor rate reductions, if it is in error at all, will be on the low side.

If rail market share is 80 percent or greater in a distance block, and in the next shorter distance block railroads carry over 60 percent of the traffic, we assume a decline in motor-carrier rates will not result in diversion of traffic. If the market share for a given commodity is 80 percent, but the market share in the preceding distance block is under 60 percent, however, some traffic may well be divertible as a result of a reduction in motor-carrier rates, since market share would be partly distance related. In such an instance, we estimated that either rail rates would have to be reduced by 25 percent of the reduction in motor-carrier rates, or 25 percent of the rail contribution to overhead previously earned on that traffic would be diverted to motor carriers. This implies that, either because of rate reductions or diversion of traffic, the railroads will lose net revenue equal to one-quarter of the reduction in motor-carrier rates. This is the least reliable estimate of cost presented because the reasoning is most tenuous. It can, however, be shown that only a small portion of the railroad traffic that falls into this category could be carried by motor carrier over any distance even at substantially lower rates.

If the rail market share is between 50 and 80 percent in a distance block, we estimate that railroads will have to reduce their rates by one-half of the reduction in motor-carrier rates in order to maintain their market share. Alternatively, if they fail to make the rate reduction, the reduction in revenue will be at least as severe as the reduction associated with lowering the rates. The estimate is conservative since it assumes a relatively low cross elasticity of demand. Thus, while the methodology is not precise, the diversion estimate is again biased downward to minimize the possibility of overstatement of the cost of a motor-carrier rate reduction to railroads.

If railroads move less than 50 percent of a commodity in a given distance block, we estimate that the elasticity of substitution is very high and that all of the traffic is subject to diversion. Thus, railroads that do not respond to motor-carrier rate reductions with matching rail rate reductions will lose most of their traffic in that commodity and distance block.

The adjustment factors are conservative estimates. If regulatory constraints or inertia of railroad management inhibit the adjustment of rail rates to changed competitive conditions, diversion is likely to be higher than estimated. While one could dispute the 50 and 80 percent break points, it is likely that the dispute would be centered on whether the adjustment posited would be adequate to hold market share rather than on whether the adjustment was too great. In the majority of cases for which significant additional diversion will result from lower motor rates, railroads are already competing against private common and contract motor carriers who move more than 50 percent of the commodity involved.

The nature of American industry has changed to the point that relatively few products move over 2400 km (1500 miles). Firms have chosen either to establish regional production centers servicing markets relatively close or at least to locate in the center of the country (as in the case of the automobile industry). Thus, the length of haul to most of their markets is reduced. Agricultural products are to a large extent produced in more than one region of the country. As a result, relatively small amounts of traffic move over longer distances relative to the share moving over shorter distances. It has also tended to make railroads compete primarily in the short-haul markets where the disadvantages of slowness and unreliability are magnified. Predictably, the result has been that traffic once moved exclusively by rail is now moving largely by truck. The prospect that railroads will lose their remaining market share is substantial if motor sizes and weights lead to 16.8 percent reductions in rates and the railroads do not match those reductions. In light of this, we can estimate that the cost of lower truck rates to railroads will be high no matter what course of action the railroads choose to take.

RESULTS OF ANALYSIS

The factors developed above were used to adjust the gross traffic data by commodity to determine what the effect of a reduction in motor-carrier costs and rates would be on rail traffic moving under each circumstance. In some instances, we estimated that a reduction in motor rates would require a reduction of lesser magnitude in rail rates if the railroad were to escape diversion. We also assumed that a failure to reduce rail rates would result in a diversion of part of the affected rail traffic to motor. In either case, the revenue loss estimated for the railroads was about the same. The dispute as to how much traffic is moving at what cost/price ratio makes clear that such measurement precision is not yet available, at least to the public. Thus, the simplifying assumption is not likely to yield results significantly less precise than would an examination based on available cost data.

On the traffic for which the rate reduction must match the motor-carrier rate reduction, we assumed that all of the traffic was moving at levels sufficiently above variable cost to make such a reduction the least cost alternative. Again, it is not clear that this is always correct. It is clear, however, that available cost information is sufficiently imprecise that it is not a good indicator of whether carriers choose to continue to carry particular traffic at reduced rates.

Finally, the data themselves are most interesting. The evidence available on market share shows that railroads face effective competition for the movement of most goods at the 3-digit Transportation Commodity Code at distances. The census data provide market share data for traffic moving in distance blocks from under 160 km (100 miles) to over 2400 km (1500 miles). Given the propensity to produce either in regional facilities or facilities in the center of the country, this means that almost all commodities are available from at least some producers at distances less than market. Thus, while available data include all traffic moving over 2400 km (1500 miles) in one distance block, the effect on this analysis is not likely to be substantial.

The analysis of the effect of increased sizes and weights was predicated on both size and weight increasing. The cost of moving a heavier truck was calculated but the cost of operating a double bottom was not. However, at the 3-digit level, all of the commodities moving in truckload lots—and therefore competitive with railroads—were generally sufficiently dense to permit heavier loadings. If only an increase in weights were permitted with no increase in cubic capacity, the estimate of cost to railroads could be reduced. The low estimate presented here provides an estimate of cost that assumes some volume limitations on expansion exist.

The evidence on share of traffic by mode shows that railroads compete with motor carriers for most of the traffic they carry. For example, even at distances over 2400 km (1500 miles), railroads carry only 54.6 percent of grain mill products; private trucks carry 16.6 percent, and common carriers carry 26.5 percent. In that same distance block, railroads carry 29.5 percent of manufactured fiber and silk broadwoven fabrics, 66.6 percent of the thread and yarn, 32 percent of household and office furniture, 23 percent of the plastic materials, 56 percent of the glass and glassware (blown), and 65 percent of the fabricated rubber products. [The market share information for all commodities is available in the Census of Transportation (1).] Thus, even at these distances, railroads face substantial motor-carrier competition for the traffic they carry.

Market shares were identified for each 3-digit commodity at the following distance blocks: under 160 km (100 miles), 160-318 km (100-199 miles), 320-478 km (200-299 miles), 480-798 km (300-499 miles), 800-958 km (500-599 miles), 1600-2398 km (1000-1499 miles), and over 2400 km (1500 miles). The market share possessed by railroads in each distance block was weighted by the diversion factors discussed here to determine the proportion of traffic subject to diversion. These factors were then weighted by the total revenue earned by railroads for each commodity in each distance block. The resulting estimate of divertable traffic is summarized in Table 1. Column 1 shows the percentage of total revenues not subject to diversion. Column 2 shows gross freight revenues attributable to each commodity (5), and column 3 shows the revenue earned on traffic not subject to diversion. The sum of the remaining revenue is that which will be reduced if motor carriers lower rates on the commodities and force railroads to either post matching rate reductions or suffer diversion. The percentage motor-rate reduction multiplied by the revenue earned by railroads on traffic subject to diversion provides an estimate of the cost to railroads of motor carrier and rate reductions. If motor carriers reduced rates by 16.8 percent on all traffic for which they competed with railroads, in 1974 it would have cost the railroads 16.8 percent of their $12.2 billion in revenues, or $2 billion. If one assumes that size constraints and market imperfections inhibit the decline in motor-carrier rates, the amount diverted would be reduced. For example, if one assumed that size constraints and market rigidities caused motor-carrier rates to fall by only 11 percent, the resulting cost to railroads would be $1.35 billion. Most traffic for which

Table 1. 1974 railroad gross freight revenues not subject to diversion.

Commodity	Percent	Gross Freight Revenues ($000 000s)	Revenues Not Subject to Diversion ($000 000s)
Grain-mill products	8.5	504 890	43 015
Sugar (beet, cane)	7.8	123 353	9 560
Cigars	17.2	304	52
Carpets, rugs, textile	33.1	12 056	3 992
Yarn and thread	1.3	4 826	64
Men's, youth's, and boy's clothing	27.7	931	258
Women's, misses', girls', and infants' clothing	7.7	508	39
Miscellaneous apparel and accessories	23.7	8 707	2 064
Primary forest products	8.9	515 919	44 266
Millwood, veneer, plywood	19.2	228 771	43 855
Miscellaneous wood products	1.0	128 196	1 329
Household, office furniture	3.3	86 822	2 891
Partitions, shelving, lockers, and fixtures	2.9	2 617	76
Pulp and pulp-mill products	18.2	146 012	26 529
Paper, except building paper	2.1	335 252	6 973
Paperboard, pulpboard, and fiberboard	4.8	326 673	15 583
Converted paper and paperboard products	17.4	151 682	26 317
Drugs	0.2	10 028	180
Tires, inner tubes	46.8	81 986	38 378
Miscellaneous fabricated rubber products	3.7	7 894	293
Miscellaneous plastic products	2.1	56 828	1 187
Glass and glassware, pressed and blown	1.7	38 898	661
Structural clay products	0.5	77 492	403
Concrete, gypsum, and plastic products	0.4	83 794	335
Abrasives, asbestos, and nonmetallic products	2.8	368 770	10 325
Steel works and rolling mill products	0.9	696 868	6 132
Plumbing fixtures and heating apparatus	7.9	14 452	1 136
Metal stampings	44.5	20 050	4 476
Miscellaneous fabricated metal products	2.8	39 584	1 097
Engines, turbines	2.9	12 189	350
Farm machinery, equipment	14.8	61 837	9 170
Construction, mining, and materials handling equipment	3.7	73 555	2 692
Specialized industrial machinery	2.2	9 616	210
Office, computing, and accounting machines	27.0	749	202
Service industry machines	18.0	18 209	3 274
Miscellaneous machinery and parts	2.3	14 708	338
Household appliances	67.8	153 992	104 467
Radio, receiving sets	10.1	17 004	1 719
Motor vehicles and motor vehicle equipment	58.9	1 199 642	703 829
Railroad equipment	17.4	52 006	9 065
Photographic equipment and supplies	32.5	1 006	327
Toys, sporting, and athletic goods	22.9	21 747	4 987
Miscellaneous manufactured products	10.9	7 173	781
Metallic ores	100.0	494 207	494 207
Coal	100.0	1 848 352	1 848 352
Nonmetallic minerals	100.0	603 934	603 934
Cut stone, stone products	100.0	327	327
Ashes	100.0	724	724
Containers, shipping, returned empty	100.0	27 930	27 930
Commodities completely subject to diversion	0.0	7 669 378	0
Total	25.1	16 353 448	4 108 351

motor carriers compete with railroads is sufficiently dense to be loaded to 40 834 kg (90 000 lb) in existing equipment. Further, the truckload motor-carrier industry is extremely competitive. Thus, increased weight adjustments are likely to impose net revenue reductions equal to at least $1.35 billion on railroads. If both weight and size adjustments are permitted, railroad revenues are likely to fall $2 billion or more.

CONCLUSION

This analysis is not designed to provide an argument against increasing truck sizes or weights. Such arguments revolve around questions of safety, wear of the roads, and whether motor carriers receive right-of-way subsidies or pay their own way. It is designed to show the effect of increasing motor-carrier sizes and weights on railroad revenues. An increase in allowable motor-carrier sizes and weights will substantially reduce railroad revenues. Any societal problems this creates should be dealt with at the same time that the motor-carrier sizes and weights are increased.

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