TRANSPORTATION RESEARCH RECORD 889

Freight Modeling and Forecasting

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1982

Transportation Research Record 889
Price $7.00
Edited for TRB by Mary McLaughlin

modes
1 highway transportation
3 rail transportation

subject areas
12 planning
13 forecasting

Library of Congress Cataloging in Publication Data
National Research Council (U.S.). Transportation Research Board.
Freight modeling and forecasting.

(Transportation research record; 889)
1. Freight and freightage–United States–Forecasting–Congresses. 2. Freight and freightage–United States–Planning–Congresses. I. Title. II. Series.
TE7.H5 no. 889 380.5s [380.5'24'0724] 83-8047
[HE199.U5]
ISBN 0-309-03501-5 ISSN 0361-1981

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889

Contents

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Practical Methodology for Freight Forecasting

FREDERICK W. MEMMOTT AND RUSSELL H. BOEKENKROEGER

A practical and workable technique for preparing freight forecasts, which may be used in addressing freight-related problems at the state or subregional level, is described. The flexibility of the overall approach and technique is demonstrated by examples of the use of the technique drawn from two recent studies. The structure of the process involved in using and adapting the technique is described. The importance of following prudent and pragmatic research principles is emphasized. Special attention is given to providing detailed information on each of the components of the technique.

Although freight demand forecasting is far from a new subject area, the techniques developed to date have not generally been in a form suitable for immediate application by states to freight-related problems. All too often, the techniques that are available (a) are not directly applicable to the problems being faced today by states, (b) require a level of education or understanding of modeling and mathematical procedures beyond that typically available today within state transportation or highway agencies, or (c) are simply not adequately documented (1-6). Furthermore, examples of their application to real problems are not readily available. Until now, it has been felt that such technology and examples would eventually evolve through further research and that the main need was for funding (and time).

Meanwhile, the world has not stood still. The formation of transportation agencies in a majority of states and heightened interest in multistate, state, and regional transportation systems planning have created a growing need for techniques with which to quantitatively address freight-related problems. Recent passage of deregulation legislation is bringing about unprecedented change as carriers seek to exploit new opportunities and eliminate unprofitable services. At the same time, there is an increasing awareness of the need to stop looking at problems in an isolated sense (e.g., abandonment of a seldom-used rail line) and to address the much wider range of potential problems and issues arising from the greater freedom and competition brought about by the deregulation legislation. This is virtually impossible without an easily understood, practical freight demand forecasting technique.

PRACTICAL FREIGHT FORECASTING APPROACH

The freight demand forecasting technique discussed in this paper is an adaptation and generalization of a rather simple and straightforward methodology that we have applied in several recent freight studies. It emerges from a philosophy that emphasizes substantive knowledge and understanding of a given situation in interpreting related, practical problems rather than relying on interpretations grounded solely in economic or econometric theory. The technique is really more a process for systematically making a large number of revenue and/or cost calculations than a formal mathematical model.

First, the methodology--which, for lack of a better title, is referred to as a transport costing model--is briefly described. Its usefulness and flexibility are then illustrated with examples drawn from two applications of the technique (7,8). One application involves the conduct of a reconnaissance-level study of an "All-American Navigation System" connecting the Great Lakes with the Eastern Seaboard to determine maximum potential traffic diversion to 13 alternative canal routings or physical configurations from the existing Great Lakes-St. Lawrence Seaway inland waterway system and overland to a tidewater port.

The second application involves a grain subterminal study for the State of Montana to determine quantitatively the economic feasibility of modernizing Montana's grain transportation system by using subterminals to gain the efficiencies of centralized collection and unit-train movements. In this case, feasibility depended on whether the proposed subterminals could generate sufficient economic benefits for grain growers (reduced "charges" for transportation resulting in higher prices for wheat) and additional profitability for transportation companies. This technique has been found to be flexible and adaptable to the wide range of problems increasingly being encountered by states in dealing with freight transportation.

COSTING MODEL

Structure

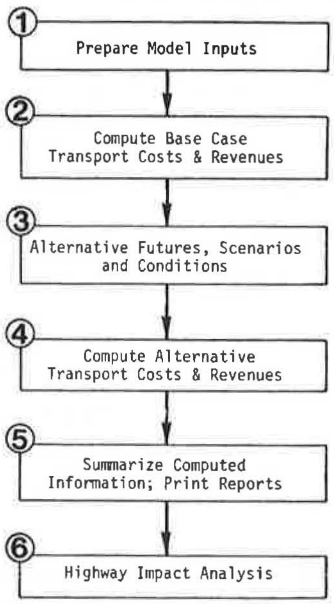
Conceptually, the freight forecasting procedure or costing model presented here is relatively simple and straightforward. For each commodity movement or flow, the process involves systematically computing and then comparing costs and revenues associated with two or more routings between points of commonality. The first routing is the null situation or base case. Subsequent routings consist of the hypothesized or forecast conditions being examined. These routings will never totally displace the first, since there will always be some traffic that will not be affected. At each stage, information on the cost of providing the transport-terminal service and the revenues derived therefrom by the transport company (or the rates and charges levied on the purchaser of the transport service) is developed and accumulated. In effect, the costing model is nothing more than a systematic procedure for making a large number of revenue and cost calculations that, in the aggregate, provide insight on the traffic, revenue, and cost changes expected to be brought about by the hypothesized or forecast condition.

The basic structure of the model is shown schematically in Figure 1. The first component simply prepares the data required in applying the model. The second and fourth components represent the heart of the model and in practice can be performed simultaneously. Data for each commodity flow are sequentially processed, revenues and costs are computed by using the base case and each hypothesized or forecast alternative, and decisions are made between routing possibilities. In the fifth component, information on commodity flow, revenue, cost, distance, and vehicle volume is summarized. The last component is likewise optional and involves determining highway impacts caused by potential changes in truck volumes expected to occur along the major segments of a state's highway system.

As used in this paper, a model is simply an objective process for determining transport costs, revenues, and throughputs under different assumptions. The focus of this paper is on the principles and concepts involved and their general application. The problems and issues likely to be encountered by individual states vary immensely, which makes it necessary to adapt the principles to the particular application at hand. In some cases, this involves the preparation of computer programs; in other cases, the techniques could be accomplished by hand calculations. Which components of the process are selected and how the computations are made can only be determined once the problem or issue to be addressed is known.

This structure can be modified by adding or combining components, as shown by the flowchart of a grain transport model in Figure 2 (9). Depending on the options selected, the model can have a recursive structure (i.e., feedbacks can be used to optimize a parameter). This would occur in the model if (a) unit costs and revenues are treated as a function of throughput volumes, such as would occur in terminal operations, and (b) the user is seeking to optimize the number and location of terminals. Although an optimizing process can be designed, there is no corresponding guarantee of producing more useful results. Optimizing models can only handle objective measures. Consequently, they can only discriminate between good and bad terminal locations in terms of their physical suitability and site development costs. Although it is possible to quantify other important criteria such as long-standing commercial trading relations and include them in optimizing models, the procedures by which this is generally accomplished belie the underlying processes involved.

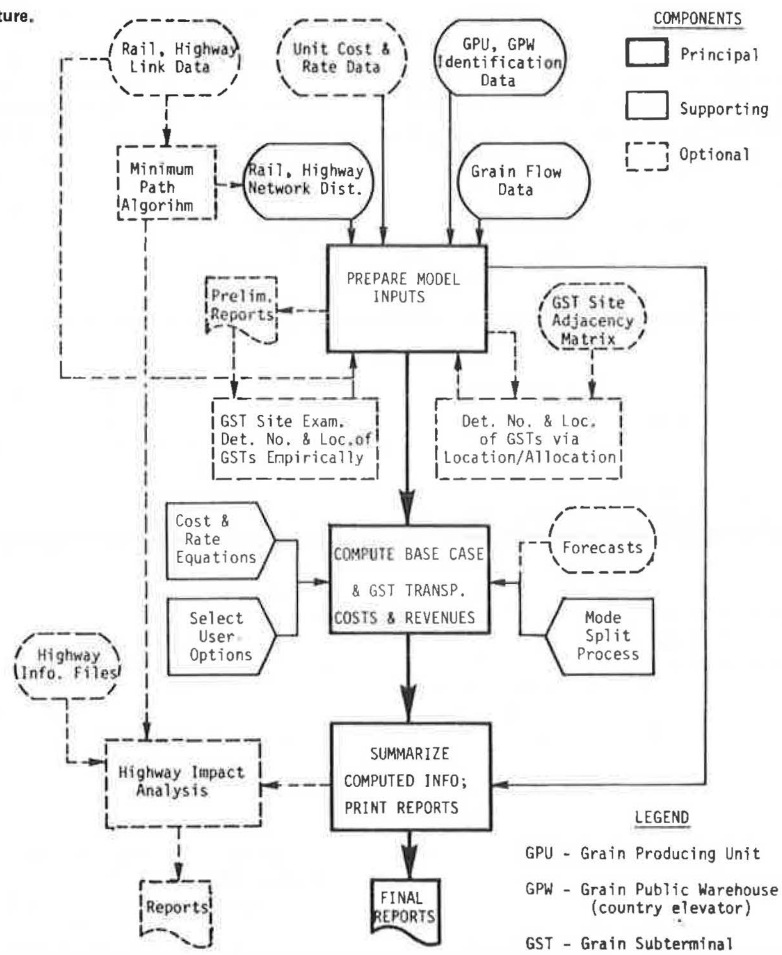
Figure 1. Costing model structure.



Initial Inputs

The two main inputs are a commodity flow matrix and unit cost and rate data. Depending on the particular application, the flow matrix or unit costs and rates used in examining an hypothesized alternative may differ from that used in computing the revenues and costs of the base case. Other inputs, such as distances and identification data, are also required. Because the preparation of these data is

Figure 2. Grain transport model structure.



straightforward, they are not discussed in detail in this paper.

Commodity Flow Matrix

One of the most time-consuming and troublesome tasks occurs right at the beginning: developing the commodity flow matrix. Conceptually, this step is no different from preparing the "trip table" for use in highway traffic assignment work. However, the freight world introduces complications in the form of (a) different commodity types, (b) different modes or mode combinations, (c) individual corporate entities providing services, (d) stability of marketing patterns (i.e., the quantity moved between specific origin-destination pairs), and (e) the service factor. Yet, a four- or five-dimensional array is not a particularly workable solution.

The most straightforward procedure is to reduce the above down to a two-dimensional array in which commodity, modal, institutional, marketing, and service variations have been collapsed into a composite attribute vector and are treated as alternative routings between points of commonality--namely, the origin and termination of the movement or flow. Roger Creighton Associates, Inc., has found that, through consolidation and elimination of minor and relatively unimportant movements, enough simplification can be done to make the problem fully manageable. Examples of this simplification are presented below.

In the U.S. Army Corps of Engineers study (7), the commodity flow table was set up on a Bureau of Economic Analysis (BEA) domestic port to foreign port basis, with one port representing a trade route. Domestic ports were likewise limited to major Great Lakes, river, or tidewater ports. Commodities were restricted to six generalized groupings. Modes or mode combinations were limited to three: ocean shipping via the St. Lawrence Seaway; barge transport to New Orleans and Baton Rouge, transferring to ocean shipping; and rail to tidewater port, transferring to ocean shipping.

In the Montana study (8), the commodity flow table consisted of 188 origins (termed grain-producing units) and five mode-destination combinations consisting of rail-export, rail-domestic, truck-domestic, and two variations of truck-barge-export. In preparing this table, movements that did not have subterminal/unit-train potential (i.e., nonwestbound wheat and all barley) were first eliminated. Movements through each of the 230 county elevators were treated as routing alternatives of the more basic movement. Movements bypassing county elevators ("track buying") were excluded.

There is no quick, simple method of preparing the commodity flow matrix. Much depends on the particular problem at hand and data availability and quality. Preparing a commodity flow matrix is always a struggle. Because information on origin and terminating volumes is usually more readily available then information on the flows themselves, a distribution algorithm may have to be used to approximate the flows taking place. If there is any key, it is to keep the matrix as simple as possible by retaining the important movements and rejecting the relatively unimportant ones. One always finds problems with data that can only be corrected by playing detective, applying common sense, and making intelligent estimates to fill the gaps. No matter how good the data may appear to be, a great deal of time must still be spent in supplementing, cross-checking, and reconciling differences among data sources.

Unit Costs and Revenues

Equally important (and time-consuming) is the process of developing the cost and revenue relations or estimating equations to be used in conjunction with the commodity flow matrix. The chief ingredients in these estimating equations are the unit costs or rates developed by the user.

Cost and revenue relations or estimating equations generally have the following format:

$$R_1 = (\text{volume})\,(\text{distance})\,(\text{unit revenue/charge}) \quad (1)$$

$$R_2 = (\text{volume})\,(\text{unit revenue/charge}) \quad (2)$$

$$C_1 = (\text{volume})\,(\text{distance})\,(\text{unit cost}) \quad (3)$$

$$C_2 = (\text{volume})\,(\text{unit cost}) \quad (4)$$

where

- R = revenue or change,
- C = cost,
- 1 = a physical movement through space (e.g., transport company), and
- 2 = terminal, transfer, or warehousing services (e.g., grain elevator).

Variations in these basic relations come primarily in the form of differing unit revenues and costs, which reflect modes, commodities, competing companies, and even service differences. When combined together, individual mode relations or estimating equations produce an estimate of total revenues and costs, such as that used in the Montana study:

$$R_b = V_b\,[R_1 + R_3 + R_4 + R_6 + R_7] \quad (5)$$

$$C_b = V_b\,[C_1 + C_3 + C_4 + C_6 + C_7] \quad (6)$$

$$R_{alt} = V_r\,[R_1 + R_3 + R_4 + R_6 + R_7] + V_s\,[R_2 + R_5 + R_6 + R_8] \quad (7)$$

$$C_{alt} = V_r\,[C_1 + C_3 + C_4 + C_6 + C_7] + V_s\,[C_2 + C_5 + C_6 + C_8] \quad (8)$$

where

Item	Volume	Total Revenues	Total Costs
Base case (through GPWs)	V_b	R_b	C_b
Alternative (GST portion)	V_s	R_s	C_s
Scenario [GPW portion (residual)]	V_r	R_r	C_r

and where (in Montana, for example)

Mode	Revenues/ Charges	Costs
Line-haul		
Single-car rail	R_1	C_1
Unit train	R_2	C_2
Grain truck	R_3	C_3
Barge	R_4	C_4
Feeder service		
Collector truck	R_5	C_5
Farm truck	R_6	C_6
Terminal services		
GPW	R_7	C_7
GST	R_8	C_8

It is well to remember that the results obtained through application of cost and revenue estimating equations are only as good as the quality of the inputs; hence, there is a need for very careful reasoning and cross-checking in developing unit charges or unit costs to minimize the possibility of unintended distortion of the resulting answers. One can make the above equations as complex as one likes providing that the fiscal and data resources available permit this to be done. We prefer to keep such equations as simple as possible, concentrating instead on ensuring that the parameters used are correct. Again, what is done depends on the specific application.

For unit revenues, it is recommended that a matrix of established rates (one corresponding to each possible movement in the commodity flow matrix) be used where possible rather than develop special rate-estimating equations. The reason for this is that it accounts for the abnormalities that have crept into common-carrier tariffs and rates over the years that cannot be reasonably reflected in generalized estimating equations. However, often this cannot practically be done and approximating relations must at times be used instead.

For example, in the Montana study (8) single and multiple car rates for wheat moving west to Pacific North Coast ports were used. Truck rates for line-haul service were derived from the rail rates (undercut rail by 3¢ to 3¢/bushel). Truck rates for collector service were obtained from several in-state cooperatives that are literally dictating to grain truck owners the maximum they are willing to pay for hauls of different lengths. A revenue estimating equation was developed for county elevators based on "maximums" established by the State for storage and handling plus information on storage capacity and annual throughput. Barge rates were obtained through direct inquiry.

For unit costs, the following generalized procedure is recommended:

1. If sufficient time and fiscal resources are available, then it is possible to dig out rather detailed information on the modal or competitive organizations, infrastructure and equipment, and general economics involved in providing transport services. Such research is typically carried out on a sample basis by using in-depth interviews with traffic managers and accounting personnel to obtain information from which to derive unit costs.
2. If the transport or terminal services are provided by multiple firms, there obviously are multiple unit costs. These costs, known to businessmen, are not the type of information that is readily furnished to the public sector simply because accidental disclosure could adversely affect competitive relations.
3. In such circumstances, additional assumptions regarding organization, infrastructure and equipment (e.g., age, payload capacity, cost, depreciation, labor inputs, energy inputs, and operating efficiency), and utilization may have to be made before an attempt is made to estimate unit costs.
4. In developing unit costs within a limited budget, one is forced to rely primarily on telephone conversations, secondary information, and professional judgment to identify and refine cost components, which are then combined to produce a unit cost. Once a reasonable value has been established, it must be carefully cross-checked with related information as well as reviewed and discussed with persons who are knowledgeable about such costs to obtain outside opinions as to its overall reasonableness. Only then should the unit cost be used.
5. Even if the transport service is provided by a single firm, it is still usually necessary to independently estimate costs simply because of the reluctance of private companies to share such information with government.
6. There is a varying amount of published and unpublished information available on unit costs--some good and some not very useful. The tendency on the part of those not very experienced in freight studies is to latch onto such information and consider it as gospel without realizing its true source, its strengths and weaknesses, and whether it is indeed applicable to the situation at hand. It is absolutely necessary to undertake an in-depth investigation to modify secondary information before it is used in a cost-estimating equation. Often this is not done.
7. The simplicity or complexity of the unit cost is partly determined by whether the components themselves are being treated as variables. This occurs if the costing model must be sensitive to variations in the cost of capital, labor, and/or energy.

In the Corps of Engineers study (7), we somewhat reluctantly used unit cost estimates developed by the U.S. Maritime Administration and the Corps of Engineers for U.S. and foreign flag vessels of different types and sizes. At the time, we did not have sufficient fiscal resources to go as deeply as we would have liked to in estimating vessel capital and operating costs and fleet mix so as to be totally comfortable with the derived equations. Nevertheless, we were later told by the special panel set up by the Corps of Engineers that our unit costs were essentially comparable to theirs. For barge traffic, we used data we had primarily developed through queries to barge companies that use the New York State Barge Canal System. Inland waterway unit costs were developed by carefully updating previous estimates prepared by a major railroad in direct competition with barge companies on the Lower Mississippi. Rail unit costs were derived by using standard Interstate Commerce Commission (ICC) procedures.

In the Montana study (8), farm truck unit costs were derived on a per-mile basis from the ground up by using assumptions on mileage, cost, life, fuel consumption, price, etc. Grain truck unit costs were derived by reworking some fairly good up-to-date operating cost data obtained from a trade organization to fit the Montana situation. Estimating truck costs demands extreme care because the information resources are just not that good and variations in equipment investment, annual mileage, and backhaul utilization significantly affect the results. Rail unit costs were estimated by using ICC procedures (10) modified to fit a car mix situation. County elevator costs were derived by carefully reworking an earlier U.S. Department of Agriculture study (11) and from recent testimony of elevator operators seeking regulatory revisions of maximum storage and handling charges.

Computing Transport Costs and Revenues

The heart of the model lies in a series of basic cost and revenue relations or estimating equations--one applicable for each commodity-flow/routing possibility. A number of variations of this theme are described below in generalized form:

$$C^a_{mij} = V^a_{mij} (D^a_{mij}\, c^a_{mij}) \quad (9)$$

$$R^a_{mij} = V^a_{mij} (D^a_{mij}\, r^a_{mij}) \quad (10)$$

where

C = total transport costs,
R = total transport revenues or charges,
V = volume of commodity moved over some specified period of time,
D = distance between i and j,
c = unit transport costs,
r = unit transport charges or revenue,
a = a specific commodity or commodity group (a = 1 to t),
m = mode of transport from i to j (m = 1 to s),
i = origin zone (GPU location) (i = 1 to q), and
j = destination zone (market) (j = 1 to p).

In the above equations, V^a_{mij} defines the movement of commodity a between origin i and destination j via mode m. With more complex mode and routing possibilities, the basic relations must be modified to incorporate components or portions into a complete movement.

$$C_{ij}^{a} = \sum^{s} V_{mij}^{a} \left[(D_{mij}^{a} c_{mij}^{a}) + T_{mi}^{a} + T_{mj}^{a} + T_{m1}^{a}\right] \quad (11)$$

$$R_{ij}^{a} = \sum^{s} V_{mij}^{a} \left[(D_{mij}^{a} r_{mij}^{a}) + T_{mi}^{a} + T_{mj}^{a} + T_{m1}^{a}\right] \quad (12)$$

where m = 1 to s and T denotes the unit transfer or terminal charge or cost that can occur at the origin, termination, or intermediate points of the movement (the latter is indicated by the subscript 1).

Equations 11 and 12 depict the total cost and total revenue, respectively, for the situation in which there is a combination of transport modes (hence, the summation over all modes m) with both end-point and intermediate terminal operations.

This can be extended further to account for multiple firms by adding a superscript b, as illustrated below:

$$C_{ij}^{ab} = \sum^{s} V_{mij}^{ab} \left[(D_{mij}^{ab} c_{mij}^{ab}) + T_{mi}^{ab} + T_{mj}^{ab} + T_{m1}^{ab}\right] \quad (13)$$

$$R_{ij}^{ab} = \sum^{s} V_{mij}^{ab} \left[(D_{mij}^{ab} r_{mij}^{ab}) + T_{mi}^{ab} + T_{mj}^{ab} + T_{m1}^{ab}\right] \quad (14)$$

where m = 1 to s, all subscripts, superscripts, and variables are as indicated above, and b is a superscript denoting an individual firm.

Putting it all together, total costs and revenues for the state would be computed as the summation over firm, commodity, mode, and geographic origin and destination:

$$C = \sum^{q} \sum^{s} \sum^{t} \sum^{u} \sum^{p} V_{mij}^{ab} \left[(D_{mij}^{ab} c_{mij}^{ab}) + T_{mi}^{ab} + T_{mj}^{ab} + T_{m1}^{ab}\right] \quad (15)$$

$$R = \sum^{q} \sum^{s} \sum^{t} \sum^{u} \sum^{p} V_{mij}^{ab} \left[(D_{mij}^{ab} r_{mij}^{ab}) + T_{mi}^{ab} + T_{mj}^{ab} + T_{m1}^{ab}\right] \quad (16)$$

where i = 1 to q, m = 1 to s, a = 1 to t, b = 1 to u, and j = 1 to p.

Fortunately, it is usually possible to simplify the general-purpose model presented above by using assumptions such as the following:

1. The commodities involved can be considered homogeneous.
2. Destinations can be limited to the principal gateways rather than the markets themselves.
3. Costs are limited to those occurring between points of commonality.
4. Inventory costs can be ignored based on the premise of a temporally uniform demand even though one is dealing with a cyclically produced commodity.
5. The intricacies of the particular business can be ignored except for the transport end.

Alternative Futures, Scenarios, and Conditions

So far, we have only considered the present or base case situation. What has to be done is to construct similar arrays to represent hypothesized futures, scenarios, or conditions.

The freight world is in a continual state of change with the rise and fall of agricultural, industrial, and extractive industry production. Markets and suppliers change and so do origin and destination patterns. Transport technologies, services, component costs, and efficiencies likewise affect modal use. In our previous work on NCHRP Project 20-8 (12), we spent a considerable amount of time examining the then state-of-the-art methodology for demand estimation and modal-choice modeling. In the present context, demand estimation can be viewed as a linkage between the base case commodity flow matrix and one expected at some point in the future. Modal-choice modeling can be viewed as changes in market shares beyond those explainable through production and consumption changes. Although considerable effort has gone into developing a methodology for demand estimation and modal-choice forecasting in recent years, much of the present methodology in these areas remains very elementary and is not yet suited for inclusion in an immediate application of a statewide freight demand forecasting technique. Although development proceeds on this front, questions must still be answered. In this regard, we prefer simpler, more direct approaches such as those outlined below.

Projecting Future Origin-Destination Patterns

Many applications do not require projections to be made, since no overall change in the origin-destination matrix is expected. Such was the case with our Montana work, where the interest lay in the changes resulting from the introduction of a more efficient mode (subterminals/unit trains). Sometimes projections can be handled simply by use of a compound growth factor, as was done in our Corps of Engineers work. There are times, though, when changing conditions dictate that a new origin-destination matrix be prepared.

If the problem is large enough, the best way of modifying the matrix is to use econometric model outputs as a guide in modifying the base commodity flow matrix. If such a model is not being used, we then encourage the pragmatic approach of informally tapping the collective intuition, estimates, and judgments of those knowledgeable in the commodities being produced or consumed. This is quite workable if the projections are relatively short range. Given good inputs, the transportation specialist can then apply this reasoning and intelligent guesses and modify the commodity flow matrix appropriately to represent expected conditions.

The longer the time frame, the more speculative is the projection. At times, it might even be worthwhile to tap the skills of experts capable of assessing where things are headed and the resulting impact on the state economy, production and consumption, employment, technology, living standards and patterns, etc. Rather than attempting to make projections mechanically, we recommend the collective "think tank" approach.

Projecting Modal Choice

The importance of modal choice will vary with the application and so will the procedure for dealing with it. Modal-choice decisions partly reflect economics and partly reflect service; the former lends itself to quantitative solutions whereas the latter does not. Introducing a new mode or mode combinations or a new service is really a routing alternative. If it costs less (revenues represent charges to the user) than the existing mode (for service of comparable quality), substitution will take place. Our technique can easily be set up to perform such a test and to reorder the traffic among modal alternatives. In so doing, the user may wish to impose two constraints on such a quantitative process: (a) a minimum threshold governing the point at which modal diversion will occur (e.g., users rarely divert just for a 1¢/ton savings) and (b) a limit on the maximum market share.

For example, in Montana the introduction of subterminals/unit trains potentially results in a sizable reduction in transport charges for virtually every movement. Were a "modal split" made on the basis of user economics, the projected outcome would have been near total diversion from the present to the proposed mode. Such drastic shifts are quite unlikely. In the end, an approach based on reasoning out what the maximum market share might be for subterminals/unit trains was used rather than an objective process based solely on savings. In this case, it was felt that there would always be a residual of low-volume, special-destination, or high-priority shipments not appropriate to subterminals/unit trains. Again, we think that it is far more important to apply careful reasoning and seek information on related or parallel situations rather than apply a quantitative modal-split process blindly.

Handling Scenarios and Conditions

Sometimes the problem is simply one of determining how much traffic might divert to one or more alternatives. This can usually be done quantitatively by adding the new alternatives as additional routings. For example, in the Corps of Engineers study, costs via 13 shallow draft barge, deep draft barge, and deep draft ship canal alternatives were computed in addition to the three existing routings mentioned earlier, and the traffic split between the alternative and base case situation was determined through determination of the least-cost routing. "What if" conditions, which include such possibilities as changes in pricing, energy availability, service, and regulatory constraints, can often be handled by the same basic process of adding and then quantitatively evaluating routings.

Summary of Results

Whereas the cost and revenue equations must be tailored to the specific issue or problem being examined, the outputs from the computational process can often be standardized. Concern generally lies in efficiency and distributional benefits potentially achieved by the alternative being examined in comparison with the base case. It is the degree of change, rather than the absolute values per se, which generally is of greatest interest to those affected.

What we like to do is to first prepare a comprehensive output record, which can then be summarized in a variety of ways. A record containing (a) control information, (b) commodity flows, (c) revenues or charges, (d) costs, (e) unit distances, and (f) vehicle equivalents would be prepared for each unique movement. Revenues/charges and costs would be further broken down into those that occur under the (a) base case, (b) alternative alone, (c) residual, (d) alternative plus residual, and (e) difference between the alternative and residual and the base case.

For example, in the Montana study, control information consisted of grain-producing unit, county elevator, grain subterminal, and market designations and origin county. Grain flow data consisted of grain that has subterminal potential and all other grains. Revenues and costs were subdivided by components: line-haul modes (single-car rail, unit train, grain truck, and barge), collector modes (collector truck and farm truck), and terminal handling (county elevator and grain subterminal). These components were then summarized to produce line-haul, collection, terminal, grain company, grower, and total revenues and costs. Distances consisted of farm to elevator, farm to subterminal, elevator to market, and subterminal to market mileage, and vehicles consisted of rail cars (covered hoppers), grain trucks, collector trucks, and farm trucks.

Although the format is admittedly long, the user can divide it into several shorter records, if so desired (or for software reasons). Once output records have been prepared, various reports summarizing the results can be prepared. Summary tables can be produced either on an aggregate or a unit basis. Either detailed or abbreviated revenue and cost summaries can be prepared. The former would be appropriate in determining the projected impact on the different modes (distributional effects), whereas the latter would be of interest particularly in preparing geographic summaries (efficiency benefits). In addition to revenue and cost summaries, vehicle-mile and ton-mile summaries could also be prepared.

Highway Impact Analysis

The previous section discussed one type of output that could be obtained from a computerized version of the costing model. The second type of output, which is optional, consists of base and alternative commodity flows (in vehicles) over each link of the transport system: rail, highways, and waterways. It is possible to design the process in such a way that programs from the Federal Highway Administration (FHWA) urban transportation planning series can be used to determine routings and accomplish the necessary accounting, provided that the state highway and county highway networks have already been coded for this purpose. Depending on how a state has organized its highway information files, it may be possible to directly use segment data on physical characteristics, condition, and use, although network inputs are usually at a macro rather than a micro level.

Three possible assessments can reasonably be made. Their positive and negative points are discussed below:

1. One approach is to summarize vehicles on a link basis and determine the differential between the scenarios and the base case. The problem with this approach is equating different types of trucks, which have different impacts on pavement structure. Consequently, a simple change in the number of vehicles with the alternative (as compared with the base case) is often meaningless.
2. Determining the change in equivalent annual load applications (EALAs) neutralizes the differences between different vehicle types, although it requires other assumptions or data on the proportion of different wheel-axle configurations, tare weights, and loadings. The problem with this approach is that differential EALA does not directly relate to pavement life. For example, a 10 percent increase in EALAs does not mean a 10 percent decrease in the remaining pavement life, since the effects of pavement age, design strength, and other traffic have not been included.
3. Another extension to the approach given in item 1 is estimating the change in service life. The data used in this process can be either very detailed information on pavement condition and structure contained in a state's highway information system files and traffic volume and classification information or various assumptions and default data developed by FHWA for highway needs studies. The problem with the first type of data is that they will not be available uniformly across the state and involve a level of detail that goes far beyond the level of planning and analysis presented in this paper. Determination of service life depends on the following factors: (a) present pavement condition (present serviceability rating or index or the equivalent); (b) pavement structure or thickness, expressed as a structural number, slab thickness, or correlation thereto; (c) soil support value(s) or

correlation thereto; (d) number of present 18-kip single-axle EALAs applied to the roadway; and (e) the average annual rate of traffic growth.

In considering the above possibilities, we conclude that most states are primarily interested in potential changes in truck volumes or truck loadings that are likely to occur in the vicinity of traffic generators and along principal truck routes. The former can be handled quite readily by reassigning vehicles back to the rail and highway networks by (a) identifying the specific links involved in minimum distance (or time), (b) assigning computed traffic vlumes to these links, and (c) summarizing the data on a link basis. Normally, this would be done separately for the base case and each alternative and the final product would be the difference in volumes and the relative change projected to take place.

CONCLUSIONS

The goal of this paper was to present and describe a technique that enables users to prepare freight forecasts in a simple and straightforward manner, deriving insights and related information on changes and impacts brought about by hypothesized or future conditions. In illustrating the use of this technique with examples drawn from two distinctly different problems and applications, it has been demonstrated that the technique is both flexible and adaptable. The framework of the technique, which consists of basic concepts and principles, permits users to organize and structure a process to examine the complex issues involved in freight-related problems. Each of the components of the technique may be expanded on to meet the particular requirements of given situations.

The approach presented encourages the user to incorporate substantive knowledge and understanding in interpreting a problem or situation as well as adapting the technique. Reliance on economic theory and econometric networks is not appropriate in analyzing many freight-related problems, and a balance must be established between what theory tells us and the way the real world behaves. In this sense, the technique is more of a process tailored to a specific situation than a standardized methodology in which only a specified set of data inputs is required to produce results.

REFERENCES

1. Y. Chiang, P. Roberts, and M. Ben-Akiva. Development of a Policy Sensitive Model for Forecasting Freight Demand. U.S. Department of Transportation, Rept. DOT-P-30-81-04, Dec. 1980.
2. E. Miller. Effect of Rates on the Demand for Railroad Services. Proc., Transportation Research Forum, 1972.
3. Studies in the Demand for Freight Transportation. Mathematica, Vols. 1-3, 1967-1969.
4. A.L. Morton. A Statistical Sketch of Intercity Freight Demand. HRB, Highway Research Record 296, 1969, pp. 47-65.
5. J. Sloss. The Demand for Intercity Motor Freight Transport: A Macroeconomic Analysis. Journal of Business, Univ. of Chicago, Jan. 1971.
6. P. Watson, J. Hartwig, and W. Linton. Factors Influencing Shipping Mode Choice for Intercity Freight: A Disaggregate Approach. Proc., Transportation Research Forum, 1974.
7. Roger Creighton Associates, Inc. Reconnaissance Level Economics Study of an All-American Navigation System Connecting the Great Lakes to the Eastern Seaboard. U.S. Army Corp of Engineers, New York District, Dec. 1979.
8. Roger Creighton Associates, Inc. Bulk Freight Grain Transportation System Study. Montana Departments of Highways and Agriculture, Helena, Jan. 1981.
9. Roger Creighton Associates, Inc. Grain Transport Model for States in the Old West Region. Old West Regional Commission, Rapid City, SD, June 1981.
10. Rail Carload Cost Scales 1977: Statement ICI-77A and Notice 3006-02, Rail Update Ratios. Interstate Commerce Commission, Nov. 1979.
11. Cost of Storing and Handling Grain and Controlling Dust in Commercial Elevators: 1971-1972. U.S. Department of Agriculture, 1972.
12. Roger Creighton Associates, Inc., and R.L. Banks and Associates. Freight Data Requirements for Statewide Transportation Systems Planning. NCHRP, Rept. 177, 1977, pp. 50-86.

Publication of this paper sponsored by Committee on Statewide Multimodal Transportation Planning.

Development and Application of Statewide, Multimodal Freight Forecasting Procedures for Florida

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The development and application of a goods movement forecasting methodology resulting from the Statewide Multi-Modal Planning Process Project sponsored by the Florida Department of Transportation are described. The methodology involves two steps. First, the generation and distribution of freight are projected through a Fratar model that applies growth factors to current flows of commodities. In the second step, the projected freight flows are distributed among competing modes through modal-split models. The Fratar model was successfully applied to produce reasonable projections of freight traffic to, from, and within Florida in 1985 and 2000. Efforts to develop modal-split models by using the logit formulation were not successful. The Fratar model was based on existing secondary sources of data. Because these sources exist in the same or an analogous form in other states, a similar modeling approach could be developed and applied elsewhere.

State departments of transportation are becoming increasingly involved in multimodal freight planning. The reorganization of railroads in the Northeast and Midwest, state rail plan requirements under the "4-R" Act (Rail Revitalization and Regulatory Reform Act of 1976), railroad mergers, regulatory changes, branch-line abandonments, increasing energy and shipping costs, the availability of all-weather roads, and the importance of financially sound competitive freight service for the overall economy of the states are examples of issues, problems, and developments that are giving rise to increasing state interest and involvement in multimodal freight planning.

In 1977, the Florida Department of Transportation (FDOT) initiated a program to develop a comprehensive statewide transportation plan and to update this plan on a continuing basis. This planning program encompassed all modes of transportation serving the movement of persons and goods throughout the state. Its purpose was to assist FDOT in evaluating and implementing financially sound transportation policies, facilities, and services that would promote the social, economic, environmental, and development goals of the State of Florida.

As part of the statewide transportation planning program, FDOT sponsored the Statewide Multi-Modal Planning Process Project to develop and apply modeling techniques to forecasting future movements of persons and goods by mode to and from as well as within the state. These procedures were intended to assist FDOT in evaluating alternative transportation policies and issues and to facilitate the analysis and evaluation of new or improved intercity transportation facilities and services.

This paper describes the development and application of the goods movement forecasting procedures resulting from the Statewide Multi-Modal Planning Process in Florida. Although the literature on freight forecasting techniques is growing, much of it is theoretical. Relatively little has been written about the development and use of freight forecasting methods in an actual planning situation. Therefore, it is hoped that this paper will give statewide transportation planners not only a better understanding of the problems and issues involved in developing a freight forecasting methodology but also an idea of what can be done with existing secondary sources of data to simulate and forecast the movement of freight.

FLORIDA GOODS MOVEMENT MODELING APPROACH

A large number of freight demand and modal-choice models were reviewed and evaluated early in the Florida Statewide Multi-Modal Planning Process Project. Prior surveys of freight demand estimation and modal-choice techniques were used as sources of information and evaluation for this task (1,2). Among the models that were given special consideration were an adaptation of the abstract mode model developed by Quandt and Baumol, the Herendeen model (3), the inventory theoretic model developed by Townsend (4), and the integrated freight forecasting model developed as part of the 1972 National Network Simulation Program.

One of the conclusions drawn from the assessment of existing freight forecasting methods was that, with few exceptions, the goods movement forecasting methods that have been used with some success have been of the sequential type. The exceptions noted in the literature are all models that have been developed for one or two specific commodities or for a special market situation.

Another important conclusion drawn from the survey of freight demand and modal-split models derives from the intimate connection between freight flows and regional economic development. The difficulty of forecasting regional economic development is one of the inherent problems of freight forecasting. Very few freight forecasts made to date span more than 10 years into the future because technology and the state of the economy are so difficult to predict. In addition, freight forecasts become less stable and reliable as the geographic level of aggregation and the classification of commodities become more detailed or smaller. Thus, national forecasts tend to be more reliable than state forecasts, which in turn are more reliable than county or substate projections. Contributing to the problem is the fact that states are not closed economic systems.

Clearly, the difficulty of forecasting even aggregated goods movements at the state level raises questions about the credibility of models that purport to predict modal freight movements in detail. Thus, the historical emphasis has been on dividing the freight forecasting problem into two parts: demand estimation and modal split. This approach was recommended for the Florida project.

The simulation and forecasting of goods movements to, from, and within the State of Florida were accomplished in two steps. In the first step, the generation and distribution of freight were projected through a technique known as the Fratar method, which applies growth factors to current flows of commodities. Projections were made for each of 13 groups of commodities. In the second step, the projected flows of each group of commodities were distributed among competing modes through modal-split models. A separate modal-split model was necessary for each commodity group.

FREIGHT GENERATION AND DISTRIBUTION GROWTH FACTOR MODEL

Figure 1 is a diagram of the freight generation and distribution growth factor model. The input to the model consists of two sets of growth factors--one for the production of goods and one for the consumption of goods--and a set of base year origin-destination (O-D) volumes of freight for each group of commodities. The growth factors themselves are calculated from forecasts of personal income and earnings and the results of the U.S. Department of Commerce national input-output model. The Fratar technique is then used to apply the growth factors to the base year O-D volumes to obtain tables of O-D freight volumes for a future year. The development of each of the inputs to the growth factor model is discussed below.

Base-Year Freight Flows

The first step in the development of the base-year freight flows was to classify the many thousands of types of commodities into a manageable number of meaningful commodity groups. The definition of the commodity groups depended heavily on how detailed were the available data on the production, consumption, and transportation of various commodities. Almost every source of data examined in this project had its own system for classifying commodities. One of these classification systems, the Standard Transportation Commodity Code (STCC) used in the Interstate Commerce Commission (ICC) annual percent sample of railroad waybills, is very detailed. Most of the classification systems, however, were much broader than the STCC. Fortunately, many of them were related to the STCC and the Standard Industrial Classification (SIC) system, although at a very high level of aggregation.

To determine the principal commodities hauled to, from, and within Florida by each mode, freight volume data from the following sources were analyzed:

1. ICC 1 percent sample of railroad waybills for 1975;
2. The Federal Highway Administration (FHWA) Nationwide Truck Commodity Flow Study, conducted between July 1972 and June 1973; and
3. Waterborne commerce statistics published by the U.S. Army Corps of Engineers in 1975.

Figure 1. Freight generation and distribution growth factor model.

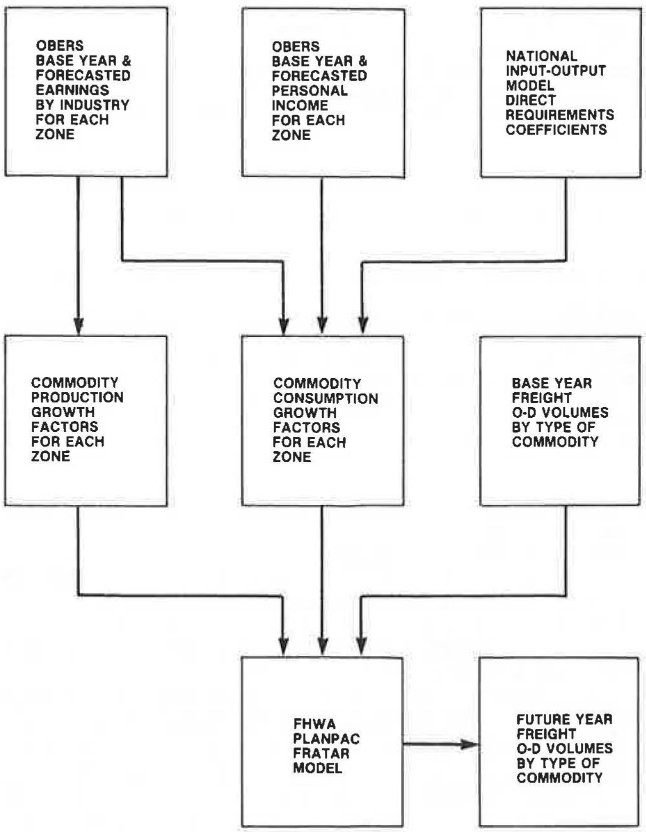


Table 1. Commodity groups selected for freight forecasting in Florida.

Group No.	Description	STCC
1	Citrus fruit	0121
2	Farm products, except citrus fruit	01[a]
3	Coal	11
4	Crude petroleum	13
5	Phosphate rock	14714
6	Dimension stone	141
	Crushed or broken stone	142
	Gravel and sand	144
7	Food and kindred products	20
8	Lumber and wood products	24
9	Pulp, paper, and allied products	26
10	Chemicals and allied products	28
11	Petroleum and coal products	29
12	Clay, concrete, glass, and stone products	32
13	Miscellaneous manufactured goods	
	Textile mill products	22
	Apparel	23
	Furniture and fixtures	25
	Rubber and miscellaneous plastics products	30
	Leather and leather products	31
	Primary metal products	33
	Fabricated metal products	34
	Nonelectrical machinery	35
	Electrical machinery and equipment	36
	Transportation equipment	37
	Instruments and photographic goods	38
	Miscellaneous products of manufacturing	39

[a]Excluding citrus fruit (STCC 0121).

Two of the principal commodities--nonmetallic minerals and farm products--were further subdivided. A more detailed analysis of the truck and rail data revealed that the motor carriers and the railroads were transporting different kinds of nonmetallic minerals. The motor carriers were primarily hauling stone, sand, and gravel, and the railroads were mostly hauling phosphate rock. Because phosphate mining is an important industry in Florida, phosphate rock was selected as a separate commodity group. For the same reason, citrus fruits were separated from other farm products to form two groups of agricultural commodities.

The commodity groups finally selected and approved by FDOT are given in Table 1 along with the corresponding STCC. The last commodity group given is a conglomeration of 12 manufacturing industries, none of which is extremely large in Florida. Together, however, these industries account for a significant percentage of the freight shipped to, from, and within Florida.

1975 O-D Freight Flow Tables

Once the commodity groups were specified, the next task was to determine the volume of freight transported between each origin zone and destination zone in the base year 1975 by mode of transportation and by commodity group. The results of this task were several sets of freight flow O-D tables similar to the trip tables developed in urban transportation planning.

The O-D freight flow tables indicated the volume of freight in hundreds of tons shipped in 1975 between each origin zone and each destination zone by a particular mode of transportation. Each Florida county and each state outside of Florida constituted a zone. This resulted in a total of 67 internal zones (counties) and 49 external zones (other states). A separate freight flow O-D table was developed for each of the 13 commodity groups and for each of three modes--truck, rail, and water.

Four sets of truck freight O-D tables were produced: true O-D truck freight volumes, truck freight volumes to ports, truck freight volumes from ports, and total truck freight volumes.

The true O-D freight flow tables consisted of the volumes of freight shipped from the zones where the goods were produced (production zones) to the zones where the goods were consumed (consumption zones). These freight flow tables, therefore, did not include truck shipments to and from ports, since ports are places where goods are transferred between modes of transportation.

The volumes of freight shipped by truck to and from ports were determined separately and stored in separate O-D tables. For truck shipments to ports, the origin zone was the zone of production and the destination zone was the Florida county containing the port. Similarly, for truck shipments from ports, the origin zone was the Florida county containing the port and the destination zone was the zone of consumption. The truck-to-port and truck-from-port freight flow O-D tables included only domestic goods. Foreign imports and exports were excluded because the true origin and destination zones of these goods could not be determined from the data that were available.

The total truck freight O-D tables were simply the sum of the true O-D, truck-to-port, and truck-from-port freight flow tables.

The truck freight O-D volumes had to be synthesized from a large number of secondary sources of data. The sources used are given in Table 2. All of

Table 2. Sources of data for development of true O-D truck freight flow tables.

Commodity Group[a]	Source
1-2	Florida Department of Agriculture and Consumer Services
	Florida Agricultural Statistics: Citrus Summary, 1975
	Florida Agricultural Statistics: Vegetable Summary, 1975
	Florida Fresh Fruit and Vegetable Shipments: 1974-1975 Season
	Florida Agricultural Statistics: Poultry and Livestock Summary, 1975
	U.S. Department of Agriculture
	Fresh Fruit and Vegetable Unloads by Commodities, States, and Months (4 volumes)
	Fresh Fruit and Vegetable Shipments by States, Commodities, Counties, Stations
	U.S. Bureau of the Census, 1974 Census of Agriculture
3-4	FHWA Nationwide Truck Commodity Flow Study
5	Central Florida Phosphate Industry, Draft Areawide Environmental Impact Statement
6	Bureau of Mines, U.S. Department of the Interior, Minerals Yearbook
7-13	U.S. Bureau of the Census, 1972 Census of Transportation Commodity Transportation Survey public use tapes
11	Florida State Energy Office, Monthly Florida Motor Gasoline Consumption

[a]From Table 1.

Table 3. Sources of data for development of total rail freight O-D tables.

Commodity Group[a]	Source
1	U.S. Department of Agriculture
	Fresh Fruit and Vegetable Shipments by States, Commodities, Counties, Stations
	Fresh Fruit and Vegetable Unloads by Commodities, States, and Months: Southern Cities (Volume 3)
5	U.S. Army Corps of Engineers, Waterborne Commerce of the United States: Parts 1 and 2
1-13	Federal Railroad Administration, magnetic tapes of 1975 ICC rail waybill sample
1-13	Florida Public Service Commission, State Statistics Section from annual report forms R-1 and R-2 submitted by individual Class I and Class II railroads to ICC

[a]From Table 1.

these sources, with two exceptions, are produced periodically by the agencies listed in the table. The two exceptions are the FHWA Nationwide Truck Commodity Flow Study and the environmental impact statement of the Central Florida Phosphate Industry. The Census of Transportation is conducted every five years by the federal government. All of the other sources given in Table 2 are produced annually.

Four sets of freight flow O-D tables were also developed for the rail mode. These O-D tables correspond to those developed for the motor carriers. In the true O-D rail freight flow tables, the zone of origin was the county or state in which the commodities were produced and the zone of destination was the county or state in which the commodities were consumed, either by households or by industries. The rail-to-port and rail-from-port freight flow tables contain O-D volumes for freight shipped by rail to and from a port, respectively. As noted earlier, ports are not considered to be the true origin or the final destination of freight; rather, they are points of transfer among modes. The total rail freight O-D tables were the summation of the above three O-D tables.

In the case of truck freight, the true O-D freight flow tables were developed from the secondary sources of data. The total truck freight O-D tables were then generated by simply adding the truck-to-port and truck-from-port tables. Because of the nature of the data on rail freight, it was easier to develop the total rail freight O-D tables first. The true O-D rail freight tables were then obtained by subtracting the rail-to-port and rail-from-port O-D tables.

Table 3 summarizes the sources of data used to develop the total rail freight flow O-D tables. The principal source was the ICC rail waybill sample tape, which consists of a 1 percent sample of waybills collected each year by the ICC. Each record on this tape represents a sampled waybill. The ICC waybill sample was supplemented by annual reports prepared by the rail carriers for the ICC. The annual reports provided independent estimates of the tons of freight originating and terminating on each carrier's line in Florida.

Additional data were needed to adjust the O-D volumes of citrus fruits and phosphate rock. These data were obtained from reports issued annually by the U.S. Department of Agriculture and the U.S. Army Corps of Engineers.

Two sets of waterborne freight O-D tables were developed. One consisted of tonnages among ports. In these tables, the origin was the zone in which the shipping port was located. The destination was the zone containing the receiving port. In the other set of waterborne freight O-D tables, the origin was the zone in which the commodity was produced and the destination was the zone in which the commodity was consumed. The first set of tables was referred to as the port-to-port freight flow tables; the second set was referred to as the true O-D waterborne freight flow tables.

The most basic source of data on waterborne freight was the information reported to the Corps of Engineers by all operators of vessels on the inland and intracoastal waterways. This information represented a complete enumeration of the movements of all vessels and their cargo at the ports and harbors and on the waterways and canals of the United States, the Commonwealth of Puerto Rico, and the Virgin Islands. The data collected on each shipment included the originating dock, the destination dock, the type of commodity, and the weight in tons. The Corps of Engineers maintains these data on magnetic tapes. Because these tapes contain proprietary data, they are not available to the states. Each year, the Corps of Engineers summarizes the information in a series of five reports entitled Waterborne Commerce of the United States. Although they are useful, these reports do not include data linking origins and destinations.

The U.S. Maritime Administration has aggregated the basic data collected by the Corps of Engineers to avoid disclosing information about individual companies. Computer printouts of the aggregated data were obtained for waterborne freight to, from, and between Florida's ports and waterways in 1975.

Each listing in the printouts gave the names of the shipping and receiving ports, the commodity, the type of vessel, and the tonnage.

The process of developing the various O-D freight flow tables for the three modes was too long and complicated to be described or summarized adequately in this paper. Numerous secondary sources of data, many assumptions, and a considerable amount of judgment were involved. Each combination of commodity group and mode had to be treated separately. In some cases, different procedures had to be followed for interstate and intrastate freight flows. A full description of the derivation of the O-D freight flow tables can be found in two reports prepared for the Florida Statewide Multi-Modal Planning Process Project (5,6).

Production Growth Factors

Production growth factors were defined as the ratio of the amount of the commodity produced in a zone in a future year to the amount of the commodity produced in the same zone in the base year of 1975. They were calculated for each county in Florida, each state outside of Florida, and each commodity group. The most recent Office of Business Economics/Economic Research Service (OBERS) forecasts of earnings (wages and salaries) by industry were used to calculate these factors. These forecasts were prepared by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce. The state forecasts were contained on a magnetic tape purchased by FDOT during the study. Forecasts for each Florida county were obtained from BEA projections (7).

It was assumed that the rate of increase in earnings in a particular industry was the same as the rate of increase in production. Thus, the production growth factors were calculated as follows:

$$PGF_{ik} = E_{ik}^{f}/E_{ik}^{75} \quad (1)$$

where

PGF_{ik} = production growth factor for zone i (either Florida county or another state) and commodity group k;

E_{ik}^{f} = OBERS forecasted earnings for zone i and industry k (corresponding to commodity group k) in a future year (in 1967 dollars); and

E_{ik}^{75} = OBERS estimated earnings for zone i and industry k in the base year, 1975 (in 1967 dollars).

Note that both the forecast and base-year earnings were expressed in constant dollars. Production growth factors were computed for the years 1980, 1985, and 2000.

Consumption Growth Factors

Consumption growth factors were defined as the ratio of the amount of the commodity consumed in a zone in a future year to the amount consumed in the zone in the base year of 1975. The total consumption of a commodity is composed of two parts--industrial and personal. Industrial consumption is simply the amount purchased by an industry in order to produce its own goods. Personal consumption is the amount purchased by consumers.

To calculate the industrial and personal consumption of goods in each commodity group and zone, the following sources of data were used:

1. OBERS forecasts of earnings by industry, prepared by BEA;
2. OBERS forecasts of personal income, also prepared by BEA;
3. The 1974 Annual Survey of Manufacturers;
4. The 1976 Statistical Abstract of the United States; and
5. The national input-output model developed by BEA.

Industrial Consumption

The first step in the calculation of industrial consumption was to determine the value of the goods produced by each industry. The value of output in the base year and the forecast value of output were determined by the following equations:

$$VO_{ik}^{75} = E_{ik}^{75} \times VER_k \quad (2)$$

$$VO_{ik}^{f} = E_{ik}^{f} \times VER_k \quad (3)$$

where

VO_{ik}^{75} = value of goods produced in 1975 by industry k (corresponding to commodity group k) in zone i (in 1967 dollars),

VO_{ik}^{f} = forecast value of goods produced in a future year by industry k in zone i (in 1967 dollars),

E_{ik}^{75} = OBERS estimated earnings in industry k and zone i in 1975 (in 1967 dollars),

E_{ik}^{f} = OBERS forecast earnings in industry k and zone i in a future year (in 1967 dollars), and

VER_k = ratio of the value of output to earnings in industry k.

The ratios of value of output to earnings were calculated from data in the 1974 Annual Survey of Manufacturers and the 1976 Statistical Abstract of the United States. The former source was used for manufactured goods and the latter for goods from agriculture and mining. The ratios of value of output to earnings have been quite stable for a number of years. Therefore, it was assumed that they would not change significantly in the future. These ratios are given below:

Commodity Group	Ratio
Farm products (including citrus)	2.58
Phosphate rock	4.74
Stone, sand, and gravel	2.38
Food and kindred products	10.03
Lumber and wood products	4.22
Pulp, paper, and allied products	4.67
Chemicals and allied products	8.08
Petroleum and coal products	11.52
Clay, concrete, glass, and stone products	5.29
Other manufactured goods	3.65

After the value of each industry group's output had been calculated, the amount and types of commodities purchased by each industry group to produce this output were determined. The basis for this computation was the national input-output matrix developed by BEA. This matrix, also known as a transaction tabloid or a direct requirements coefficients table, is given in Table 4. Each column of this table indicates how much of each commodity listed in the first column of the table is needed by the industry group at the top of the column to produce $1 worth of output. For example, to produce $1 worth of food products requires $0.2929 worth of

Table 4. National input-output matrix.

Input Commodity Group[a]	Production Commodity Group[a]										
	1	2	5	6	7	8	9	10	11	12	13
1	0.0317	0.2807	0.0000	0.0000	0.0769	0.0057	0.0000	0.0020	0.0000	0.0000	0.0034
2	0.0975	0.1676	0.0000	0.0000	0.2929	0.0468	0.0000	0.0006	0.0000	0.0000	0.0013
3	0.0000	0.0001	0.0000	0.0025	0.0004	0.0003	0.0016	0.0022	0.0004	0.0039	0.0022
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.4284	0.0000	0.0000
5	0.0004	0.0000	0.0594	0.0008	0.0000	0.0000	0.0006	0.0132	0.0000	0.0031	0.0001
6	0.0042	0.0001	0.0068	0.0268	0.0001	0.0001	0.0013	0.0017	0.0093	0.0566	0.0002
7	0.0000	0.1687	0.0000	0.0000	0.1658	0.0000	0.0030	0.0133	0.0011	0.0004	0.0010
8	0.0038	0.0005	0.0010	0.0000	0.0013	0.1767	0.0268	0.0014	0.0001	0.0059	0.0038
9	0.0005	0.0041	0.0049	0.0089	0.0344	0.0046	0.1280	0.0250	0.0060	0.0333	0.0075
10	0.0805	0.0044	0.0263	0.0204	0.0085	0.0111	0.0226	0.2508	0.0269	0.0261	0.0257
11	0.0317	0.0059	0.0029	0.0314	0.0024	0.0055	0.0038	0.0429	0.0679	0.0075	0.0025
12	0.0009	0.0001	0.0000	0.0000	0.0112	0.0093	0.0008	0.0064	0.0022	0.1039	0.0064
13	0.0231	0.0104	0.0516	0.1019	0.0392	0.1086	0.0366	0.0594	0.0119	0.0627	0.3345

Note: Each entry indicates the fraction of a dollar spent on goods in the commodity group at the left to produce $1 worth of goods in the commodity group at the top of the column.
[a]From Table 1.

citrus fruit, $0.0004 worth of coal, $0.1658 worth of other food products, and so on. The amount of goods in a particular commodity group purchased by an industry is simply the value of the industry group's output multiplied by the appropriate input-output coefficient. The total consumption of goods in a commodity group by all industry groups is then given by the following equations:

$$IC_{ik}^{75} = \sum_j (VO_{ij}^{75} \times C_{jk}) \quad (4)$$

$$IC_{ik}^{f} = \sum_j (VO_{ij}^{f} \times C_{jk}) \quad (5)$$

where

- IC_{ik}^{75} = total amount of goods in commodity group k purchased by all industries in zone i in 1975 (in 1967 dollars),
- IC_{ik}^{f} = total amount of goods in commodity group k purchased by all industries in zone i in a future year (in 1967 dollars),
- VO_{ij}^{75} = value of goods produced by industry group j in zone i in 1975 (in 1967 dollars),
- VO_{ij}^{f} = value of goods produced by industry group j in zone i in a future year (in 1967 dollars), and
- C_{jk} = input-output coefficient corresponding to industry group j and commodity group k.

Personal Consumption

Coefficients from the national input-output model used to determine personal consumption in each zone are given in the table below. The coefficients indicate how much consumers spend on goods in each commodity group out of each dollar of disposable income.

Commodity Group	Coefficient
Citrus fruit	0.0077
Other farm products	0.0051
Coal	0.0002
Natural gas	0.0091
Stone, sand, and gravel	0.0004
Food and kindred products	0.1255
Lumber and wood products	0.0091
Paper and allied products	0.0143
Chemicals and allied products	0.0169
Petroleum and coal products	0.0227
Clay, concrete, glass, and stone products	0.0015
Other manufactured goods	0.1240

Total personal consumption was computed from the following equations:

$$PC_{ik}^{75} = 0.75 \times I_i^{75} \times C_k \quad (6)$$

$$PC_{ik}^{f} = 0.75 \times I_i^{f} \times C_k \quad (7)$$

where

- PC_{ik}^{75} = amount of goods in commodity group k purchased by consumers in zone i in 1975 (in 1967 dollars),
- PC_{ik}^{f} = amount of goods in commodity group k purchased by consumers in zone i in a future year (in 1967 dollars),
- I_i^{f} = OBERS estimated personal income in zone i in a future year (in 1967 dollars),
- I_i^{75} = OBERS estimated personal income in zone i in 1975 (in 1967 dollars), and
- C_k = input-output personal consumption coefficient for commodity group k.

The factor 0.75 was used to convert personal income to disposable income. It was assumed that the overall effective tax rate on personal income is 25 percent.

Total Consumption

The total consumption of goods in a particular commodity group was the sum of the industrial consumption and personal consumption. The consumption growth factors were simply the ratio of total consumption in the future year to total consumption in the base year, 1975. Consumption growth factors were computed for each zone for the years 1980, 1985, and 2000.

Fratar Model

As Figure 1 shows, the production and consumption growth factors as well as the 1975 true O-D freight flow tables became the input to a distribution model known as the Fratar model. The Fratar model was one of the earliest trip distribution techniques used in urban transportation planning. A discussion of the theory behind this model and its mathematical formulation can be found in the FHWA publication describing the FHWA PLANPAC battery of computer programs for transportation planning (8).

The output of the model was a set of O-D freight flow tables for a future year. The FHWA PLANPAC battery of computer programs contains a program for

Table 5. Total tons of domestic freight by type of commodity by all modes combined.

	Tons (000s)			
Commodity Group	1975	1985	2000	%Δ 1975-2000
Citrus fruits[a]	9 578	10 544	12 872	34
Other farm products[a,b]	4 664	5 178	6 146	32
Coal	5 967	8 567	13 048	119
Crude petroleum	1 102	1 066	1 621	47
Phosphate rock	36 695	NA	NA	NA
Stone, sand, and gravel	67 401	92 773	145 562	116
Food and kindred products	14 054	17 803	23 922	70
Lumber and wood products	7 674	9 879	14 518	89
Pulp, paper, and allied products	5 151	7 191	11 074	89
Petroleum and coal products[c]	25 002	30 727	38 319	53
Chemical and allied products	14 084	20 097	32 667	132
Clay, concrete, glass, and stone products	9 118	18 031	35 573	290
Other manufactured goods[d]	6 875	8 824	12 190	77

Note: Tonnages given represent tonnages between the origins (the zones of production) and true destinations (the zones of consumption) and were obtained by adding the true O-D freight flow tables for truck, rail, and water. Therefore, they do not include truck and rail shipments to and from Florida's ports. Only domestic shipments were used; international shipments are not included.
[a]Excludes truck shipments into Florida except those to Miami.
[b]Excludes truck shipments of all farm products except principal fruits and vegetables and feeder calves.
[c]Excludes intrastate truck shipments and interstate truck shipments from Florida.
[d]Excludes truck shipments of textiles and apparel, furniture and fixtures, rubber and plastics products, leather products, primary metal products, nonelectrical machinery, instruments, and photographic goods originating in Florida.

distributing freight by the Fratar method.

MODAL-SPLIT ANALYSIS

The analysis of the base-year freight flow O-D tables revealed very little apparent competition between the motor, rail, and water carriers. For most of the commodity groups, one mode was predominant, hauling at least three times as much tonnage as the other modes. The analysis, however, also indicated that a more detailed examination of the modal split between truck and rail might be warranted for four of the commodity groups: (a) food products, (b) lumber and wood products, (c) chemicals and allied products, and (d) clay, concrete, glass, and stone products.

Consequently, an attempt was made to develop mathematical models of the modal split between truck and rail for each of these commodity groups. These models were to be sensitive to changes in shipping times and shipping costs by truck and by rail. The logit equation was selected as the formulation of the modal-split models.

Many separate formulations of the logit model were attempted. In each case the pseudo R-square statistic, a measure of how well the logit model accounts for the variation in the modal split, was extremely low. Although the signs of the coefficients for shipping time and shipping cost should have been positive, in many cases one or both of the signs were negative because of the high correlation between the two explanatory variables.

The fact that a mathematical relation between modal choice and shipping costs and times could not be found for the four commodity groups was most likely due to the high level of aggregation of the commodities. The four commodity groups chosen for the modal-split analysis were very heterogeneous. They included bulk commodities as well as packaged goods and commodities with a low unit value as well as commodities with a high unit value. It is possible that a more detailed breakdown of the commodities in each of the four groups would have revealed that the motor carriers and the railroads were hauling different kinds of food products, wood products, chemicals, and clay, concrete, glass, and stone products. Shipping costs could also be determined more accurately if a more detailed breakdown of these commodities could be made. Unfortunately, the existing secondary sources of truck data did not permit a more disaggregate approach to modeling the modal split of freight.

GOODS MOVEMENT FORECASTS FOR FLORIDA

As mentioned earlier, the Fratar model was used to project the generation and distribution of freight to, from, and within the State of Florida. Table 5 presents the projected tonnages of domestic freight for all modes combined in 1985 and 2000. The commodity groups that showed the largest percentage increases were (a) clay, concrete, glass, and stone products; (b) coal; (c) chemical and allied products; and (d) stone, sand, and gravel. Projections of phosphate rock tonnages were not developed because of uncertainties associated with environmental impacts of future mining operations in central Florida. The draft areawide environmental impact statement for the central Florida phosphate industry was considered to be a better source of phosphate production estimates.

Although projected increases in citrus fruit and other farm products were relatively modest, the growth in tonnages of food and kindred products (i.e., processed products that use sizable quantities of citrus fruit and other farm products) was estimated to be on the order of 70 percent between 1975 and 2000. The projected 67 percent increase in the state's population between 1975 and 2000 appears to be promoting major increases in the use of construction-related commodities such as stone, sand, and gravel and clay, concrete, glass, and stone products.

Intrastate movements of virtually all commodities were projected to increase more significantly then interstate movements to and from Florida. This appears to be attributable to the large growth in population and economic development projected for the state through the year 2000. The percentage increases in interstate commodity movements to and from Florida were similar to the intrastate projections. The state is likely to continue to "import" more goods than it "exports" to other states.

Projections of freight tonnages by mode were made under the assumption that the current modal choice of freight shipments in Florida will continue in the future. For many commodity groupings, truck tonnages were estimated to increase more significantly than rail and water tonnages. Both rail and water were estimated to experience large increases in tonnages of bulk commodities and products, including lumber and wood products, chemical and allied products, and clay, concrete, glass, and stone products.

Intrastate shipments of virtually all commodity groups by both truck and rail were estimated to increase dramatically over the 25-year forecast period. These intrastate movements are generally increasing by several hundred percent as a result of projected economic development in the state.

Interstate shipments by truck, rail, and water were projected to increase but at a more modest rate than intrastate shipments. The percentage increases in truck movements into Florida were larger than those for movements out of the state. This finding also applied to rail and water movements.

ASSESSMENT OF FLORIDA FREIGHT FORECASTING PROCEDURES

The Fratar model for forecasting future goods movement flows by commodity group, mode, and geographic area (i.e., county in Florida and state outside of Florida) produced reasonable projections based on the demographic and economic forecasts formulated by FDOT. The goods movement model can be used to identify the potential demands for freight services by mode and geographic area. The methodology is sensitive to important state economic factors, such as personal income and earnings by type of industry.

It should be recognized that external governmental policies may have a significant impact on future freight flows. For example, national energy policy with regard to the fuels used in power plants may have a significant impact on coal movements. Environmental policy may have a significant impact on the mining and transportation of phosphate rock.

The Florida model was built for long-range planning purposes. Because the model was built on secondary data sources, it is both feasible and advisable to update its base-year freight flows. For instance, the 1977 Census of Transportation could be used, with other sources, to construct a 1977 data base. The 1967 input-output coefficients could be replaced with 1972 coefficients. Finally, by updating the base year, the "old" model can be run on the "old" base-year data set to forecast the new base year. Any major discrepancies can be used as a check on the soundness of the model.

The FDOT model does not contain capacity constraints and does not assign freight flows over particular routes. However, the model can be used to indicate potential congestion points in the state's transportation infrastructure. In particular, the model can be used to determine (a) which ports will experience substantial increases in waterborne activity, (b) which county pairs will experience significant growth in truck traffic between them (and thus possible congestion on the highway system linking the pairs), and (c) which city pairs will experience significant increases in rail traffic.

In this manner, state DOT officials can ascertain where transportation bottlenecks may occur, where increased road construction and maintenance may be expected, and, based on the economic forecasts used, when in the future these problems will probably occur. Such information gleaned from the model's results can then be used for long-range local and state capital budgeting plans.

One aspect of statewide goods movement that was not addressed in the development of the Florida freight forecasting methodology and data base was the movement of goods that neither originate nor terminate within the state. Through traffic is relatively minor in a peninsular state like Florida. However, in most states, particularly those in the Midwest, through traffic is quite significant. A national network analysis is needed to analyze this portion of freight traffic.

The Florida model and data base also did not cover international traffic. In Florida, international goods movements are either waterborne or airborne. In states bordering Canada, international truck and rail traffic could also be significant. More research is needed on the generation and distribution of international freight.

The FDOT model was built on existing secondary data sources. Most of those sources exist in the same or analogous form in other states. Thus, the same set of exercises could be repeated to construct a freight transport model in another state.

REFERENCES

1. Roger Creighton Associates, Inc., and R.L. Banks and Associates, Inc. Freight Data Requirements for Statewide Transportation Systems Planning: Research Report. NCHRP, Rept. 177, 1977.
2. Some Consideration of Modal Split Models for the 1972 Transportation Needs Study: An Interim Report. Arthur Young and Co., New York, 1970.
3. J.H. Herendeen, Jr. Theoretical Development and Preliminary Testing of a Mathematical Model for Predicting Freight Modal Split. Transportation and Traffic Safety Center and Department of Civil Engineering, Pennsylvania State Univ., University Park, April 1969.
4. H. Townsend. Two Models of Freight Modal Choice. In Studies on the Demand for Freight Transportation: Volume III, U.S. Department of Transportation, March 1969.
5. Peat, Marwick, Mitchell and Company; DTM, Inc. Goods Movement Forecasting Procedures User's Manual. Florida Department of Transportation, Tallahassee, April 1979.
6. Peat, Marwick, Mitchell and Company; DTM, Inc. Person Travel and Goods Movement Forecasting Procedures for Multi-Modal Statewide Transportation Planning. Florida Department of Transportation, Tallahassee, June 1979.
7. Projections: Economic Activity in Florida--Series E Population. Bureau of Economic Analysis, U.S. Department of Commerce, Dec. 1975.
8. Federal Highway Administration. Computer Programs for Urban Transportation Planning: PLANPAC/BACKPAC--General Information. U.S. Government Printing Office, April 1977.

Publication of this paper sponsored by Committee on Statewide Multimodal Transportation Planning.

Model for Statewide Freight Transportation Planning

T. JOHN KIM AND JERE J. HINKLE

A planning model for statewide freight transport systems planning is proposed that is a modification of the existing and readily available Urban Transportation Planning System (UTPS) package. The model is modified in such a way that it can be used for the analysis of multicommodity freight flows by highway, rail, water, and pipeline for a region and/or a state. The issues and problems that can be analyzed by using the model include the identification of the anticipated impacts of deregulation, rail mergers, a shift in the economic base of an area, and changes in population, transportation rate, energy availability, and service.

The state of the art of analyzing freight demand at the state level is primitive, and techniques are not readily available to state agencies for direct application (1). Because of this paucity of analytic techniques, as well as a lack of freight flow data, state agencies have not been able to adequately address and identify the anticipated impacts of deregulation, rail mergers, shift in the economic base of an area, and changes in population, transportation rate, energy availability, and service.

The purpose of this paper is to propose a multicommodity, multimodal statewide freight transportation planning model by modifying the existing Urban Transportation Planning System (UTPS) package developed by both the Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (2).

Little effort, if any, has been devoted to the use of UTPS for freight transport planning and/or regional transportation planning. This is not surprising since the main thrust of UTPS was urban transportation planning in general and passenger transportation planning in particular. A number of studies, however, explored the similarities and dissimilarities between freight and passenger transportation modeling processes in the late 1960s (3-5). At the same time, Peat, Marwick, Livingston, and Company (6) has attempted to assign aggregate commodity traffic into geocoded freight networks and the Office of Systems Analysis and Information of the Office of the Secretary of Transportation initiated a pilot study to develop a network analysis methodology (7).

The Federal Railroad Administration (FRA) developed a computer network model in 1973 specifically for railroad planning, using the FHWA highway assignment program package as the basis.

These studies resulted in models that used partial phases of the entire urban transportation planning (UTP) processes. A number of studies have suggested the integration of goods movement into the appropriate phases of the UTP processes (8-10).

The first known application of network analysis techniques to freight movement by a state was performed in 1975 by the Pennsylvania Department of Transportation (PennDOT) (11). Although a systematic process was developed for assigning interzonal traffic flows, the assignment procedure does not rely on theory or algorithms for route decision-making and thus could possibly be influenced by subjective biases (1).

In a step toward building a comprehensive interregional commodity flow model, Boyce and Hewings (12) recently developed an entropy formulation for interregional commodity flows, including specific functions for modal split and route choice that are comparable to existing entropy models for passenger transport planning.

The models in the studies cited above remain either urban in scope, nonnetwork in nature or single-mode, or a model yet to be tested. However, a network model for interregional freight transport was developed by CACI-Federal for the Transportation Systems Center (13). Benefits that can be obtained from the model developed by CACI are acknowledged, but it is not the purpose of this paper to develop "another" network model to be applied for the evaluation of the statewide transportation system. Rather, the main purpose of the study is to use the existing program package as much as possible at the minimum cost of operation. The familiarity of many state transportation planners with UTPS will preclude the need for extensive training to use the modified UTPS model.

MODIFICATION OF UTPS FOR STATEWIDE FREIGHT TRANSPORT PLANNING

The overall flows of the proposed model, as well as appropriate modification and addition to UTPS, are shown in Figure 1. The proposed model is divided into five submodels as follows:

1. Network analysis models,
2. Freight transport demand analysis models,
3. Vehicle requirements models,
4. Assignment model, and
5. Evaluation model.

Network Analysis Models

The geography assumed for the model is either the Bureau of Economic Analysis (BEA) areas, counties, or subcounty units. Preference should be given to the smaller unit if the flow data can support this level of detail.

Coding and Building Networks

Freight is shipped by three main transport modes: highway, rail, and waterway. In addition, it is anticipated that pipelines will play an increasing role in shipping commodities. In coding and building networks for the freight transport system, the UTPS.HR program will be modified and used.

At first, it might seem that the rail network should be built by using the UTPS.UNET program. However, this program implies the representation of transit lines that have the following properties:

1. A transit line is served by vehicles operating at regular intervals. In general, freight rail movements are not regular.
2. Transit lines imply two-way movements of vehicles on the same route. This does not correspond to freight rail operating practice.

Railroad, pipeline, and waterway networks for freight are built by UTPS.HR by specifying area types and facility types for each link, as shown in Figure 2. Speed by lane, area, and facility type should be provided by "look-up" tables in UTPS.UROAD for corresponding modes.

Path Building and Skimming

The network will be processed by UROAD to yield zone-to-zone impedance for the different modes under consideration. The derived impedance will be a function of travel time, including transfer times and travel costs. Different values of composite impedance may also be calculated by using the weighting options of UROAD for travel time, travel costs, and toll facilities.

Freight Transport Demand Analysis Models

As in standard UTPS procedures, freight transport demand analyses will be divided into four steps: freight volume generation, interzonal commodity distribution, modal split, and freight volume assignment. The basic decision unit will be metric tons in each step except in the final assignment stage, where the volume in metric tons will be converted into vehicle equivalents for each mode (trucks of different sizes, rail cars, barges, etc.).

Freight volume origin-destination (O-D) data between BEA regions are available (14,15). These are

Figure 1. Modification of UTPS for statewide transportation planning.

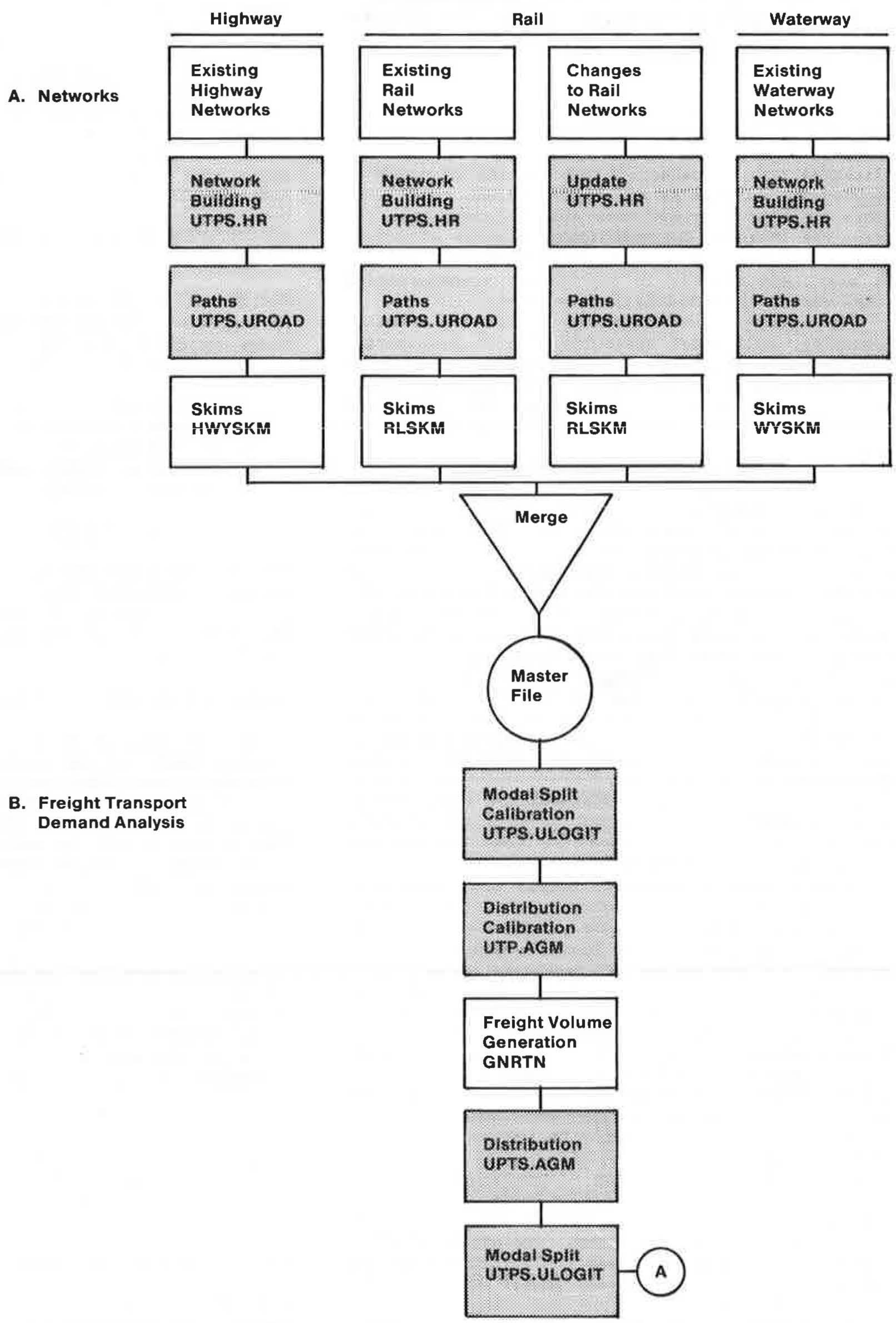


Figure 1. Continued.

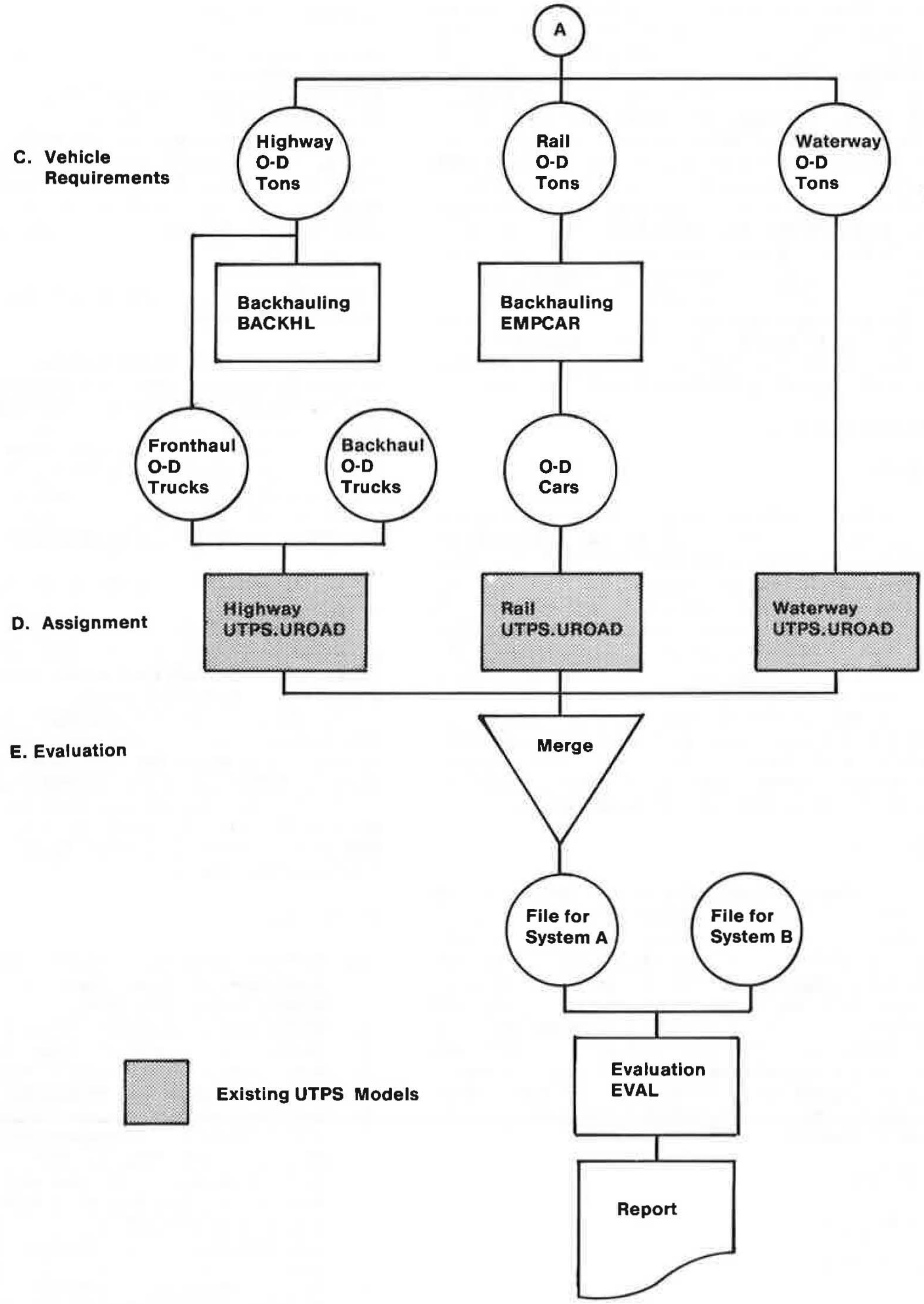


Figure 2. Sample representation of different modes by type of area and facility in UTPS.HR.

Remarks	Area Type / Facility Type	Mountainous	Hilly	Flat	Populated	Water/ Special
Access Link	1. Connector	Highway				Pipeline
Two Lane	2. Undivided Expressway					
Four Lane	3. Divided Expressway					
Rail or Waterway	4. Rail or Barge	Rail				Barge

part of data that were prepared for DOT, and thus no extensive data collection efforts are necessary for the analysis of BEA regions. Data by county for some commodities are available in many states. For example, in Illinois, coal (16) and grain movements (17,18) by rail, highway, or water are available. Data on fertilizer and petrochemical shipments at the county level were collected by the Illinois DOT and its Bureau of Railroads and Bureau of Planning.

For calibration of modal split and commodity distribution, UTPS.ULOGIT and UTPS.AGM will be used without much modification. For freight volume generation, either existing UTPS models (UMODEL and/or UFIT) will be used or a separate program can be developed if necessary according to the need of each state. For interzonal commodity distribution, UTPS.AGM will be used without significant modification. For modal split, UTPS.ULOGIT will be used.

Vehicle Requirements Models

Truck Backhaul

A backhaul model, which is not provided in the standard UTPS package, is essential to the modeling of highway freight movements because backhaul directly affects the traffic to be carried by the highway networks and also truck operating efficiency. A probabilistic type of model can be developed that calculates the probability of truck backhauling, depending on volume to be carried, distance, truck size, and cost of backhauling. If such data are unavailable, a few sample weight station surveys or truck company surveys will be sufficient and only six variables will have to be identified: origin and destination, volume carried, commodity carried, distance, truck size, and cost of backhauling.

Empty Rail Cars

Conventional transportation planning models provide estimates of the number of loaded cars required to carry freight in each direction. However, freight flows will be different in opposite directions, and there will be a requirement for the movement of empty rail cars in order to equalize their supply and demand locally. These empty-car movements must be estimated since they require system capacity and contribute to the operational costs of the railroad.

A separate linear programming type of cost minimization model can be developed, the concept for which is expressed as

$$\text{Min } Z = \sum_{i \neq j} \sum_{i \neq j} C_{ij} E_{ij}$$

subject to $E_{ij} \geq 0$:

$$\sum_{j \neq i} (F_{ij} + E_{ij}) = \sum_{j \neq i} (F_{ji} + E_{ji})$$

where

E_{ij} = number of empty cars to be hauled from i to j,
F_{ij} = number of full cars required to be hauled from i to j, and
C_{ij} = cost of hauling one empty car between i and j.

Assignment Model

After interzonal commodity flow tonnages are converted into fronthaul and backhaul trucks or rail cars, the application of UTPS.UROAD will result in the assignment of trucks or cars to the different networks.

Evaluation Model

An evaluation model is not available in UTPS, even for the passenger systems. This model is necessary for the evaluation of the impact of such policies as deregulation on freight transportation systems from the state's perspective as well as from the shipper's. A separate evaluation model will include, but not be limited to, the following criteria: (a) benefits to the public (consumer surplus), (b) accessibility, (c) vehicle utilization, and (d) energy consumption.

IMPLICATIONS FOR STATEWIDE FREIGHT TRANSPORT PLANNING

The modified UTPS model suggested in this paper for statewide freight transport purposes was applied for the national comprehensive transportation study for Korea (19). No application has been made, however, to any state in the United States as yet. Notwithstanding the fact that UTPS is an urban and passenger-oriented model, the potential and practical benefits of modifying it for statewide freight transport purposes are as follows:

1. No extensive development work will be necessary.
2. Many transportation planners, including those in state agencies, are familiar with UTPS. This implies that the modified model would not involve extensive dissemination costs.
3. Once statewide transport networks are coded, the network can be used for both freight and passenger transportation analyses since the network will be coded and built in UTPS frameworks.
4. The results of the proposed study can be used as a basis for the development of a "Statewide Comprehensive Transportation Systems" package within the UTPS framework.

REFERENCES

1. Freight Data Requirements for Statewide Transportation Systems Planning: Research Report. NCHRP, Rept. 177, 1977.
2. Urban Transportation Planning System. U.S. Department of Transportation, 1980.
3. W.J. Baumol and others. Studies in Travel Demand. Mathematica, Princeton, NJ, Vol. 3, 1967.
4. W.J. Baumol and others. Studies on the Demand for Freight Transportation. Mathematica, Princeton, NJ, Vol. 1, 1967.
5. J.H. Herendeen. Theoretical Development and Preliminary Testing of a Mathematical Model for Predicting Freight Modal Split. Transportation and Traffic Safety Center, Pennsylvania State Univ., University Park, June 1969.
6. Peat, Marwick, Livingston, and Company. Freight and Commodity Networks: Northeast Corridor Transportation Network Data Base. U.S. Department of Transportation, July 1968.
7. C.N. Swerdloff. Developing a National Network Model of Intercity Freight Movement in the United States. Proc., Planning and Transport Research and Computation Symposium, Amsterdam, Netherlands, May 4-7, 1971.
8. D.S. Gendell and others. Urban Goods Movement Considerations in Urban Transportation Planning Studies. Presented at Engineering Foundation Conference on Goods Transportation in Urban Areas, South Berwick, ME, Aug. 5-10, 1973.
9. A.H. Meyburg and others. Urban Goods Movement Planning Methodology. Transportation Engineering Journal, Nov. 1974.
10. A.H. Meyburg and P.R. Stopher. A Framework for

the Analysis of Demand for Urban Goods Movement. TRB, Transportation Research Record 496, 1974, pp. 68-79.
11. F.W. Memmott and F.S. Scholz. Trunk Route Analyses: A Useful Tool for Statewide and Regional Rail Planning. TRB, Transportation Research Record 591, 1976, pp. 44-50.
12. D.E. Boyce and G.J.D. Hewings. Interregional Commodity Flow, Input-Output, and Transportation Modelling: An Entropy Formulation. Presented at the 1st World Regional Science Congress, Cambridge, MA, June 1980.
13. M.S. Bronzini and others. Freight Transportation Energy Use: Volume II--Methodology and Program Documentation. Transportation Systems Center, Cambridge, MA, 1979.
14. R.W. Schuessler and P.A. Cardellichio. NTP Commodity Flow Projections: Data and Methods Description. Transportation Systems Center, Cambridge, MA, Rept. SS-212-U1-33, 1976.
15. Jack Faucett Associates, Inc. Freight Commodity Flows, 1972. Transportation Systems Center, Cambridge, MA, June 1976.
16. L.C. Keasler and G. Drovenzano. Inventory of Origins, Destinations, and Routes of Coal Shipment in Illinois. Institute for Environmental Studies, Univ. of Illinois, Urbana-Champaign, 1980.
17. S.C. Bermingham and L.D. Hill. Changes in Destination and Mode of Transport for Illinois Grain, 1954, 1970, and 1973. Department of Agricultural Economics, Agricultural Experiment Station, Univ. of Illinois, Urbana-Champaign, 1976.
18. S.C. Bermingham and L.D. Hill. An Analysis of Grain Movement on the Illinois River. Department of Agricultural Economics, Agricultural Experiment Station, Univ. of Illinois, Urbana-Champaign, 1976.
19. T. Kim. Optimum Transport Sector Investment Study. Regional Development Research Institute, Korea Institute of Science and Technology, Seoul, July 1980.

Publication of this paper sponsored by Committee on Statewide Multimodal Transportation Planning.

Importance of Empty Backhauling and Special Services to Cost of Exempt Truck Service

T.H. MAZE

Exempt motor carriers often provide a number of special services (such as multiple pickups, paying for loading and unloading, and multiple deliveries) at little or no charge. These services allow greater flexibility in the shipping of agricultural commodities. However, these services carry a significant cost for the carrier, and, because the truck service buyer does not bear these costs through an additional charge, he has no incentive to limit the number of services he requires. Because these practices are uncommon in other sectors of trucking, it is proposed that much of the cost of these services represents a resource misallocation. Empirical evidence taken from the Florida produce truck service market is used as an example of the significance of these costs. A second issue addressed is the cost of empty backhauling by returning exempt carriers. In the market studied (the Florida produce market), regulation, rather than a natural commodity flow imbalance, appears to be causing empty backhauling. Although empty backhauling inefficiently increases the average cost of truck service, more importantly, it distorts the values paid for agricultural truck service. Empirical evidence collected from the Florida market is used to show that the distortion of prices is much more important than the average costs of inefficient empty backhauling.

It is common for carriers of perishable agricultural commodities to provide multiple pickups and deliveries with tractor-semitrailers. In addition, carriers often provide loading and unloading services by hiring freelance labor at shippers' and/or receivers' docks. The willingness of agricultural carriers to provide such "special services" at no charge or little charge has been hailed as a benefit of agricultural exemption from motor carrier regulation (1). On the other side of the coin, on return trips agricultural carriers often have to backhaul empty. The problem of empty backhauling is often attributed to too much regulation, the argument being that carriers without regulated authority who haul exempt agricultural commodities cannot return with regulated commodities (2). The fact that most commodities bound for agricultural areas are regulated promotes an imbalance in flows of commodities that agricultural carriers may haul on their fronthauls and backhauls.

The intent of this paper is twofold. The first purpose is to show that the existing pricing structure of produce truck service is causing a resource misallocation. Because each additional special service is not priced at its cost, the buyers of truck services do not bear the cost of requiring added special services. Hence, buyers are not being given the proper pricing signals to make efficient choices and a resource misallocation results. Furthermore, estimates of the costs of special service will be used to show that these costs are quite significant. The second purpose of the paper is to shed new light on the costs of regulatory constraints that cause empty backhauling. Typically, the costs of empty backhauling are assumed to be equal to the average costs of truck travel times the empty miles traveled. However, the situation is more complex than this. Regulation causes an artificial scarcity of truck suppliers bound for agricultural areas and results in a distortion of truck service markets in both directions (inbound and outbound). An example is used to show that the distortion of the markets causes a greater burden on agricultural truck-service buyers than just average costs of empty backhauling.

FREIGHT MARKET

The area investigated was the Florida produce truck-service market. During 1978-1979, Florida produce shippers depended almost totally on truck transpor-

Table 1. Interstate produce truckload shipments: 1978.

	No. of Truckloads			
Region	Total Yearly	Largest Weekly	Weekly Avg	Week of Yearly High
Florida	165 499	7 157	3 183	First week of June
U.S. total	1 083 379	26 615	20 892	Third week of May

tation. Only a few shipments of dense, high-sale-volume commodities were made by piggyback or rail car during 1978 (3). Annually, approximately 165 000 truckloads of produce are shipped from Florida, or about 15 percent of all interstate produce shipments (see Table 1). The size distribution of firms that haul Florida produce is similar to that of all agricultural carriers (4):

No. of Trucks	Firms (%)
1	45
2-5	35
6-10	7
≥11	13

Seventy-three percent of Florida produce truckloads are arranged by truck brokers compared with 51 percent nationally (5). Thus, brokers play a dominant role in the Florida market.

Because a trucking firm may move its equipment around the country to meet needs for truck transportation, the trucker sometimes has to lead a gypsy-like life. Random truck operating patterns create confusion for those attempting to investigate the operations of these truckers. Therefore, this discussion proposes three simplifying generalizations about truck operating patterns:

1. When the truck leaves Florida with a load of produce, the truck is on its fronthaul trip.
2. When it returns to Florida, the truck is on its backhaul trip.
3. The sum of the two legs is a truck cycle tour.

Thus, the smallest unit of output of the trucking firm is a complete tour. During the tour, the trucking firm supplies service in both directions, and hence the firm's expected revenue for its output is the sum of the prices the firm expects to receive in both directions. However, the price received for service in either direction may not be greater than the firm's marginal costs for that leg. This is obviously true when a truck backhauls empty; the cost of empty backhauling must then be covered by the fronthaul revenue. By viewing the prices in both directions as being dependent on one another, a relation between the markets in each direction can be established.

By viewing truck service in terms of a tour, one can isolate the fraction of the output, and hence the cost of service, devoted to each special service or empty backhaul within the tour. Specifically, in the analysis a ratio is developed of the average revenue received to the average output of the tour (miles traveled). As special services or empty backhauling is incrementally removed from the tour, the change in the ratio indicates the percentage of the average revenue (cost) that covers the portion of the tour removed.

The analysis estimates the quantity of special services rendered by truckers while hauling Florida produce based on field surveys of Florida produce haulers. The expected revenue to be received during a tour must at least cover the marginal cost of the service rendered during the tour. This means that the sum of the expected prices to be received in both directions must at least equal the marginal cost of the tour and that neither price necessarily has to be equal to the cost of that particular leg. Instead, prices for truck service in the direction of the greatest commodity flow are expected to be greater than in the reverse direction, which would cover the costs of those that are forced to return empty due to the directional commodity flow imbalance. Thus, by viewing service in terms of a two-way tour, buyers in both directions can be allocated their relative share of the cost of truck service.

ANALYSIS

The analysis uses the results of written surveys given to Florida produce haulers during the winter of 1978-1979 to characterize their truck cycle tours. The discussion of the results is divided into three sections. The first section uses information taken from the surveys to estimate the quantity of special services rendered by truckers while hauling Florida produce. The second section uses the same information to estimate the quantity of empty backhauling accrued by returning produce haulers. Finally, the truck cycle tours of Florida produce haulers are coupled with revenue estimates to estimate the average costs of special services and empty backhauling and the market distortion caused by regulatory constraints placed on the commodities that returning produce carriers may haul.

Special Services

When hauling Florida produce, it is quite common for a trucking firm to supply special services. During the collection of field data, many operators complained that they supplied special services but that the prices offered them were insensitive to the quantity of the services they render. For example, a trucker who accepts a load that requires few special services (fewer stops and loading-unloading charges) receives the same price as a second trucker who is going to the same destination and rendering more special services (more stops and loading-unloading charges). This was noted as a common complaint by Taff (6). In a study of national produce trucking by Manalytics, Inc. (7), it was found that any payment for supplying special services was quite uncommon and, when an additional sum is paid, it amounts to "little more than token recognition of the expenses involved". Thus, special services rendered by produce haulers are not priced with respect to the cost of each additional service.

Two questionnaires were distributed to facilitate the estimation of the average quantity of special services rendered on Florida produce fronthauls: (a) a mail-out questionnaire and (b) a hand-out fronthaul questionnaire. The mail-out questionnaire asked trucking firms general questions about their normal experiences when hauling Florida produce and specific questions about their last Florida produce haul. A total of 290 mail-out questionnaires were distributed and 131 were completed and returned. The hand-out fronthaul questionnaire was given to produce haulers as they stopped for inspection at one of Florida's three interstate portals (I-95, I-75, and I-10). This questionnaire asked specific questions about the Florida produce fronthaul the driver was on at the time. A total of 355 questionnaires were distributed and 67 were completed and returned. These two bodies of data are merged to provide the information on special services presented here.

In loading, the accumulation of a full truckload of produce often requires multiple pickups. Table 2 gives the number of loading stops made by trucks when accumulating a load of produce. Boston, New York, and Philadelphia are the only destinations with more than 10 fronthaul samples. The remainder is spread across 32 other U.S. and 4 Canadian cities.

The mean number of loading stops was 2.32, and the number of stops varied from 1 to 9. The way in which trucks were routed from pickup to pickup caused the truck to travel an average of 65 miles out of the way of the line-haul trip path for every pickup beyond the first. Because few of the respondents indicated that they were charged to load, charges for loading averaged only $6/load.

In unloading, there were often multiple delivery stops. Table 3 gives the number of stops made while delivering Florida produce. The mean number of stops was 1.51, and the number of stops varied from 1 to 7. The way in which trucks were routed between delivery stops caused the trucks to travel an additional 28 miles out of the way for every additional stop beyond the first.

When produce trucks are making deliveries, unloading fees of some kind are often paid by the trucker. Terminals sometimes charge to let trucks enter, often the trucker will have to tip or pay off platform workers to expedite unloading, and the trucker is frequently coerced into hiring labor at the terminal to unload. To estimate the frequency and total cost of these unloading practices, the mail-out questionnaire asked operators, with regard to their three most common destinations, (a) whether they are charged to enter or leave the unloading area, (b) whether they tip or pay off platform workers, (c) whether they are required to hire labor to unload, and (d) what the usual total cost of these expenses is.

The distribution of responses as to whether the trucker encountered unloading charges is given in Table 4 for the three practices individually and for all combinations. Values are given for all destinations that received more than 10 responses, and the rest are spread across 13 other U.S. and 4 Canadian cities. Table 5 gives the responses summed for each charging practice and the mean and total costs of these charges. At all unloading destinations, the trucker was charged to enter 50 percent of the time, tipped or paid off platform workers 49 percent of the time, and was required to hire labor to unload 42 percent of the time. The distribution of the total cost of all three charging practices is given in Table 6. The average total charge for all destinations is $33.40.

To compare these results with practices in regulated truck service, it must first be understood that the regulated service is terminal oriented. When a truckload of regulated commodities is made up of packages from different origins [less than truckload (LTL)], a full load is usually consolidated at a terminal and truck service is charged at an LTL rate that is higher than a truckload (TL) rate. Even if an LTL load is picked up from different origins but not consolidated at a terminal, it still receives an LTL rate. If a TL shipment requires more than one delivery (split deliveries), the shipper is usually charged a flat rate per stop. Hence, in the scheme of the regulated trucking industry, multiple pickups and deliveries bear a price.

Loading-unloading charges are uncommon in other sectors of trucking. The Interstate Commerce Commission recently surveyed 156 owner-operators trip leased to regulated carriers; when asked about their experiences on their last trip, none reported being charged to enter or leave the loading-unloading area, 3 percent reported tipping or paying off platform workers, and 3 percent were required to hire labor to unload (8). This may be compared with the responses of 50, 49, and 42 percent, respectively, when Florida produce haulers were asked the same questions.

Empty Backhauling and Backhaul Special Services

Empty backhauling is a fundamental problem of most haulers of agricultural commodities (1). Typically, greater amounts of freight originate in agricultural areas than are delivered there. This imbalance causes a greater need for transportation services out of agricultural areas, and naturally some trucks must return empty. Another factor that tends to aggravate the problem of empty backhauling is that unmanufactured agricultural commodities are exempt from regulation and returning manufactured commodities are regulated. This means that, even if manufactured commodity loads are available, firms without regulated authority (exempt trucking firms) cannot carry manufactured commodities back unless the firms are leased to a regulated trucking firm. The natural imbalance between inbound and outbound commodity flows coupled with the imbalance between exempt and regulated goods has caused the problem of empty backhauling.

Recently, Ramirez (9) studied the commodity flows carried by truck between Florida and the remaining 47 contiguous United States. He found that Florida was a much greater sink for truck freight than a source, even during the height of the produce shipping season. Therefore, if trucks were matched to loads, disregarding regulatory constraints, trucks should be leaving Florida empty instead of the reverse. Hence, there is at least no natural imbalance of truck freight that would cause trucks to return to Florida empty.

To facilitate the estimation of the quantity of empty backhaul encountered (and of special services rendered) by returning produce haulers, a hand-out backhaul questionnaire was given to returning produce haulers when they were stopped for inspection at one of Florida's three interstate portals (I-95, I-75, and I-10). This questionnaire asked specific questions about the produce hauler's return trip. A total of 327 questionnaires were distributed to truck drivers, but only 55 were returned.

Although Ramirez's findings show that truck freight originating from all points entered Florida at a faster rate than loads leaving Florida to each point, the responses to the questionnaire showed that 20 percent of the trucks sampled returned empty. This presents an ironic circumstance. As Ramirez discovered, because Florida is a greater receiver of regulated freight than it is a generator of all kinds of truck freight, even under optimal conditions, there should be trucks traveling outbound empty. Because existing conditions are clearly less orderly than the optimal matching of trucks to loads, there must be trucks that currently travel empty out of Florida. In contrast, some produce haulers now travel empty inbound. Thus, there are trucks traveling in both directions empty. It would appear that this gross inefficiency is due primarily to regulatory constraints that prohibit exempt trucking firms from participating directly in regulated inbound freight markets.

On backhauls, loaded trucks also supply special services. The mean number of loading and unloading stops and the mean loading and unloading charges are given in Table 7. The magnitudes and frequencies of special services are much less on backhaul loads than on fronthaul loads. This is largely because special services are almost exclusively rendered for exempt loads or regulated perishables (meat and

Table 2. Frequencies of multiple pickup stops.

Destination	No. of Pickup Stops Required 1	2	3	4	5	6	7	8	9	Avg No. of Stops	No. of Samples
Boston										2.23	13
Samples	6	2	2	2	1	0	0	0	0		
Percent	46.2	15.4	15.4	15.4	7.6	0	0	0	0		
New York										1.71	17
Samples	11	3	1	1	1	0	0	0	0		
Percent	64.7	17.6	5.9	5.9	5.9	0	0	0	0		
Philadelphia										1.92	12
Samples	5	4	2	1	0	0	0	0	0		
Percent	41.7	33.3	16.7	8.3	0	0	0	0	0		
Other										2.53	89
Samples	37	19	14	6	4	4	3	1	1		
Percent	41.7	21.3	15.7	6.7	4.5	4.5	3.4	1.1	1.1		
All										2.32	131
Samples	59	28	19	10	6	4	3	1	1		
Percent	45.0	21.4	14.5	7.6	4.6	3.0	2.3	0.8	0.8		

Table 3. Frequencies of multiple delivery stops.

Destination	No. of Stops Required 1	2	3	4	5	6	7	Avg No. of Stops	No. of Cases
Boston								1.38	13
Samples	9	3	1	0	0	0	0		
Percent	69.2	23.1	7.7	0	0	0	0		
New York								1.33	17
Samples	12	4	1	0	0	0	0		
Percent	70.6	23.5	5.9	0	0	0	0		
Philadelphia								1.33	12
Samples	10	1	0	1	0	0	0		
Percent	83.3	8.3	0	8.4	0	0	0		
Other								1.58	89
Samples	62	15	4	5	2	0	1		
Percent	69.7	16.9	4.5	5.6	2.2	0	1.1		
All								1.51	131
Samples	93	23	6	6	2	0	1		
Percent	71.0	17.6	4.6	4.6	1.5	0	0.7		

Table 4. Distribution of types of unloading charges.

Destination	Distribution (%) No Charge	Tips or Payoffs Only	Hired Labor Only	Entry Charge Only	Tips or Payoffs and Hired Labor	Tips or Payoffs and Entry Charge	Entry Charge and Hired Labor	Tips or Payoffs, Hired Labor, and Entry Charge
Atlanta	10	10	0	0	0	30	10	40
Boston	12	0	0	8	0	56	12	12
Buffalo	37	9	18	0	0	27	0	9
Chicago	21	7	14	4	18	14	4	18
Cincinnati	37	27	9	0	9	18	0	0
Cleveland	30	8	23	0	15	8	8	8
Detroit	30	5	0	10	0	10	20	25
New York	6	4	0	6	4	30	29	21
Philadelphia	16	10	21	3	10	21	16	8
Raleigh	60	0	30	0	10	0	0	0
Washington, D.C.	5	10	15	0	15	25	20	10
Other	33	10	19	3	6	16	1	12
All	23	8	12	6	7	21	10	13

Table 5. Unloading charges per trip.

Destination	Trucks (%) Paid Tips or Payoffs to Platform Workers	Required to Hire Labor	Charge to Enter Unloading Area	Avg Total Unloading Area Charges[a] ($) Lower Limit	Mean	Upper Limit	No. of Responses
Atlanta	90	50	70	20.77	31.29	41.81	10
Boston	68	24	84	31.80	39.29	46.77	25
Buffalo	46	27	36	15.87	28.14	40.41	11
Chicago	57	54	39	19.27	34.29	49.31	28
Cincinnati	54	18	18	14.09	25.91	37.73	11
Cleveland	38	46	23	21.13	33.23	45.33	13
Detroit	50	45	65	15.46	27.04	38.62	20
New York	60	54	83	38.88	45.21	51.54	47
Philadelphia	45	55	47	30.54	38.96	47.38	38
Raleigh	10	40	0	5.50	22.00	38.50	10
Washington, D.C.	60	60	55	39.58	46.70	53.82	20
Other	39	34	39	23.79	26.84	32.94	122
All	49	42	50	31.15	33.40	35.65	355

[a]Lower and upper limits are those of the 90 percent confidence interval.

Table 6. Distribution of unloading charge amounts.

	No. of Respondents in Charge Category					
Destination	$0	$1-$25	$26-$50	$51-$75	$76-$100	$101-$125
Atlanta	1	2	5	2	0	0
Boston	3	2	17	2	1	0
Buffalo	4	0	6	1	0	0
Chicago	6	4	13	4	1	0
Cincinnati	4	1	5	1	0	0
Cleveland	4	1	6	2	0	0
Detroit	6	5	5	2	2	0
New York	3	6	26	8	3	1
Philadelphia	6	2	23	4	3	0
Raleigh	6	0	3	0	1	0
Washington, D.C.	1	1	9	8	1	0
Other	42	22	50	7	5	0
All	86	46	168	41	17	1

Table 7. Backhaul special services.

	Avg No. of Stops		Loading Charge[a] ($)			Unloading Charge[a] ($)			
Category	Pickup	Delivery	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	No. of Responses
All backhauling trucks	1.09	1.12		5.04			14.40		55
All backhauling trucks returning with a load	1.36	1.40	2.85	6.30	9.74	15.29	20.44	25.59	44

[a]Lower and upper limits at 90 percent confidence interval. Confidence intervals are not included when empty backhauling trucks are included in the sample because the loading-unloading charges are strictly zero (or undefined) when no load is carried and thus their variance is zero. Adding them into the estimate of the confidence interval of the mean charge would be meaningless.

frozen foods), which tends to support Taff's finding that the practice of charging for loading and unloading is generally only found in the food industry (10).

Truck Cycle Tour

To estimate the average cost of each special service and of empty backhauling, it is necessary to know the total average price paid for truck service and the portion of the average work effort devoted to each. In the preceding sections, quantities of special services rendered and of empty backhauling were estimated. These estimates are coupled with estimates of the miles traveled (output) and prices paid to estimate the average cost (average price paid) per unit of output for the average truck cycle tour.

The average revenue estimates and other loading-unloading charges are given in Table 8 (1979 dollars). Average estimates are given, including and excluding those trucks that returned empty. Note that the average revenue received by all returning trucks after loading and unloading charges are subtracted is approximately half the fronthaul revenue. Even those that returned loaded average less than 70 percent of the average revenue received on fronthaul loads.

The average number of fronthaul miles traveled is given below (all values are rounded off to the nearest mile, and lower and upper bounds are at the 90 percent confidence interval):

	Avg Fronthaul Miles		
Segment	Lower Bound	Mean	Upper Bound
Pickup	73	86	99
Delivery	10	14	18
Line-haul	1181	1189	1297
Total		1289	

Total fronthaul miles was defined to be the mileage traveled between the first fronthaul pickup until the last fronthaul delivery. Total backhaul mileage is a little less straightforward. For instance, if a trucker obtains a backhaul load, he must first move the truck from the last fronthaul delivery point to the point where the backhaul is to be loaded. This load may be bound for an area outside of the Florida produce-growing region. After dropping off the backhaul load, the truck will have to deadhead into Florida's produce-growing areas. Defining the total backhauling distance as the miles traveled between the last fronthaul delivery and repositioning for the next fronthaul resulted in the estimates given in Table 9.

Those trucks that backhauled empty averaged a total trip length of 554 fewer miles than those that found a load. This difference is partly due to the fact that empty trucks could return directly to Florida whereas trucks that obtain a load are sometimes forced to take a circuitous route. But most of the difference is due to the fact that the majority of empty backhauling is done by trucks returning from nearby urban areas such as Birmingham, Alabama, Savannah, Georgia, and Columbia, South Carolina.

Approximately 13 percent of the returning miles are traveled by empty backhauling trucks. However, even those that obtained loads traveled approximately 11 percent of their return trip empty while repositioning to accept a return load, and approximately 11 percent of their return miles were spent deadheading into a Florida produce-growing area. If all the empty miles are considered, approximately 32 percent of all returning miles are traveled empty.

Costs of Special Services and Empty Backhauling

In the analysis, the incremental changes in the trucking firms' revenue per unit of output (miles traveled) are calculated under six conditions. The incremental change is assumed to be the average cost (to the buyer) of each special service or empty backhaul or some combination under the condition specified:

1. Average revenue per mile is calculated under existing conditions.

Table 8. Average revenue and loading and unloading charges.

Source	Fronthaul (1979 \$) Lower Bound	Mean	Upper Bound	Backhaul (1979 \$) All Returning Trucks Lower Bound	Mean	Upper Bound	Loaded Trucks Only Lower Bound	Mean	Upper Bound
Freight rate	1137	1213	1289	527	643	759	718	828	938
Loading charge	6	14	22	2	5	8	3	6	10
Unloading charge	31	33	36	10	14	18	15	20	26
Revenues – charges		1166			624			802	

Note: All values are rounded to the nearest dollar. Lower and upper limits are at 90 percent confidence interval.

Table 9. Average backhaul miles by segment.

Segment	Avg Backhaul Miles: All Returning Trucks Lower Bound	Mean	Upper Bound	Loaded Trucks Lower Bound	Mean	Upper Bound	Empty Trucks Lower Bound	Mean	Upper Bound
Pickup	7	12	17	6	15	24	-	-	-
Repositioning for load	81	120	159	104	150	196	-	-	-
Delivery	0	2	4	0	3	6	-	-	-
Deadheading in Florida	87	116	145	104	144	184	-	-	-
Line-haul	911	1009	1107	938	1057	1175	647	815	983
Total		1259			1369				

Note: All values are rounded to the nearest mile. Lower and upper bounds are at 90 percent confidence interval.

2. Average revenue per mile is calculated under the condition that all loading and unloading-area charges would no longer be paid by the trucking firm.
3. Average revenue per mile is calculated under the condition that, through better management, trucks hauling exempt commodities would no longer need to make multiple pickups and deliveries.
4. Average revenue per mile is calculated under a combination of conditions 2 and 3 above.
5. Average revenue per mile is calculated under the condition that all trucks obtain revenue loads on backhauls.
6. Average revenue is calculated under a combination of conditions 2, 3, and 5 above.

The average price paid per mile is used as a basis for comparison. With existing conditions as an example, the ratio is calculated by using Equation 1 below. The values derived in the preceding sections are placed in Equation 1 to derive the calculation in Equation 2.

$$[(\text{Average tour revenue}) - (\text{loading and unloading charges})] \div \text{average truck cycle tour mileage} \quad (1)$$

$$[(\$1213 + \$643) - (\$14 + \$33 + \$5 + \$14)]/(1289 + 1259) = \$0.703/\text{mile} \quad (2)$$

where

\$1,213 = average fronthaul revenue,
\$643 = average backhaul revenue,
\$14 = average fronthaul loading charge for all stops,
\$33 = average fronthaul unloading charge for all stops,
\$5 = average backhaul loading charge for all stops,
\$14 = average backhaul unloading charge for all stops,
1289 = average fronthaul total miles, and
1259 = average backhaul total miles.

The average cost per mile of a truck cycle tour under existing conditions is \$0.703. All five remaining improved conditions were calculated in the same manner. The average cost improvement for each is given in the third column of Table 10; the fourth column gives the percentage average cost improvement. To arrive at the total annual cost of truck service under each condition, the price paid for the entire tour under each condition is multiplied by the annual number of Florida produce truck shipments made. For instance, under existing conditions, \$1856 is paid for the average tour. Florida shipped 165 449 truckloads of produce during 1978, for an approximate total cost of \$307 million/year for truck service on tours originating with a Florida produce load. The changes in yearly cost from existing conditions are reported for the five improved conditions in the last column of Table 10.

Notice that the total average cost of special services (policy 4) is 8.5 percent of the cost of truck services; annual special services costs to buyers of Florida truck service are \$26.1 million. In other sectors of trucking where such costs of services are reflected in the buyer's price, these services are uncommon. Thus, it is not unreasonable to believe that many of these services would not be requested if truck-service buyers were forced to bear their costs. Hence, the major part of the costs of providing special services appears to represent a resource misallocation caused by a pricing system that is insensitive to the number of special services required.

It should also be noted that empty backhauling only accounts for 5.3 percent of the average cost of truck service even though 20 percent of the trucks returned empty. However, those trucks that obtained a load traveled an average 1370 miles whereas those that did not obtain a load backhauled empty from closer cities (on the average) and backhauled empty an average of 815 miles. Trucks that were loaded on their backhauls traveled farther, received less revenue than they would on a comparable fronthaul, and incurred loading-unloading charges. Because the loaded returning truck goes farther, incurs more charges, and receives meager revenues, it should be expected that the average revenue per mile would not be changed greatly by removing the 20 percent of the returning trucks that backhauled empty. However, much more important than the average cost of empty

Table 10. Yearly costs of special services and empty backhauling.

Policy No.	Policy	Cost per Truck Mile[a] ($)	Portion of Total Cost of Service[a] (%)	Yearly Cost ($000 000s)
2	Elimination of loading and unloading charges	0.025	3.6	11.1
3	Elimination of multiple pickups and deliveries	0.042	6.0	18.4
4	Combination of policies 2 and 3	0.060	8.5	26.1
5	Elimination of empty backhauling	0.037	5.3	16.3
6	Combination of policies 2, 3, and 5	0.0101	14.4	44.2

[a]Relative to existing conditions.

backhauling is the disproportion between fronthaul prices and backhaul prices that is caused by the empty backhauling.

As Ramirez's findings showed, under optimal conditions where regulatory constraints are ignored in matching trucks to load, more inbound capacity would be required from all points during all times of the year than would be required in the reverse direction. Then the excess truck service needed for inbound commodity flows would require some trucks to travel outbound empty, and, if the market worked properly, buyers of excess inbound service would bear the costs of empty travel. However, under the current regulatory system, loads are not matched to trucks, trucks return empty to Florida, and the average cost of truck service for a truck that fronthauls produce is increased by 5.3 percent. It should be noted, however, that the average revenue received for Florida-originating truck service ($1213) is nearly double the revenue received, on the average, for all truck service bound for Florida ($643). Even when only the average backhaul revenue is considered for only loaded trucks ($828), the average fronthaul revenue received is approximately 1.5 times greater. Although the 5.3 percent addition in average costs of empty backhauling is artificially caused by regulatory constraints, it causes the agricultural buyer to bear a larger portion of the tour cost than simply the average cost of empty backhauling.

CONCLUSIONS

By using the Florida produce truck-service market as an example, it was shown that the cost of truckers paying loading-unloading fees and making multiple pickups and deliveries with over-the-road trucks is quite significant. Because these services are not priced at their cost, buyers of truck service have no incentive to conserve on the special services they require, and hence a resource misallocation results. Because these services are not common types of truck service where buyers pay for each service, the resource misallocation is probably nearly equal to the cost of these services. Furthermore, this creates interesting means for those firms that can avoid loads requiring special services to accrue lower costs and earn greater returns (11).

Greater efficiency could be achieved by pricing each special service equal to its cost. Buyers of truck service who require few special services would accrue lower costs through reduced prices, and buyers who require special services would be forced to bear their costs. Presumably, once the cost of special services is passed directly to the truck-service buyer, such questionable and atypical practices as coercing truckers into paying off or tipping platform workers would be stopped through pressure by the buyers. Furthermore, shippers and receivers would obtain incentives to find more efficient means to accumulate and disperse loads.

In the Florida example, exempt produce haulers were found backhauling empty even though Florida is a greater receiver of truck freight from all points in the United States than it is a source of truck freight. Thus, it appears that empty backhauling by Florida produce haulers is largely due to regulatory constraints. But in the Florida sample, empty backhauling accounted for 5.3 percent of the average costs of truck service. In contrast, on the average the revenue truck-service suppliers receive from agricultural loads is approximately twice what they receive for backhaul service. The allocation of empty travel costs that distorts the burden more greatly toward the agricultural buyer (through higher prices) is probably due to the fact that (a) freight transportation demand is generally inelastic (12) and hence transportation buyers are generally insensitive to prices and (b) a backhaul is a joint output of a fronthaul and any revenue received, no matter how meager, will help to cover costs or increase profit margins. In the case of Florida, however, because there is more truck freight flowing into than out of the state, the distortion in the share of empty travel costs is probably caused by regulatory constraints that preclude produce haulers from participating in regulated return truck-service markets. Thus, at least in the Florida case, the cost accrued by agricultural truck-service buyers through regulatory constraints is far greater than simply the average cost of empty backhauling.

REFERENCES

1. J.H. Lauth, J.O. Gerald, P.L. Mills, and L.H. Keely. Background Paper on the Agricultural Exemption and Other Agricultural Problems. U.S. Department of Agriculture, 1977.
2. E. Miller. Effects of Regulation on Truck Utilization. Transportation Journal, Fall 1973, pp. 5-14.
3. T.H. Maze. An Empirical Study of the Economics of Supply of Truck Service Available to Haul Florida Produce. Univ. of Florida, Gainesville, draft dissertation, n.d.
4. W. Miklius and K.L. Casavant. Stability of Motor Carriers Operating Under Agricultural Exemption. U.S. Department of Agriculture, 1975.
5. F.S. Gaibler. Truck Brokers: An Integral Part of Exempt Agricultural Movements. Economic Research Service, U.S. Department of Agriculture, 1977.
6. C.A. Taff. A Study of Truck Brokers of Agricultural Commodities Exempt from Economic Regulation. Transportation Journal, Spring 1979, pp. 5-15.
7. Manalytics, Inc. A Long-Term Study of Produce Transportation. Federal Railroad Administration, U.S. Department of Transportation, Vol. 5, 1977.
8. The Independent Trucker. Bureau of Economics, Interstate Commerce Commission, 1978.
9. H.E. Ramirez. The Impacts of Empty Backhauls on the Fuel Consumed in Truck Transportation of Florida Fresh Fruits and Vegetables. Univ. of Florida, Gainesville, Master's thesis, 1980.

10. C.H. Taff. Commercial Motor Transportation. Cornell Maritime Press, Inc., Cambridge, MA, 1975.
11. T.H. Maze. The Value of Information of Unregulated Truck Service Markets. Transportation Journal, Winter 1980, pp. 57-62.
12. A.E. Friedlander. The Dilemma of Freight Transport Regulation. Brookings Institution, Washington, DC, 1969.

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

Price Response of Truck-Service Suppliers in an Unregulated Market

T.H. MAZE

The unregulated Florida produce truck-service market is studied to determine whether truck-service suppliers respond to competitive signals. Each year, Florida has two produce shipping peaks—one in winter and one in spring. Although weekly shipping volumes for the two peaks are approximately the same, the predominant truck-service buyers in the two peaks have very different price bidding behavior. The prices bid in the winter fluctuate with the quantity of truck service supplied, and there is a strong statistical relation between the two. The prices bid during the spring remain rigid, and spot shortages in truck service are generally observed in the spring. By using the winter shipping season as an example, truck-service supply is found to respond efficiently to competitive price signals. This implies that, if spring prices were bid with respect to market conditions instead of at rigid levels, shortages could be alleviated. This finding also provides an example of the efficient response of unregulated truck service to price signals.

Studies in favor of trucking-industry deregulation have generally found that on the average prices will fall and truck services will improve through deregulation. In a previous paper, I postulated that there were two trucking-industry regulation-deregulation issues that have not been investigated (1). Because these areas have been overlooked, arguments for less regulation of the trucking industry are based on a simplified view of average traits of unregulated service. Furthermore, the fact that traits are based on averages could lead to the misconception that generally prices will fall and service will improve through deregulation.

The purpose of this paper is to determine whether truck-service buyers will be able to barter for truck-service quantity and quality through an unregulated market. Pricing determined through an open market is generally ignored in the existing literature. This can best be seen in studies of prices of exempt agricultural truck service (2) and prices of localized, unregulated truck service (3) that are modeled with a nonmarket variable (distance). The use of distance rather than relative scarcity of truck service assumes that prices in unregulated sectors are a function of average costs, much the same as truck-service prices in the regulated sector. Of course, this is not true.

It is important to know whether truck-service suppliers react to price fluctuations (a) for the purpose of making estimates of the benefits (cost savings) of not regulating currently exempted markets and (b) for making forecasts of the benefits of deregulating currently regulated markets. Clearly, if unregulated truck-service supply does not respond to price fluctuations, this must be accounted for in benefit estimates and forecasts. However, because studies of unregulated markets view prices as being a function of average costs, the performance of supply, in an unregulated context, has not been examined. Therefore, benefit studies implicitly assume that, once markets are deregulated, suppliers will efficiently adjust equipment allocations with respect to price fluctuations. Yet this has not been shown to be true. Thus, this paper investigates the truck-service supply response to prices in an unregulated market and specifically models the unregulated Florida produce truck-service response to fluctuations in competitive prices.

FLORIDA MARKET

The volumes of Florida produce truck shipments change dramatically throughout the year. As can be seen in Figure 1, Florida has a large and lengthy peak in the late spring. In 1978, the spring shipments peaked during the first week of June with a weekly volume of 7157 truckloads. The spring peak is largely caused by a peak in vegetable and melon harvesting. For instance, in 1978, Florida shipments of sweet corn, cucumbers, potatoes, and tomatoes peaked in May and watermelon shipments peaked in June (4). Shipping volumes fall off sharply in late June as the harvesting season moves northward.

Florida also has a winter shipping-volume peak in December. Although the winter peak is more short-lived than the spring peak, shipment volumes during the respective peak weeks are almost the same. The winter peak is largely due to increases in the shipments of fresh citrus. For instance, 1978 shipments of oranges, tangerines, and tangelos all peaked in December (4).

Although both peaks have approximately the same intensity and shippers during both peaks use the same pool of trucking firms, the predominant truck-service buyers in the market behave quite differently during the two seasons. The winter season normally passes smoothly, and all shipments are generally hauled without major commodity losses. This is not the case in the spring. The spring shipping peak generally passes with a number of spot shortages of truck service. In expectation of the spring peak, the state government usually puts on an advertising campaign to make trucking firms aware that the Florida peak is coming. In the spring of 1979, the governor even declared a state of emergency and rolled back the state weight laws. In addition, the Florida Farm Bureau generally sets up a station at a freeway rest stop to direct trucks to areas in need of truck service. In spite of such efforts, there generally are at least spot shortages in truck service.

Figure 1. Florida weekly shipments by truck: 1978-1979.

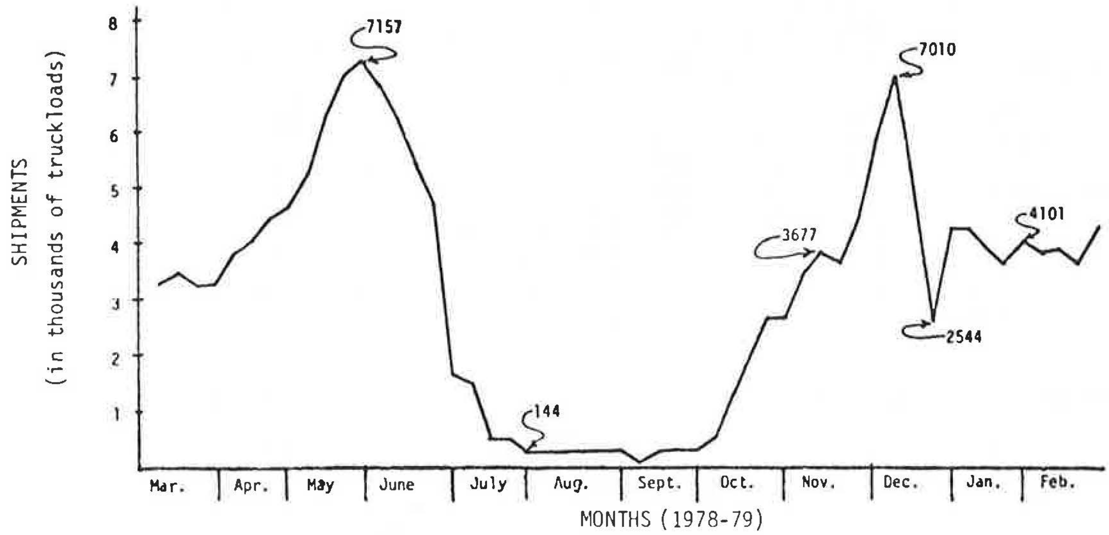
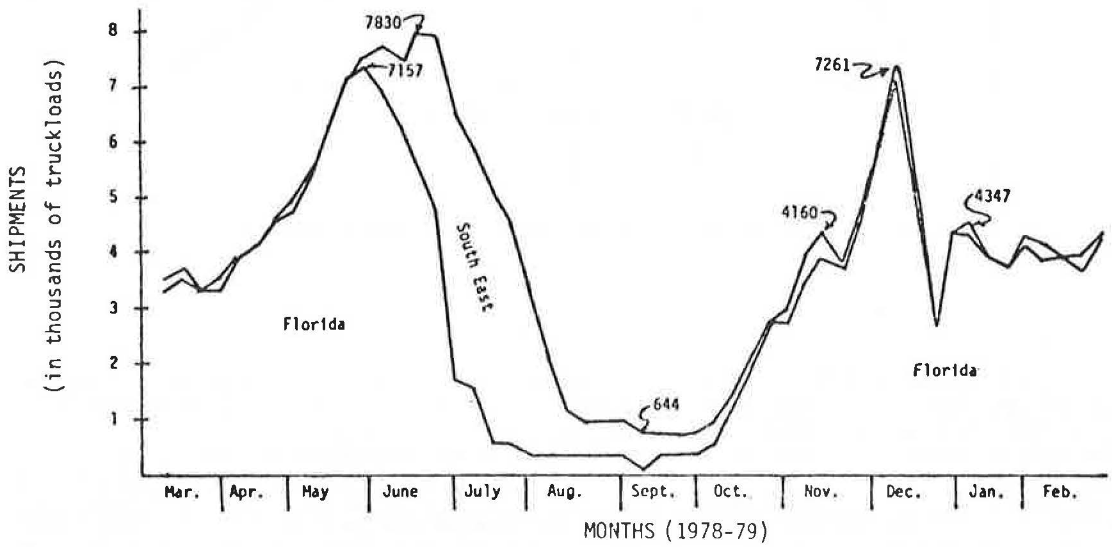


Figure 2. Weekly produce shipments by truck: 1978-1979.



On the surface, there seems to be a very simple reason for the cause of Florida's spring dilemma. The end of Florida's spring peak overlaps shipping peaks in southeastern states to the north. Truck shipments for Florida and those for Florida plus the southeast region are plotted in Figure 2. Note that just after Florida's peak the entire southeastern area peaks, and, because Florida is farthest south, it is believed that trucks that would have returned to Florida stop at states farther north and thus a shortage results in Florida.

This explanation would seem logical and straightforward, but in fact the situation is more complex. The buyers of truck service for commodities whose shipments peak in the winter and commodities whose shipments peak in the spring exhibit completely different buying behavior, and it is believed that this difference is the cause of the problems in the spring.

BUYING BEHAVIOR

In investigations of Florida produce truck-service buyers, it became apparent that not all buyers showed the same price bidding behavior. Buyers of truck service for commodities whose shipments peak during the spring appeared to be bidding a rigid price throughout the year. In contrast, buyers of truck service for commodities whose shipments peak during the winter appeared to be bidding nonrigid, competitive prices.

To illustrate the difference, monthly Florida freight rates taken from U.S. Department of Agriculture (USDA) reports and converted to an approximate price per mile are given in Table 1. The table gives monthly freight rates for a commodity that peaks in winter--oranges from the Lakeland area--and a commodity that peaks in spring--celery from southern Florida. Shipments of Florida oranges typically increase during November, peak in December, and decrease from January into the spring months (4). Shipments of Florida celery typically increase during the late winter months, peak during April or May, and fall off sharply in June.

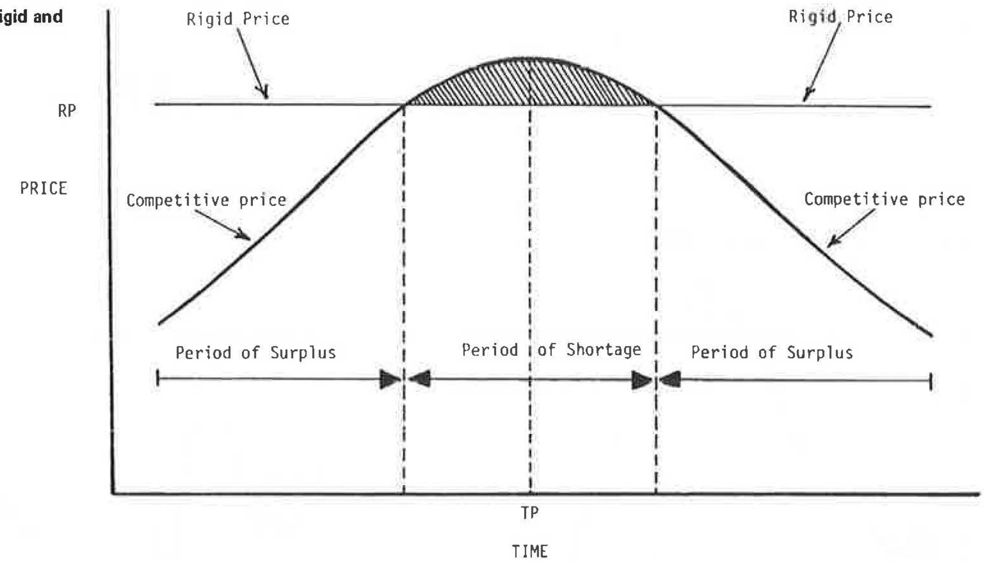
Uniform freight rates were reported for celery in

Table 1. Monthly truck service rates: 1976.

Commodity	Origin	Destination	Rate ($/mile) January	February	March	April	May	June	November	December
Oranges	Lakeland, Florida	Atlanta	0.66	0.66	0.66	0.70	0.91	-	0.83	0.83
		Chicago	0.75	0.75	0.75	0.77	0.90	-	0.75	0.79
		New York City	0.79	0.80	0.80	0.83	0.98	-	0.77	0.80
		Pittsburgh	0.86	0.86	0.88	0.88	1.05	-	0.84	0.88
Celery	Southern Florida	Atlanta	1.51	1.51	1.51	1.51	1.51	1.51	-	1.51
		Chicago	1.00	1.00	1.00	1.00	1.00	1.00	-	1.00
		Dallas	0.96	0.96	0.96	0.96	0.96	0.96	-	0.96
		New York City	0.96	0.96	0.96	0.96	0.96	0.96	-	0.96
		Washington, D.C.	1.11	1.11	1.11	1.11	1.11	1.11	-	1.11

Note: No prices were listed for July through October.

Figure 3. Relation between rigid and competitive prices.



every month of 1976 and are given in Table 1 (5). However, the monthly freight rates for citrus were not uniform. It is evident that freight rates for celery were rigid but freight rates for oranges were not. This contrasting behavior in freight rates between commodities that peak in spring and those that peak in winter was also observed in all years examined. In addition, in all months except May 1976, truck-service prices for oranges to New York City, Chicago, and Atlanta are greater than truck-service prices for celery to the same cities. The only time they come close to the same level is during the late spring months, which is the period when the spring peak usually falls (4).

Two important characteristics of the buying behavior of buyers of truck service for spring-peaking commodities and winter-peaking commodities are illustrated through the USDA truck rate reports:

1. Buyers of truck service for spring-peaking commodities are bidding a rigid price, whereas the buyers of truck service for winter-peaking commodities are not.
2. The prices of truck service for spring-peaking commodities were always higher than those for winter-peaking commodities except when they rose to nearly the same level around the late spring months.

Because of these characteristics, the prices bid for truck service for winter-peaking commodities are believed to be competitive (the lowest value the market could bear and still clear) whereas prices bid for truck service for spring-peaking commodities appear to be set with respect to something other than competitive considerations.

Figure 3 shows the differences in buying behavior and what these differences mean with respect to the Florida truck-service market. The horizontal axis shows the time of the peak in shipment volume (TP), and the vertical axis shows the rigid price (RP). As time approaches the peak, more and more truck service is needed. To attract more truck service, the competitive price increases. The competitive price reaches a peak at TP, when the largest quantity of truck service is needed. If the rigid price is above the competitive price throughout the peak, then enough trucks are attracted to carry all Florida produce shipments even during the peak. If the rigid price were to fall below the competitive price, as shown in Figure 3, a shortage would result around the time of the shipping peak.

The differences in buying behavior are largely caused by the widespread use of rate sheets by truck brokers who work as middlemen for vegetable and melon truck-service buyers. Rate sheets list the prices of truck services that can be obtained through the truck broker and are given to customers. Once these sheets are published, the prices of truck services are fixed until another superseding sheet is published. The practice of rate-sheet pricing has quite questionable antitrust implications and, although the U.S. Department of Justice investigated truck brokers and indicted a few, rate sheets in the industry still persist. However, the subject of this paper is to investigate the supply response to price changes and not the reasons for price rigidity in the spring-peaking truck-service market.

Regardless of the cause of price rigidity, it is fairly safe to conclude that the spring season is not indicative of competitive conditions. Non-competitive buyer behavior (including truck brokers) precludes the truck-service market from performing with competitive efficiency even if it could. Therefore, it is impossible to ascertain whether truck-service suppliers will respond efficiently to prices by using the spring market as an example. Instead, the winter market is used to determine whether truck-service suppliers respond efficiently to competitive price signals. However, if winter truck-service suppliers are responsive to price signals, it would appear that the cause of spring truck-service shortages is the rigidity of prices for truck service for spring-peaking commodities.

AGGREGATE SUPPLY-RESPONSE RELATION

Two characteristics of truck-service supply make the decision to respond to prices with equipment allocations different from the typical decision to supply a good or service. First, the trucking-firm decisionmaker must judge the desirability of accepting a price bid in one direction with respect to the desirability of the origin of the reverse trip. For instance, a firm might accept an offer to haul a load from a northern city to Florida (a produce hauler's backhaul); the acceptance of this load also implies an allocation of equipment to the destination region (Florida) for a fronthaul load. The decision to haul in one direction must be made not only in light of the desirability of the current haul but also in light of the joint output of the reverse haul. Therefore, trucking-firm decisionmakers must judge the profitability of accepting one load based on the outcome of a truck cycle tour (a fronthaul plus a backhaul). Second, Florida buyers of truck service forecast prices to a number of destinations. The response of allocating equipment to Florida may partly be a result of any one of these prices. Furthermore, the supplier may be equally willing to accept loads going to a number of destinations. These two characteristics make truck service unlike most goods or services, whose suppliers need to consider only one sale price for their output.

Because of these atypical characteristics, supply modeling structures typically used to study the supply of most goods and services are not applicable. Hence, a conceptual structure tailored to the unusual nature of trucking is constructed to give guidance to the empirical modeling of a truck-service supply response to competitive prices. In structuring the conceptual model, a theory on how the individual trucking-firm decisionmaker reacts to price stimulus in equipment allocation decisions is defined, and it is proposed that trucking-firm decisionmakers in the aggregate will react similarly to the same stimulus. The variables used in the hypothesized individual decision process are thus used in modeling the aggregate equipment allocation.

The development of the equipment allocation process is based on the neoclassical theory of the firm, which assumes that firm decisionmakers act as if they are maximizing profits. Decisionmakers are assumed to judge the profitability of accepting a load in the light of the revenue and costs expected in both directions. In other words, a load is accepted based on the expected outcome of a complete truck cycle tour. Since the object of the model is to investigate the truck service supplied to Florida, the conceptualization of the process must start at the point in a truck cycle tour where the decisionmaker decides to allocate his or her equipment to Florida. The decision to enter Florida must be made at the beginning of the trip immediately preceding the acceptance of a Florida load (the backhaul trip).

Not all truck cycle tours take the same length of time, and the total expected profit for a short tour may not be as great as that for a longer tour. To find a common measure for tours of different lengths, the decisionmaker is assumed to judge backhauling options on the expected profit per time period. Thus, decisionmakers will allocate equipment to Florida based on the expected profitability per time period of a truck cycle tour that starts with a Florida-bound backhaul.

Once attracted to Florida, the decisionmaker faces the problem of deciding exactly which price bid to accept. A trucking-firm decisionmaker will accept a Florida bid price to one destination instead of another only because one destination's expected profit per time period is greater. If Florida buyers need more service to one destination, they will bid up prices to that destination to attract more service and thus increase the expected profits per time period. Higher expected profits will attract trucks to serve that destination until the expected profits per time period of the last firm to enter are only a small increment greater than its anticipated profits from serving another destination.

In aggregate, the expected profits per time period of serving a destination may be considered to form a distribution. If buyers bid up the price of servicing one destination, then the mean expected profits per time period (expected value) of firms already servicing that destination will be temporarily adjusted upward. New firms that found the new expected profits per time period greater than those for other destinations would enter. New firms would continue to enter until expected profits per time period, on the average, were no greater than those of other destinations. In terms of the distribution of expected profits per time period, after all new firms have entered, the mean of expected profits per time period will be no greater at the destination with an increased bid price than that of other destinations.

If it is assumed that bid price changes take place in small increments and that firm decisionmakers respond instantly, the quantity of service to each destination would change in relation to the quantity of service to other destinations. However, the expected values of the anticipated profits of serving all destinations adjust together. This property is called "intramarket equilibrium".

This relation should be quite sensitive to relative price changes for two reasons:

1. In view of the fact that the services offered by and the operating characteristics of these trucks are quite standard, the differences in the decisionmakers' expected truck-cycle-tour profit per time period to be earned by starting the next truck cycle tour with carrying a truckload to any one destination should be quite similar among decisonmakers. In other words, the distribution of decisionmakers' expected profits per time period should be narrow. Thus, it should take only small increases in expected profit per time period to make that destination more attractive compared with other destinations for a great many trucking firms that serve Florida.

2. Intuitively, it can be seen that because of the tremendous flexibility of truck service it should require little incentive (increased price) to

cause decisionmakers to choose to serve one destination over another, especially those destinations that are quite similar in terms of service characteristics (i.e., location and length of haul). Therefore, the linkage between the number of trucking firms serving Florida to one destination and the number of firms serving all other destinations should be quite sensitive (elastic) to changes in their relative profitability.

ABSTRACT CONCEPTUAL MODEL SPECIFICATION

It is hypothesized that decisionmakers respond to the expected profit per unit of time when allocating equipment. The individual decisionmaker is assumed to calculate the difference between expected truck-cycle-tour revenue and costs to arrive at an expected profit per truck cycle tour for all available backhaul alternatives. The expected profit per truck cycle tour is divided by an anticipated duration for each alternative, and the decisionmaker selects the alternative that offers the greatest expected profit per time period. In the aggregate, these expected profits can be described by the mean expected profits per time period. Thus, the quantity of truck service supplied (equipment allocated) to Florida depends on the mean expected profit per time period of allocating equipment to a Florida-bound backhaul versus the mean expected profit per time period of allocating equipment to other areas. The dependence on these variables of truck service supplied to Florida is expressed by the following equation:

$$Q_i = F(PB_i, PA_{1i}, PA_{2i} \ldots PA_{ni}) \quad (1)$$

where

- Q = quantity of truck service supplied (equipment allocated) to Florida,
- F = abstract aggregate supply function,
- PB = mean profit per unit of time expected from allocating equipment to a truck cycle tour starting with a Florida-bound backhaul,
- PA = mean profit per unit of time expected from allocating equipment to a truck cycle tour starting with a backhaul bound for an area competing for truck service with Florida,
- i = time period over which all variables are measured, and
- n = number of areas competing with Florida for truck service.

EMPIRICAL ESTIMATION OF SUPPLY-RESPONSE RELATION

By using the abstract model for guidance, an empirical econometric model can be derived that is suited to satisfying the original objective in studying the supply-response relation. Specifically, do truck-service suppliers adjust equipment allocations with respect to changes in competitive prices? Because there were few available data, the development of the empirical model is also partly constrained by the data sets that could be collected during the research effort.

Some of the variables specified in the abstract conceptual model are not measurable (expected profits), and data are unavailable for others (backhaul price and prices in agricultural transportation markets outside of Florida). Furthermore, because an econometric model relates changes in the dependent variable (in this case, the quantity of truck service supplied to Florida) that result from changes in the value of the independent variable or variables, only those variables of the conceptual model or inputs to the conceptual variables that do not remain unchanged over the data collection period are useful in describing changes in the dependent variable during the same period (6, p. 200). This does not mean that variables that remain unchanged are unimportant in modeling the quantity supplied; rather, it means that, within the context of econometric modeling and during that particular data collection time period, unchanged variables are not useful in describing changes in the dependent variable. In light of these data considerations, a model structure has to be defined that satisfies the original modeling objective. But first, the time period over which the quantity of truck service supplied is to be modeled has to be specified.

Price bids of buyers of truck service for spring-peaking commodities are generally above competitive levels and rigid. Because the response to competitive prices is of interest here, noncompetitive prices bid by buyers of truck service for spring-peaking commodities would not be useful in describing changes in the dependent variable. Therefore, the competitive prices of buyers of truck service for winter-peaking commodities are targeted for analysis. Prices were collected from buyers beginning at the start of the seasonal increase in shipments in the fall and ending weeks after the typical winter peak (7). The resulting data collection period covered 21 weeks of the 1978-1979 winter Florida shipping season (October 1978 through February 1979).

To determine the impact, if any, of dropping some of the abstract variables or inputs to the abstract variables from the empirical model, assumptions were made regarding economic conditions at the time:

1. Inflation was less than 1 percent/month (8). Because the data collection period preceded the Carter Administration's deregulation of petroleum fuel prices and because inflation was insignificant compared with other model inputs (e.g., Florida shipments varied from 460 to 7010 truckloads/week), costs are assumed to have remained nearly constant.
2. Most of the firms that carry Florida produce were found to be small owner-operator firms (7). The predominant business option for these firms, other than hauling produce, is to lease themselves to regulated carriers. Although the prices under which leases are arranged are unregulated, the prices paid to lessors are generally set by the lessee at a fraction of the regulated price or with respect to the length of haul (9). Thus, prices paid to lessors are set with respect to the regulated revenue the lessee receives or with respect to nonmarket considerations (distance). Because aggregate regulated commodity flows are fairly uniform throughout the year, it is reasonable to assume that lease prices are uniform throughout the data collection period (10).
3. Exempt produce truckers have two options when they obtain a return load (backhaul): (a) lease to a regulated carrier or (b) carry an exempt commodity. Although lease prices should be uniform throughout the data collection period, prices for truck service for exempt loads into or toward Florida may change over time. This change in prices is due to the dramatic changes in the volume of shipment of agricultural freight flowing toward Florida. Examples of commodity flows toward Florida that fluctuate would be iceberg lettuce from California or apples from Washington. During the winter data collection period, only minor quantities of agricultural commodities were shipped from areas near those midwestern and northeastern cities that consume the majority of Florida produce. Thus, trucks returning to Florida from these destinations should be unaffected by price fluctuations of agricultural return-trip freight markets.

Based on these assumptions, minimum data requirements necessary to model the supply response can be defined. First, because expected values are not measurable, actual changes in independent variables must be used. The changes in actual profits are the changes in the relative values of expected revenues (price bids) and costs. Costs are assumed to remain constant throughout the time of data collection; thus, changes in price bids should define changes in profit per time period, and costs can be dropped with little impact on the results. Second, price time-series data from backhaul and regulated markets are unavailable. However, prices in these markets are assumed to remain uniform throughout the period of data collection, and not having these data available for modeling should have little impact on the results.

By using these minimum data requirements, the information necessary to investigate the supply response to prices can be summarized. The changes in each area's agricultural bid prices are used in lieu of mean anticipated profits per time period. Dropping variables from the empirical specification will affect how much of the variance of the dependent variable is accounted for in the resulting model and the bias created in its estimates of parameter variance (11). If some of the variance in the dependent variable is explained by a variable that is dropped from the model, then that variance is not accounted for. The lost explained variance will affect the magnitude of the percentage of account for variance (the coefficient of determination). Bias is the difference between the mean of a given parameter estimate and the true value of the parameter. When a variable that should be included is dropped from a model, the variance of the dropped variable becomes part of the residuals (error). Greater model error will put a greater load on the variance of the parameter estimates for the remaining variables. Thus, the estimates of the variance of model parameters will be biased upward, and the result will be conservative tests of the significance of parameter estimates. Once the empirical model is estimated, the impact of dropping variables can be determined by investigating the model statistics.

Weekly price information for Florida produce truck service was derived by asking Florida businesses what they paid to have produce shipped by truck. However, information on the amount paid per week to ship agricultural commodities by truck from origins outside Florida was unavailable at the time of the study, and there were no resources to permit the collection of data outside Florida. A number of proxy variables were used in lieu of unobtainable bid prices from sources outside the state. However, all attempts to account for the variability of prices outside Florida failed, and thus prices bid from other sources had to be omitted from the model. Again, the effect of the omission will be reflected in estimate bias and a loss in accounted-for variance.

DATA

Interstate shipments of fresh fruit and vegetables from all states and shipments entering the United States from Canada and Mexico are monitored by the Market News Branch, Fruit and Vegetable Division, USDA. The shipment data supplied by this organization are in the form of a preliminary compilation of shipments of produce from all shipping origins by all modes (truck, rail, air, and boat). The availability, service quality, and price of service of modes other than trucking would affect the demand for truck service. However, because the focus of this study is on the supply of truck service and not the demand for truck service, the other modes are ignored.

Prices actually paid for truck service during the 1978-1979 winter peak shipping period were solicited from truck brokers, receivers, and shippers. The sources of prices used in this study indicated during the introductory contact or in follow-up contacts that they priced with respect to "what the market would bear". Because the prices of these sources fluctuated with respect to the buyers' perception of market conditions, they were assumed to be indicative of competitive, market-clearing prices. However, a problem arose regarding how to treat the slight variations in freight rates. This is dealt with by weighting sources with respect to the share of shipments estimated by produce industry observers from the Florida Department of Agriculture and Consumer Services. The freight rates are estimated to be the truck-service prices for at least 50 percent of Florida fresh citrus shipments.

EMPIRICAL MODEL ESTIMATES

The objective of the empirical model is to determine whether there is a relation between competitive prices and the quantity of truck service supplied and, if such a relation exists, to determine its sensitivity. A relation of this nature is known as a supply-response relation (13). This is the quantification of supply's response to price change when other things are not held constant. However, the problem remains of determining which prices to which destinations or combination of destinations are most indicative of the price changes in the Florida market.

The prices thought to be bid at competitive levels were for truck service to six eastern and midwestern cities and one southeastern city: Atlanta, Boston, Chicago, Cleveland, Montreal, New York, and Washington, D.C. Earlier in the discussion, intramarket equilibrium defined the linkage between prices to all destinations. It was hypothesized that prices to various destinations should be closely linked and that, if in fact there is a strong relation between price changes, then the change in all prices should equally describe the change in quantity supplied. Thus, one model was specified by using the price to each city as the independent variable in a linear regression with the aggregate quantity of truck service supplied to Florida as the dependent variable. The results of the regressions, in which a Cochrane-Orcutt iterative technique was used to correct for autocorrelation, are shown in Equations 2-8. Another similar model is estimated with prices weighted by the proportion of the total produce loads delivered to all seven destinations that were delivered to those particular destinations during the 21 weeks. This model is shown in Equation 9, where the weekly prices for truck service to the seven cities are multiplied by their fraction of deliveries to all seven cities from Florida--10, 17, 11, 6, 9, 33, and 14 percent, respectively--and are totaled for each week (14). The result is used as the independent variable of the regression, and the aggregate quantity of truck service supplied to Florida is used as the dependent variable (t-statistics are shown in parentheses below the parameter estimates):

$$Q_t = -2331.1 + 6161.5\,X_{t,1} \qquad R^2 = 0.68 \qquad (2)$$
$$(1.01) \qquad (2.74) \qquad DW = 1.66$$

$$Q_t = -22\,954.5 + 25\,711.0\,X_{t,2} \qquad R^2 = 0.69 \qquad (3)$$
$$(2.33) \qquad (2.73) \qquad DW = 1.60$$

$$Q_t = -22\,632.1 + 24\,226.1\,X_{t,3} \quad R^2 = 0.77 \tag{4}$$
$$(3.70) \quad (4.43) \quad DW = 2.62$$

$$Q_t = -13\,105.6 + 14\,954.0\,X_{t,4} \quad R^2 = 0.69 \tag{5}$$
$$(2.17) \quad (2.83) \quad DW = 1.62$$

$$Q_t = -16\,125.3 + 16\,750.5\,X_{t,5} \quad R^2 = 0.69 \tag{6}$$
$$(2.32) \quad (2.89) \quad DW = 1.66$$

$$Q_t = -12\,679.2 + 15\,109.9\,X_{t,6} \quad R^2 = 0.70 \tag{7}$$
$$(2.25) \quad (2.95) \quad DW = 1.61$$

$$Q_t = -22\,728.4 + 21\,773.3\,X_{t,7} \quad R^2 = 0.75 \tag{8}$$
$$(3.38) \quad (3.96) \quad DW = 2.25$$

$$Q_t = -18\,965.5 + 20\,632.6\,AX_t \quad R^2 = 0.77 \tag{9}$$
$$(3.17) \quad (3.83) \quad DW = 1.54$$

where

Q = equilibrium quantity of truck service supplied,
t = time period (week),
X = competitive price from Florida to each city ($/mile),
1 = Atlanta,
2 = Boston,
3 = Chicago,
4 = Cleveland,
5 = Montreal,
6 = New York,
7 = Washington, D.C., and

$AX_t = 0.10X_{t,1} + 0.17X_{t,2} + 0.11X_{t,3} + 0.06X_{t,4} + 0.09X_{t,5} + 0.33X_{t,6} + 0.14X_{t,7}$.

INTERPRETATION OF FINDINGS

All regressions account for 68-77 percent of the variance in the independent variable, which indicates that competitive prices account for most of the change in the quantity of truck service supplied. The omitted variables and error account for the remaining variance in the dependent variable. Therefore, competitive Florida price changes are by far the most important determinant of the quantity of truck service supplied. Furthermore, because in all eight regressions the independent variable parameter estimate is significant at the 98 percent confidence interval or greater, the bias of omitting other variables does not appear to have affected the estimates of the relation. The relatively good statistical properties of the estimates are interpreted to mean that supply does respond to competitive price signals and that truck-service buyers can express their desires for truck service through an unregulated market.

The price elasticities of each supply-response function are elastic and vary at the midpoint (3701 truckloads/week) from a low of 1.6 when Atlanta prices are used to a high of 7.2 when Boston prices are used. The supply-response function with weighted prices has a price elasticity of 6.1. An elastic supply would tend to agree with the results of trucking-industry cost studies; that is, in a competitive industry the supply curve of one firm will be that firm's marginal cost curve (13). An aggregate supply curve (all firms) is the summing, with respect to quantity, of the marginal cost curves of all firms (15, p. 251). Although some studies have found no economies of scale in the trucking industry (constant average costs) (16-18) and some have found slight economies of scale (19-21), there do not appear to be diseconomies of scale. Therefore, at a minimum, marginal cost curves should be constant (flat) and certainly not increasing. The summing of flat marginal cost curves should result in a relatively elastic supply curve.

In summary, the empirical findings show that, on a limited basis, truck-service suppliers do respond to competitive price signals and supply response is relatively elastic. In terms of Florida produce industry policy, these findings indicate that, if truck-service prices for commodities that peak in the spring fluctuated with respect to current market conditions instead of remaining at their rigid level, truck-service suppliers would respond. In other words, common spring shipment peak-period shortages could be avoided by not pricing at rigid levels and instead increasing prices to attract additional truck service. In terms of trucking industry regulatory policy, the findings indicate that, if suppliers and buyers are left to barter for services, truck-service markets should allocate resources efficiently in response to competitive price signals. However, these findings are derived from a limited study of aggregate prices and aggregate quantity supplied in a market that deals with one commodity (produce), where buyers and sellers have historically had fair to good market information. More study should be done in more diversified markets where market information is not so readily available and with greater and more comprehensive price, cost, and quantity data.

REFERENCES

1. T.H. Maze. The Value of Information in Unregulated Truck Service Markets. Transportation Journal, Vol. 20, No. 2, Winter 1980, pp. 57-62.
2. J. Lampkin and H. Richards. Collection of Truck Freight Charges for Selected Exempt Commodities. Economic Research Service, U.S. Department of Agriculture, 1969.
3. W.B. Allen, S. Lonergan, and D. Plane. Examination of the Unregulated Trucking Experience in New Jersey. U.S. Department of Transportation, 1978.
4. Florida Department of Agriculture and Consumer Service. Florida Shipment; Fresh Fruits and Vegetables: Summary 1977-1978 Season. Federal-State Market News Service, Winter Park, FL, 1978.
5. A.J. Burns. Fruits and Vegetables: Monthly Truck Rates for Selected Fresh Fruits and Vegetables, 1976. Economic Research Service, U.S. Department of Agriculture, 1977.
6. J. Kmenta. Elements of Econometrics. Macmillan, New York, 1971.
7. T.H. Maze. An Empirical Study of the Economics of Supply of Truck Service Available to Haul Florida Produce. Univ. of Florida, Gainesville, draft dissertation, n.d.
8. CPI, Detailed Report, February 1979. Bureau of Labor Statistics, U.S. Department of Labor, 1979.
9. Truck Leasing: Staff Report on Motor Common Carrier Leasing Practices and the Owner-Operation. Bureau of Operations, Interstate Commerce Commission, 1977.
10. H.E. Ramirez. The Impact of Empty Backhauls on the Fuel Consumed in Truck Transportation of Florida Fresh Fruit and Vegetables. Univ. of Florida, Gainesville, Master's thesis, 1980.
11. G.S. Maddla. Econometrics. McGraw-Hill, New York, 1977.
12. W.G. Tomek and K.L. Robinson. Agricultural Product Prices. Cornell Univ. Press, Ithaca, NY, 1972, pp. 71-73.
13. Fresh Fruit and Vegetable Unloads. Fruit and Vegetable Division, U.S. Department of Agriculture, 1978-1979.

14. J. Hirshleifer. Price Theory and Applications. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1976.
15. M.J. Roberts. Some Aspects of Motor Carrier Costs: Firm Size, Efficiency and Financial Health. Land Economics, Aug. 1956, pp. 228-238.
16. R.A. Nelson. Motor Carrier Regulation and the Financing of the Industry. ICC Practitioners Journal, May-June 1974, pp. 436-440.
17. P.W. Emery. An Empirical Approach to the Motor Carrier Scale Economics Controversy. Land Economics, Aug. 1965, pp. 258-289.
18. S.L. Warner. Cost Model Measurement Errors, and Economics of Scale in Trucking. In The Cost of Trucking: Econometrics Analysis, William C. Brown Publishing, Dubuque, IA, 1965, pp. 1-46.
19. M.L. Ladenson and A.J. Sloga. Returns to Scale in the U.S. Trucking Industry. Southern Economics Journal, Jan. 1974, pp. 390-396.
20. M.L. Lawrence. Economics of Scale in the General Freight Motor Common Carrier Industry: Additional Evidence. Proc., 17th Annual Meeting of the Transportation Research Forum, 1976, pp. 169-176.

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

Value of Overweighting to Intercity Truckers

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An analysis of the problem of truck overweighting is presented. Legal and illegal overweighting and current enforcement procedures are discussed. The benefits to truckers of overweighting are shown by means of an incremental approach (decrease in transport cost per unit with increase in cargo weight) and by using specific cargo movements to calculate the incentives to overweight. The fine and penalty structures of various states are examined and are combined with the probability of being weighed to calculate the expected value of being weighed to the trucker. The net benefit of overweighting to the trucker is then shown by comparing the costs with the incentives. Finally, actual permit costs are examined in relation to the cost of additional pavement damage caused by overweight trucks. It is concluded that (a) economic incentives often exceed the expected costs of overweighting to the trucker, (b) current enforcement programs in some states are not effective, (c) fine structures should take account of both the amount of truck overweight and the number of miles traveled, and (d) the cost of overweight permits does not reflect the additional pavement damage caused by overweighting.

There is an ongoing controversy regarding the legal weight limits for trucks. An important part of this issue that is often overlooked is the problem of enforcement of weight limit laws. Enforcement programs are a critical part of efforts to control overweight trucks. Unless these programs are effective, truck weight limits are meaningless.

For any enforcement program to be effective, truckers must perceive the penalties for exceeding the weight limits as being greater than the economic benefits of overweighting. If truckers believe that the probability of being weighed is low and that the penalties for overweighting are low, they are more likely to run overweight. This situation will continue until effective disincentives are recognized by the trucker.

This paper demonstrates that in many cases there are economic incentives that far exceed the expected costs of overweighting. The analysis is performed by using a cost-benefit approach and specific examples.

The paper first discusses two types of overweighting: illegal and legal. Illegal overweighting subjects the driver to the possibility of fines and other penalties. Legal overweighting requires permits obtained from the individual states. The first section also deals with the enforcement process and the criteria required in order to assess the effectiveness of existing enforcement programs.

The second section presents an analysis of the benefits of overweighting. A general description of these benefits shows how transport cost per unit of weight decreases as cargo weight increases. This demonstrates the incremental advantages of overweighting to truckers. A second, more in-depth approach uses specific cargo movements to calculate incentives for the trucker to overweight.

The next section deals with the cost of illegal overweighting. Fines from different states are examined and combined with the probability of being weighed to calculate the expected value of weighing to the trucker. The costs are then compared with the incentives in order to show the net benefit of overweighting to the trucker. Other penalties, such as forced unloading and suspension of driver's license, are also examined.

The last section describes legal overweighting by the use of state-issued permits. The different types of permits and their respective costs are presented for 10 states, and an effort is made to determine whether the permit costs reflect the additional pavement damage that is caused by an overweight truck. If the cost of a permit does not reflect this additional damage, then the trucker is not paying a fair share in regard to damage to highways and bridges.

ISSUE OF OVERWEIGHTING

This paper discusses two types of overweighting: legal and illegal. Truckers can load above the maximum weight limits legally by the use of specially granted permits. There are generally two types of permits--single trip and annual (multiple) trip. The prices and availability of these permits vary from state to state.

Illegal overweighting occurs when the cargo characteristics are such that the state will not issue a permit. The issuance of permits is controlled by the individual states; therefore, the availability of permits varies among the states. Illegal overweighting subjects the driver to the possibility of fines and other penalties, but the incentives for overweighting usually exceed the expected costs of the fines.

An evaluation of permits and fines is important in determining disincentives to overweight. Permits should reflect the additional pavement damage caused by an overweight truck. Fines should be high enough to act as an effective deterrent to overweighting.

Effective enforcement programs are necessary to control the level of illegal overweighting. There are two basic components to the enforcement process: probability of detection and penalties for violation. Combined, these two make up the expected cost of overweighting to the trucker. The probability of detection is important as a deterrent. Truckers often have substantial experience to aid them in calculating the probability of being apprehended. Based on this probability, they can calculate the expected cost (in fines) of overweighting.

An effective weight enforcement program should make the avoidance of weight compliance checks difficult or impossible for the trucker. Given that a trucker is traveling a route with scale checkpoints, the probability of being weighed should be high enough to act as a deterrent.

Penalties (fines) are the second component of an effective enforcement program. If fines are levied for overweights, the fines must be a level higher than the economic benefit of overweighting. If the present fines are not sufficient deterrents, the fine system should be changed. This can be accomplished by (a) increasing the fine level and (b) introducing graduated fines where they do not already exist. Graduated fines take into account the amount of the overweight, rising incrementally as the amount of the overweight increases.

BENEFITS OF OVERWEIGHTING

The benefit a trucker receives from overweighting is increased financial returns. This results from decreasing costs per ton-mile as cargo weight increases. This decrease in cost is illustrated by the table below, which shows how costs per ton-mile decrease dramatically and costs per mile increase only slightly as the weight of the load increases [based on the 1980 Association of American Railroads (AAR) model and data from the 1979-1980 National Motor Transport Data Base (NMTDB)]:

Cargo Weight (tons)	Line-Haul Cost ($) Per Mile	Line-Haul Cost ($) Per Ton-Mile
10	0.891	0.089
15	0.895	0.060
20	0.903	0.045
25	0.905	0.036

The example given is the average line-haul cost for a typical intercity trucker (an owner-operator leased to an irregular-route carrier). It should be noted that, while the cost per mile increases only 10 percent as the weight increases from 10 to 25 tons, the cost per ton-mile decreases 60 percent.

The more a truck is overweight, the greater the financial benefit that results. For example, a commodity with a rate of $0.056/lb passing through a state with a limit of 73 280 lb will have the estimated incentives given in Table 1. The cash incentive to load 80 000 lb is $390, and the incentives increase as cargo weight increases. This illustrates the incremental advantage that a trucker has as the amount of the overweight increases. This example was chosen in order to show that, once truckers choose to violate the weight limits, they have an incentive to overweight as much as the equipment will bear.

Some specific sample cases can illustrate how decreased ton-mile costs can offer the trucker real monetary benefits. Tennessee and Indiana are two examples of states where the maximum legal truck weight limit is 73 280 lb. Most of the bordering states have limits of 80 000 lb. Therefore, a trucker hauling 80 000 lb through these states is often in violation of state limits only in Tennessee and Indiana.

Sample truck rate data from a privately collected field survey (the NMTDB) were assembled to show how these weight increases would benefit the trucker. These data, given in Table 2, show that the benefit of overloading depends on (a) the rate of the commodity hauled and (b) the length of the trip. For example, the incentive to load 80 000 lb (as opposed to 73 280) through Tennessee on a machinery movement from Pennsylvania to Texas is $300. The incentive to load 80 000 lb through Indiana on a movement of plastic products from Pennsylvania to California is $360. Overweighting can offer the trucker real monetary benefits. The purpose of Table 2 is to show that there are high incentives to overload for a

Table 1. Incremental incentives to overweight.

Vehicle Weight (lb)	Cargo Weight (lb)	Rate per Pound[a] ($)	Resulting Rate ($)	Incentive ($)
73 000	45 000	0.056	2520	0
75 000	47 000	0.054	2540	20
80 000	52 000	0.052	2700	180
90 000	62 000	0.050	3100	580
100 000	72 000	0.048	3460	940

Note: Calculated from NMTDB data.
[a]A typical rate is $0.056; the decreases in rate per pound are given in an attempt to account for the rate reduction that might be offered by a trucker planning to overweight.

Table 2. Incentives to overweight through three states.

State	Gross Weight (lb)	Origin-Destination	Commodity	Rate per Pound ($)	Incentive ($)
Tennessee	80 000	Pennsylvania-Texas	Machinery	0.046	300
		Florida-Michigan	Fruit	0.041	275
		Mississippi-Illinois	Fish	0.024	160
		Louisiana-New Jersey	Paper	0.035	235
		Minnesota-New York	Meat	0.038	255
Indiana	80 000	Pennsylvania-California	Plastic products	0.054	360
		Colorado-New York	Meat	0.039	260
		New Jersey-California	Chemicals	0.058	390
		Mississippi-Michigan	Lumber	0.027	180
		Ohio-California	Glass	0.064	430
Iowa	90 000	California-Illinois	Produce	0.047	470
		Wisconsin-California	Dairy products	0.041	410
		Michigan-Idaho	Automobile parts	0.036	360
		Ohio-Washington	Steel	0.045	450
		Illinois-California	Chemicals	0.043	430

Note: Calculated from NMTDB data.

Table 3. Fine structures for overweight trucks for 10 selected states.

State	Fine	State	Fine
Tennessee	$25 min, $50 max	Colorado	$15 + $5/1000 lb OW
Indiana	2¢/lb for 1000-2000 lb OW	Connecticut	$2/100 lb for 2-5 percent OW
	4¢/lb for 2000-3000 lb OW		$3/100 lb for 5-10 percent OW
	6¢/lb for 3000-4000 lb OW		$4/1000 lb for 10-15 percent OW
	8¢/lb for 4000-5000 lb OW		$6/1000 lb for 15-20 percent OW
	10¢/lb for ≥5000 lb OW		$8/1000 lb for 20-25 percent OW
Iowa	$10 + 0.5¢/lb for ≤1000 lb OW		$10/1000 lb for >25 percent OW
	$15 + 0.5¢/lb for 1000-2000 lb OW	Maryland	$20 min
	$80 + 3¢/lb for 2000-3000 lb OW		2¢/lb for ≤5000 lb OW
	$150 + 5¢/lb for 3000-4000 lb OW		6¢/lb for >5000 lb OW
	$200 + 7¢/lb for 5000-6000 lb OW	Minnesota	$50 for 1000-2999 lb OW
	$200 + 10¢/lb for ≥6000 lb OW		$100 for 3000-3999 lb OW
Arizona	From $30 for 1000 lb OW to		$200 for 4000-4999 lb OW
	$280 for ≥6000 lb OW		$300 for 5000-5999 lb OW
	$300 max		$400 for 6000-6999 lb OW
California	From $10 for 1000 lb OW to		$500 for ≥7000 lb OW
	$1000 for >12 500 lb	Texas	$25 min, $200 max

Note: OW = overweight.

wide variety of commodities and origin-destination pairs.

The incentive to overweight increases as cargo weight increases. Iowa is used as a sample state to demonstrate the economic effects of a load greater than 80 000 lb, which is the maximum legal limit in Iowa. Table 2 gives some sample incentives to load 90 000 lb in Iowa. For example, the incentive to load 90 000 lb on a produce movement from California to Illinois is $470.

In a competitive marketplace, some of these financial benefits might have to be passed on to shippers. This would be done through rate reductions offered to shippers for heavier loads. Table 1 demonstrates how a trucker could offer reduced rates and still increase revenues.

COST OF ILLEGAL OVERWEIGHTING

There are several components that combine to make up the cost of overweighting to the trucker. The primary cost of overweighting is fines. Table 3 (1) gives the fine structures for 10 selected states and indicates the variation in fines that exists. A truck traveling 10 000 lb overweight through Tennessee is subject to a maximum fine of $50 if apprehended. A truck traveling 10 000 lb overweight through Iowa, however, is subject to a fine of $1200. This inconsistency among fine structures is typical.

An examination of the effectiveness of fines must take into account the probability of being caught. The expected cost of the fines to truckers is a function of the truckers' ability to avoid routes that have weigh stations or, if they travel such routes, the chance of the weigh stations being in operation. Portable scales are sometimes used, but their use is nominal at best and usually accounts for less than 1 percent of total truck weighings. This is illustrated by the following FY 1979/80 data for three states:

State	No. of Truck Weighings	Truck Weighings with Portable Scales No.	Percent
Iowa	67 000	3200	0.005
Virginia	7 500 000	7500	0.001
California	4 350 000	3400	0.008

A comparison of the probable costs and benefits of overweighting can be made for the Tennessee, Indiana, and Iowa cases already discussed. Enforcement officials from each of these three states were contacted and asked to give an estimate of the probability of an overweight truck being weighed in the state, assuming the trucker was using avoidance measures. These estimates were used to calculate expected costs of the fines, which are presented in Table 4.

The expected cost of the fines can be subtracted from the incentives calculated in Table 2 to indicate that the trucker has high incentives to overweight even when the expected costs of the fines are taken into account:

State	Expected Benefit ($)	Expected Cost of Fine ($)	Net Incentive to Overweight ($)
Tennessee	245	3	240
Indiana	325	134	190
Iowa	425	180	245

Although many states have provisions for increasing the severity of the fine for subsequent offenses, inadequate record systems reduce the likelihood of enforcing this statute (2, p. i).

Penalties other than fines are also an effective deterrent to overweighting. Forced unloading of the overweight freight can inflict substantial inconvenience and time cost on the driver. Some of these costs include the cost of the truck being idle, the transportation cost to pick up the shipment at the point of unloading, and also the increased potential for loss and damage.

Unloading policies vary and can be either discretionary (up to the enforcement officer) or mandatory. Analysis of state statutes reveals that 21 states have mandatory unloading policies, 26 states have discretionary unloading, and 3 states have no unloading statutes (2, p. 10). Even though 21 states have mandatory unloading laws, interviews with 41 states revealed that only 6 states actually practiced mandatory unloading and 25 states had discretionary unloading practices (2, p. 10). Like many other states, the states that were used in the examples (Tennessee, Indiana, and Iowa) all have discretionary unloading policies that result in little or no forced unloading. The laws are often not enforced due to the lack of available storage space, the nature of the freight (if perishable), a concern for other motorists' safety, and the possibility of vandalism.

In those cases where the excess weight is not unloaded, the financial impact of the fines is not high enough to deter the trucker from overweighting. The financial incentives of overweighting in these cases exceed the expected costs. Unless the current systems are revised so that the disincentives to overweight are increased, the truckers may continue to overweight when it is in their economic interest. Although the difference between incen-

Table 4. Expected costs of fines for overweighting in three states.

State	Amount of Overweight (lb)	Fine ($)	Estimated Probability of Apprehension (%)	Expected Cost of Fine ($)
Tennessee	6 720	50	5	3
Indiana	6 720	670	20	134
Iowa	10 000	1200	15	180

Table 5. Permit costs for overweighting in 15 selected states.

State	Cost	Maximum Permit Weight
Tennessee	Single trip, $5; annual, $300	Single axle, 18 000 lb Tandem axle, 36 000 lb
Indiana	$10 if <40 miles, 25¢ for each mile above 40, $50 max	NA
Iowa	Single trip, $5; annual, $10	NA
Arizona	Single trip, $10; multiple (30 days), $30	NA
California	Single trip, $3; annual, $30	No restriction
Colorado	Single and multiple, $5	No restriction
Connecticut	No fees	5-axle vehicles, 122 000 lb gross
Maryland	Single, $150 for book of 10; 30 days, $40; annual, $350	900 000 lb for single trips
Minnesota	Single, $5; seasonal, $25; annual, $50	NA
Texas	Single trip, $5; 30-day permit, $10; annual, $50 and ton-mile	Single trip, 45 000-lb axle load

tives and costs will be different for other states, the main point to be made is that the disincentives to overweight will be, to some degree, less than the incentives in nearly all states. Therefore, continued overweighting should be expected if enforcement programs are not changed.

COST OF LEGAL OVERWEIGHTING

A trucker overweights legally by the use of permits obtained from individual states. The states control the application procedure, criteria for availability, and the types and fees for overweight permits. The permit application can usually be made by mail, telegram, or telephone.

Most state statutes allow the issuance of overweight permits only for the movement of indivisible loads. These are loads that cannot be reduced to meet statutory weight limits. The issuance of permits for divisible (reduceable) loads is normally not allowed; however, in recent practice some states (e.g., Massachusetts, Montana, North Dakota, South Dakota, Utah, and Nevada) are issuing permits for divisible loads. Permits can be used as a method of circumventing maximum weight limits, particularly when annual or continuous permits are issued (2, p. ii).

The sample permit cost for overweight authority in 10 selected states is presented in Table 5. There are extreme variations in the cost of permits. Four states (North Carolina, Massachusetts, Connecticut, and Rhode Island) do not charge for single-trip permits. Tennessee charges $5 for an annual trip permit. Indiana charges $10 for movements of less than 40 miles, 25¢ for each mile above 40, and a maximum charge of $50. Iowa charges $5 for a single-trip permit and $10 for an annual permit.

The main issue concerning these permits is whether the fees collected for the permits cover the additional road damage caused by an overweight truck. Fees charged by some states barely cover the administrative cost of issuing the permits, much less the additional highway damage caused by the additional weight.

Higher weight limits translate directly into higher levels of stress on roads, which in turn require additional maintenance and rehabilitation expenditures in order to maintain road serviceability. A special study was conducted by the State of Tennessee in an attempt to quantify the road damage caused by overweight trucks in Tennessee. The study used a measure of pavement damage developed by the American Association of State Highway and Transportation Officials (AASHTO)--the equivalent 18 000-lb single-axle loading (ESAL). The study found that the additional pavement damage cost caused by overweight trucks was 3¢/ESAL mile.

This figure can be used to estimate additional pavement costs resulting from legally overweight vehicles. AASHTO equations indicate that an 80 000-lb five-axle vehicle does approximately 0.8 ESALs/mile more than a 73 280-lb vehicle with the same configuration. This translates into additional pavement costs of 2.4¢/mile. A 90 000-lb five-axle truck imposes approximately 1.6 ESALs/mile more than an 80 000-lb vehicle of the same configuration and 4.8¢/ESAL mile more in pavement costs.

These increased costs per mile can be used to determine the appropriate cost for overweight permits. By using a 90 000-lb, 250-mile haul through Iowa (80 000-lb limit) as an example, the single-trip permit cost can be calculated to be $12 instead of the actual permit cost of $5. An annual permit, however, assuming a weight of 90 000 lb and a total of 15 000 miles/year traveled in Iowa, should cost $720. The actual cost is $10. An 80 000-lb load passing 250 miles through Tennessee (73 280-lb limit) causes additional pavement damage cost of $6 compared with the $5 cost of a permit. An annual permit, assuming a 90 000-lb load and 15 000 miles traveled/year, should cost $360. The actual cost is $300. Indiana uses a fee structure for permits that takes into account miles traveled, so that the trucker is charged a more appropriate fee of 25¢/mile for all miles traveled.

It is apparent that in some cases, particularly in the case of annual or continuous permits, the fees charged for overweight permits do not reflect the additional pavement damage caused by the overweight truck. It is concluded that, in order to make the fees more appropriate, they should be changed to take into account the weight of the vehicles and the number of miles traveled.

SUMMARY AND CONCLUSIONS

In summary, the main points of this paper are the following:

1. There are economic incentives that often exceed the expected costs of overweighting to the trucker.
2. Current enforcement programs in some states are not effective as a deterrent to overweight trucks and are in need of revision.
3. Fine structures should be more realistic, taking into account the amount of the overweight in the truck and the number of miles traveled by the trucker.
4. The probability of being weighed should be increased to discourage truckers from overweighting.
5. In many cases the cost of overweight permits does not reflect the additional pavement damage caused by overweighting. This is significant because whenever permits are offered it is clearly in the economic interest of the trucker to obtain the permit.

Several major conclusions can be drawn from these points.

The first conclusion is that, in order for the amount of illegal truck overweighting to be reduced, the effectiveness of enforcement programs must be increased. The probability of being weighed and the expected cost of the fine should, when combined, be greater than the incentives to overweight. The analysis performed in this paper indicates that in most cases the present enforcement programs are inadequate and in need of revision. The fine structure should be more realistic and take into account the expected value of being caught, the value of the overweight, and the number of miles traveled. The probability of being weighed could most effectively be increased by making fixed scales difficult to avoid and by making greater use of portable scales.

The second major conclusion is that the cost of overweight permits does not reflect the additional pavement damage caused by overweighting. To provide a more appropriate permit fee, the cost of the permit should take into account the amount of the overweight and the number of miles traveled.

REFERENCES

1. Overweight Vehicle Penalties and Permits: An Inventory of State Practices. FHWA, Nov. 1979.
2. Overweight Vehicles: An Inventory of State Practices--Report to the Congress from the Secretary of Transportation. FHWA, Nov. 1979, p. i.

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

Abridgment

Impact of Increased Truck Weights on Relative Costs of Motor Carriers and Railroads and Potential Modal Diversion

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The relative costs per ton-mile for rail boxcar, trailer-on-flatcar (TOFC), irregular-route motor carriers, and exempt owner-operators for the period 1977-1985 are examined. A specific rate of inflation was applied to each category of cost in 1977 for the four types of transportation service to determine the effect of inflation to 1985. The relative average freight costs per unit of output were then compared at truck gross vehicle weight limits of 73 280 and 80 000 lb. The principal finding of the study is that any shift in the average costs per ton-mile resulting from an increase in the truck weight limit is influenced by the impact of inflation on the various cost components. A comparison of the relative costs by type of service and mode suggests that inflation may have a more adverse impact on the railroads than on motor carriers of truckload freight. The analysis also indicates that, over the long term, the position of TOFC relative to truckload motor carriage could deteriorate because TOFC costs have been increasing faster than comparable truckload costs. Based on the economic factors specified and analyzed in this study, TOFC is not the preferred transport option over the 1981-1985 period.

There is a perception held by some people that the use of the more productive truck carrying dimensions would divert traffic from rail by lowering unit costs and thus upset the competitive truck-rail balance (1). However, since 1977 rapidly escalating prices for all factors of production have affected the unit costs of the modes differently. Liberalized truck size and weight limits, which allow greater productivity to occur (2), will dampen the influence of inflation on truck costs both for the motor carrier industry and for that segment of the rail industry that depends on truck service--i.e., trailer-on-flatcar (TOFC). Thus, such limits will benefit the shipping public by way of decreased costs without harm or prejudice to any mode.

STUDY METHODOLOGY

The analysis presented in this paper is based on a cost model developed by the U.S. Department of Transportation (DOT). In a technical supplement (3), DOT estimated the values of the various functional cost inputs (such as labor and fuel) for several types of truck and rail service for the year 1977. The results of the cost model were then used by DOT to support its conclusions in its report, "An Investigation of Truck Size and Weight Limits" (4). (DOT did not account for the terminal and overhead costs of irregular-route carriers. Therefore, adjustments were made in the DOT line-haul expense and overhead and terminal expenses were created. DOT also did not analyze exempt owner-operator costs. Therefore, irregular-route truckload line-haul costs were used to approximate these costs. Although exempt owner-operators have overhead expenses, they act as if they have only line-haul expenses.)

To project the DOT 1977 costs through 1985, each functional cost is inflated at an individual economically and historically justified rate. The estimated relative average unit freight costs for 1981 and 1985 reflect the effect of inflation on truck and rail costs.

The projected unit costs reflect cost relations that exist under truck gross vehicle weight (GVW) limits of 73 280 lb. To complete the analysis, the projected DOT costs were then adjusted to an increased payload weight of 80 000 lb.

The analysis presented in this paper compares costs for the following types of service:

1. Motor carrier--Irregular-route, common carrier, full-truckload service using 45-ft tractor-semitrailers;
2. Owner-operator--Full-truckload service using 45-ft tractor-semitrailers;
3. Rail carrier--General box carload service; and

Table 1. Adjusted cost for various types of carriers.

Carrier Type	Cost ($) Payload at 20 Tons 1977	1981	1985	Payload at 22.5 Tons 1977	1981	1985
Railroad boxcar						
Line-haul ($/ton-mile)	0.015	0.025	0.039	0.015	0.025	0.039
Terminal ($/ton)	1.689	2.626	3.896	1.689	2.626	3.896
TOFC						
Line-haul ($/ton-mile)	0.027	0.046	0.071	0.025	0.041	0.064
Terminal ($/ton)	13.418	18.900	27.159	11.929	16.803	24.145
Irregular-route truckload[a]						
Line-haul ($/ton-mile)	0.041	0.064	0.097	0.037	0.058	0.088
Terminal ($/ton)	1.889	2.436	3.569	1.678	2.164	3.170
Exempt owner-operator[a]						
Line-haul ($/ton-mile)	0.041	0.064	0.097	0.037	0.058	0.088

[a]Explained in DOT technical supplement (3).

4. Rail carrier--Rail dedicated 40-ft TOFC service.

PROJECTIONS

DOT has estimated functional costs for rail boxcar, TOFC, and irregular route for 1977 (3). For rail boxcar and TOFC, costs are presented for three regions: East, South, and West. Irregular-route motor carrier costs are presented for four regions: Northeast, South, Midwest, and West. Nationwide average costs were developed by averaging the respective regions and then projecting the nationwide average cost to 1985.

Cost projections were based on historical reports plus expectations of future changes. In recent years the inflation rate has affected the costs of the major functional inputs unequally. Some costs, notably that of fuel, have increased at rates far in excess of others. As a result, the cost projections used in this analysis were based on differential inflation rates for each functional input. For purposes of consistency, all rates of change in costs were expressed as indices with 1977 as the base year.

Railroad costs were based on historical records published by the Association of American Railroads (5). The indices of cost changes were available for 1969-1979 (and, in some cases, 1980) for each functional area. In most instances, cost projections were generated by applying the average rate of change for the five-year period from 1975 through 1980 to the period 1981-1985. This approach assumes that the economic conditions for the five-year period of 1975-1980 will follow a similar pattern over the next five years.

Several sources were used to collect historical data for each cost function for the two motor carrier groups. In addition to references cited in this paper (6-11), these sources included the following:

1. Table 799, Producers' Price Index for Intermediate Materials, Supplies, and Components, from Statistical Abstracts (1967 = 100);
2. Intercity truckload driver compensation (residuals and salaries) reported by the National Motor Transport Data Base survey conducted by Transportation Research and Marketing of Salt Lake City, originally developed for the Association of American Railroads; and
3. The Comparative Fuel Price Report of the Household Goods Carriers Bureau, Arlington, Virginia, which is compiled monthly.

The methodology for projecting future inflation rates was the same as that used for rail.

PROJECTED TON-MILE COSTS WITH AND WITHOUT CHANGE IN TRUCK WEIGHTS

The average cost per mile or per ton provides little insight into competitive areas of traffic or potential diversionary effects of increased truck weights. In this study, therefore, the comparisons among the four service types were based on cents per ton-mile at various lengths of haul.

However, because of the limitations and the incompatibility of the data, certain adjustments were made in the ton-mile costs. For example, adjustments were made in the average loadings for TOFC, irregular-route carriers, and exempt owner-operators to reflect costs at 73 280 and 80 000 lb GVW. Adjustments were also made in the mileages to account for circuity in comparing lengths of haul. Table 1 presents the 1977, 1981, and 1985 total costs per ton-mile for each of the four carrier types.

EFFECT OF INCREASED WEIGHT ON TRUCK-RAIL COMPETITION

To determine the likely extent of modal competition, the costs per ton-mile were then computed for various lengths of haul for each carrier group. Subsequently, these costs were plotted on graph paper to see at what length of haul (if any) the cost curves intersect. A more precise way to determine whether and where the cost curves intersect was to solve simultaneous equations for length of haul. Equation 1 was used to determine where, for example, the average length of haul of TOFC equals that of irregular-route truckload carriers.

$$\text{(TOFC terminal cost}/X) + \text{TOFC line-haul costs per ton-mile} = (\text{irregular-route overhead costs}/X) + \text{irregular-route line-haul costs per ton-mile} \quad (1)$$

where X is the average length of haul. In 1977, for example, TOFC and irregular-route costs intersected at 824 miles.

The lengths of haul at which the cost curves intersect for 1977, 1981, and 1985, with and without any change in GVW, are given below:

Category	Length of Haul (miles) At 20 Tons	At 22.5 Tons
TOFC versus irregular-route truckload		
1977	824	854
1981	915	861
1985	907	874
TOFC versus exempt owner-operator		
1977	968	994
1981	1050	988
1985	1044	1006

Rail boxcar is not presented because the cost curves intersect at extremely short lengths of haul. If shippers are using truckload motor carrier service instead of rail boxcar service at distances greater than 50 miles, it is for reasons other than ton-mile costs, such as lower physical distribution costs and improved service.

FINDINGS

In this analysis, the projected relevant costs of rail boxcar, rail TOFC, irregular-route motor carriers, and exempt owner-operators were determined by assuming a change in truck weights from 73 280 to 80 000 lb. The analysis considered the impact of increased gross weights on ton-mile costs and the influence of inflation on the relative costs of four carrier groups.

It was found that inflation has affected motor carriers and railroads differently. For example, in 1977 irregular-route truckload carriers had lower costs than TOFC up to 824 miles. By 1981, the truckload carriers had a cost-per-ton-mile advantage up to 915 miles. However, with increased weights, TOFC would be able to overcome, in part, the effects of inflation. For example, in 1981, with increased weight, the irregular-route carriers and TOFC had similar costs at 861 miles rather than 915 miles.

The analysis also indicated that, although fuel costs were lower for TOFC than for truckload motor carriers, on both absolute and percentage of total cost bases, the long-run total-cost-factor position of TOFC is deteriorating in comparison with truckload motor carriage. For example, by 1985 TOFC line-haul costs will have increased by 165 percent and TOFC terminal costs will have increased by 102 percent. The comparable cost-factor increases for irregular-route truckload carriage are 139 and 90 percent, respectively. Over the 1981-1985 period, the economic factors examined in this paper indicate that TOFC is not the market-preferred investment.

Finally, it must be remembered that the initial assignment of costs to particular functional areas was performed by DOT. This paper assumes that those costs were properly assigned. In addition, it should be noted that both we and DOT rounded certain arithmetic values that may have influenced the conclusions.

REFERENCES

1. L.L. Lane. Statement of Public Meetings on the Truck Size and Weight Study. Intermodal Policy Group, Assn. of American Railroads, Chicago, July 13, 1979.
2. R.W. Kolins. General Freight Common Carrier Productivity and Liberalization of Truck Dimension and Weight Statutes. In Issues in Truck Sizes and Weights, American Trucking Assns., Inc., Washington, DC, Tech. Rept. TSW-81-4, 1981.
3. D.P. Sullivan and R.J. Kochanowski. Truck and Rail Cost Effects on Truck Size and Weight Limits. In An Investigation of Truck Size and Weight Limits, U.S. Department of Transportation, Vol. 2, Tech. Supplement, Dec. 1980.
4. An Investigation of Truck Size and Weight Limits. U.S. Department of Transportation, Final Rept., Aug. 1981.
5. The Economic ABZ's of the Railroad Industry. Assn. of American Railroads, Washington, DC, 1980, Tables III-4, III-3, III-7, III-14, and II-7.
6. R.T. Selva and R.W. Kolins. The Impact of Gross Vehicle Weights on Line-Haul Trucking Cost: 1981 and 1985. In Issues in Truck Sizes and Weights, American Trucking Assns., Inc., Washington, DC, Tech. Rept. TSW-81-3, 1981.
7. Preliminary 1985, 1990, and 1995 Energy Forecasts for the Annual Report to Congress in 1980. Energy Information Administration, U.S. Department of Energy, Nov. 1980.
8. Allocation of Federal Highway Program Costs to Motor Vehicles on the Basis of the Costs They Occasion. CounselTrans, Inc., Rockville, MD, June 1981, pp. 6-5 and 6-7.
9. Second Progress Report on the Federal Highway Cost Allocation Study: Report of the Secretary of Transportation to the United States Congress, Pursuant to Section 506, P.L. 95-599, Surface Transportation Assistance Act of 1978. Office of the Secretary of Transportation, Jan. 1981, p.67.
10. Highway Cost Allocation Scale Analysis. U.S. Department of Transportation, Highway Cost Allocation Study Paper 7, Aug. 1980, pp. A-1 and B-1.
11. Motor Carrier Annual Reports. American Trucking Assns., Inc., Washington, DC, 1977-1980, Summary Table 1, p. 3.

Publication of this paper sponsored by Task Force on Technical Review Panel for Truck Size and Weight.

Abridgment

Truck Forecasts and Pavement Design

ROBERT J. HAGE

The uncertainties associated with making design load estimates for use in determining pavement structure requirements are many. A brief discussion of the problem of estimating the present or base-year annual average daily load on an existing route or alignment is presented. The discussion focuses on the five-axle tractor-semitrailer, which is regarded as causing more than 80 percent of traffic-attributable pavement damage on Minnesota's Trunk Highway System.

The AASHO Road Test provided the basis for relating the pavement deterioration resulting from any given axle load, single or tandem, to that resulting from an 18-kip dual-tire single axle. It also provided the basis for the design of both flexible and rigid pavement structures in terms of the number of equivalent 18-kip single-axle loads the pavement can be expected to carry before reaching a preselected terminal serviceability level. The Minnesota Department of Transportation (Mn/DOT) has been using the equivalent 18-kip single-axle load (18-kip ESAL) procedure for flexible pavement design for some 10 years and will soon be designing its rigid pavements on that basis. Developing a design load estimate (i.e., the total number of 18-kip ESALs expected to occur in the design lane of the roadway over the analysis period, usually 20 years for new construction) entails estimating the following parameters on an individual project basis:

1. Base-year truck volumes by truck type;
2. Annual growth rate for each truck type;
3. Average 18-kip ESAL factor, or truck factor, for each truck type (ideally reflecting future expectations as well as estimates of current loads);
4. Lane distribution of truck traffic, preferably by truck type, based on the estimated average annual daily traffic (AADT) for the analysis period;
5. Variations in the average weight of each truck type by lane, reflecting the assumption that trucks traveling in the slow lanes are more heavily loaded than those in the fast lanes and thus have above-average truck factors;
6. The percentage of equivalent axle loads (EALs) occurring during the spring freeze-thaw cycle months; and
7. The percentage of truck traffic expected to experience creep speeds during the hot summer months.

Trucks are defined here as vehicles with six or more tires, including buses.

Clearly, a full discussion of the dimensions of the problem of forecasting anything encompassing as many variables as truck volumes and loads for a specific route over a 20-year period would fill volumes. This brief presentation is thus limited to highlighting some of the problems and uncertainties associated with simply estimating the base-year design-lane load. Since the five-axle tractor-semitrailer appears to account for more than 80 percent of the traffic-attributable pavement deterioration on many sections of Minnesota's Trunk Highway System--more than 90 percent on some sections--much of the following analysis will focus on that vehicle type.

VARIABILITY IN TRUCK VOLUMES

The basis for pavement construction or improvements is often a single 16-h weekday (6:00 a.m. to 10:00 p.m.) vehicle classification count taken in the vicinity of the proposed project, and very often the count is neither current nor ideally located. There is strong evidence, however, that a single 16-h class count, no matter how recent or well located, may be grossly inadequate for estimating base-year heavy commercial AADT by truck type.

There are, of course, the obvious uncertainties associated with filling in the uncounted 8 h and the weekend traffic and with adjusting the count to reflect seasonal variations in travel for each major truck type. But, whereas one might expect truck volumes to vary significantly from season to season and perhaps even from week to week, it has now been determined that they may also vary markedly from day to day.

Class counts recently taken Monday through Friday from 8:00 a.m. to 5:00 p.m. on Trunk Highway 12 (I-94 traveled way) just east of the Minneapolis-St. Paul metropolitan area showed the five-axle tractor-semitrailer volume varying by 30 percent from the low day (Friday) to the high day (Wednesday). At this location, the AADT for this vehicle type is roughly estimated at 4000, and it accounts for an estimated 87 percent of the traffic-associated pavement wear. Obviously, the design load estimate made for the Interstate route to be constructed on this alignment could have a wide range of values that depend simply on the day or days the class count happened to be taken. It should be noted that usually two different days are represented in Mn/DOT's 16-h class counts: Typically, the 6:00 a.m. to 2:00 p.m. period is counted on one day and the 2:00 p.m. to 10:00 p.m. period is counted on another. It is not known to what extent this ameliorates the problem of daily variability in truck volumes nor whether the pattern of daily variation at that location tends to be repetitive since only a single week was counted.

In June of 1981, however, Mn/DOT began obtaining around-the-clock class count data at a prototype weighing-in-motion (WIM) scale installed on I-494 in a southwest suburb of Minneapolis. Here, the daily variation in the eastbound five-axle tractor-semitrailer volumes over the course of the five-day week appears to average about 25 percent. Friday was the low day 23 out of 28 weeks; Monday was most often the high day, with a score of 12 out of the 28 weeks. (Weeks with a holiday and those with incomplete data were excluded from the analysis.) The scale does not monitor westbound traffic. The daily two-way five-axle tractor-semitrailer volume at the site is averaging about 2000.

Because truck volumes may vary widely from one day to the next, it is inevitable that attempts to identify seasonal variations on the basis of a single 16-h class count taken at different times of the year will meet with disappointing results. To provide a basis for adjusting its 16-h class counts to an AADT basis, Mn/DOT biennially makes two such counts at each of 24 locations on the outstate Trunk Highway System. One count, representing the summer season, is made in June, July, or August; the other count represents the fall and is made in September, October, or November. Comparing the 1977 five-axle tractor-semitrailer summer-fall counts with their 1979 counterparts reveals a chaotic pattern at 10 or more of the count sites. Not only are the summer-fall relations highly inconsistent from one count to the next at these locations, but the summer-to-summer and fall-to-fall comparisons also exhibit a highly erratic character. It appears, then, that even if Minnesota had only two seasons, which is certainly not the case, even two 16-h class counts would provide an inadequate basis for estimating truck AADT or for establishing year-to-year trends.

VARIABILITY IN TRUCK FACTORS

Average truck factors, which express the pavement damage associated with a specific truck type as a fraction or a multiple of that associated with an 18-kip single-axle load, vary widely by route, by time of year, and, in the case of tractor-semitrailers, by trailer type. Unfortunately, there also appears to be a significant degree of unexplained year-to-year variability. Over recent years, the truck factor for flexible pavement design in Minnesota--based on portable scale weighing operations at 15 locations on out-state Trunk Highways--for the five-axle tractor-semitrailer has averaged about 0.84, but the factor varies significantly from one highway to another even on routes with identical legal load limits. In 1979, the truck factor ranged from a low of 0.62 to a high of 1.46. In making design load estimates, then, Mn/DOT does not rely exclusively on statewide averages.

The range of values is even more pronounced when the factors are analyzed by direction. For example, on Trunk Highway 2, which runs across northern Minnesota and carries large numbers of five-axle tractor-semitrailer grain trucks to Duluth-Superior terminals on Lake Superior, the loaded-direction truck factor for these vehicles averaged 1.95 in 1979 and on the return trip the average was 0.34. Average truck factors for five-axle tractor-semitrailers also vary markedly by trailer type; grain and dump trucks usually exhibit the highest values.

In comparing truck factors obtained in the 1977 and 1979 weighing operations, it was found that at 13 of the 15 weigh sites the "loaded direction" remained unchanged, which strongly suggests that, to reduce the likelihood of early pavement failures, design load estimates should be based on the loaded-direction truck factor rather than on the two-way average. If this procedure were used, the average out-state truck factor for the five-axle tractor-semitrailer would increase from 0.84 to 1.03. On divided highway sections, of course, the pavement structure can be differentiated by direction.

At least part of the year-to-year variation in the five-axle tractor-semitrailer truck factor at a given location is probably attributable to the proportion of grain trucks that happen to be in the traffic stream at the time the weighing operations are conducted. On a statewide basis, grain trucks account for some 20-25 percent of the five-axle tractor-semitrailers on the state's highways. But, depending on harvest dates and various market forces, their volumes fluctuate markedly over the months in which weighing operations are conducted. Thus, the proportion of grain trucks in the five-axle tractor-semitrailer volumes on a given highway during weighing operations may be quite different from year to year. And, because these vehicles typically exhibit exceptionally high truck factors, the average factor is subject to significant fluctuation.

TRUCK FACTOR VALIDITY

Assuming away other problems such as that just discussed, and perhaps biased sampling, the truck factors obtained in portable scale weighing operations are probably unrepresentative because of scale-avoidance tactics of overweight trucks. Even though truckers may be aware that these weighing operations are not directly connected with enforcement, they may nevertheless feel that it is not in their best interests over the intermediate and long term to be weighed when carrying overloads. This suggests that the truck factors obtained in these operations understate actual loads.

On the other hand, the weighing operations are conducted in the summer and fall and data collected at the WIM site show that five-axle tractor-semitrailer truck factors drop dramatically during the winter months, at least at that location. This drop is very likely a result of a disproportionate reduction in grain truck volumes.

This evidence suggests that the raw truck factors obtained in the portable-scale weighing operations should be adjusted to reflect these considerations. Further adjustments might be made to reflect (a) the probable effects of the state's newly enacted relevant evidence law (which permits weight tickets obtained at loading and unloading points to be used as evidence in prosecuting overweight violations) and also (b) the probability that in the future average truck weights may be higher because of a lower incidence of empty and lightly loaded vehicles. Such increases may well occur as a result of higher fuel prices and deregulation.

OTHER AREAS OF UNCERTAINTY

Although the foregoing analyses are limited to a single truck type, the five-axle tractor-semitrailer, it nevertheless seems clear that, in simply developing a base-year design load estimate, one must deal with a significant degree of uncertainty not only in estimating truck volumes but also in estimating the average damage factor for each truck type. Still further areas of uncertainty are discussed in the following sections.

Lane Distribution

A critical step in developing a design load estimate is determining the lane distribution of estimated truck volumes. Errors here will have the same impact as inaccurate estimates of truck volumes or damage factors. Mn/DOT is currently conducting a field study of lane distribution in which a number of four-, six-, and eight-lane sections in the Minneapolis-St. Paul metropolitan area will be counted in the peak hours, at midday, and late at night. Undoubtedly, the count data will show substantial variability in lane use for each of the route types, since lane distribution is a function not only of AADT and heavy commercial AADT but also of geometrics and turning movements upstream and downstream. A limited study, then, cannot be expected to yield categorical results. But, in learning something about the range of variability in this parameter and about worst-case values, the planner will be better equipped to make design-lane load estimates.

Other Variables

In making 20-year design load estimates, the planner has still other variables to consider. For example, full-depth asphalt pavement designs for metropolitan-area roadways require an estimate of the incidence of creep speeds, which in the summer months result in a much higher rate of pavement deterioration than free-flow speeds. And, as indicated earlier, the planner must also estimate, on an individual project basis, the percentage of the annual load expected to occur during the spring, when flexible pavements in Minnesota experience a high rate of deterioration. Accurate estimates of this percentage will result in better predictions of pavement performance. Pavement designers are now also asking planners to estimate confidence levels associated with their design load estimates so that designers can weigh the additional costs of providing a "safety margin" in their designs against the risk and costs associated with early pavement failure. Still another major challenge confronting the planner in making a design load estimate is forecasting five-axle tractor-semitrailer traffic volumes, which have grown at unsustainably high rates over recent years.

CONCLUSIONS

The dimensions of the uncertainty associated with making 20-year design load estimates are indisputably enormous. But it is also apparent that simply estimating existing loads is highly speculative. With the cost of an incremental inch of flexible and rigid pavement running at about $6500 and $7500/lane mile, respectively, it is imperative that the planner continue to improve each aspect of the design load estimating process. But the process will inevitably continue to be characterized by a high degree of uncertainty. Fortunately, the attainment of minimum pavement life objectives for critically important high-volume urban routes can generally be ensured with relatively small increases in construction cost. For example, if the 20-year design-lane load estimate for such a route is 5 million EALs, the addition of less than an inch in the design of the asphalt layer will enable the pavement to accommodate a load of at least 10 million EALs.

Publication of this paper sponsored by Task Force on Technical Review Panel for Truck Size and Weight.