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Contents

Foreword

Commercial users continually demand more efficient freight transportation. Modern transportation research is able to help supply this need in all applicable modes through the use of mathematical modeling techniques and statistical analysis. This Record describes some of the latest research in the field.

Devadoss and Maze describe their investigation of the supply of truck services available to haul fresh produce from the U.S. Southwest to domestic markets. Their results show that truck service providers allocate their resources efficiently in response to competitive price signals from truck service buyers.

Two papers by Radwan and his coworkers present several different aspects of a research project, the Arizona Freight Network Analysis, that was undertaken to help the Arizona Department of Transportation evaluate the freight movement performance of Arizona's highway system. Their first paper describes a survey conducted to collect data about freight flows on Arizona's highways and about carriers' perceptions of certain freight-related problems. The second paper describes the development of a decision support system to help plan freight movement more efficiently.

Hsu et al. describe the development of a vehicle-routing model for the home delivery operations of a major trucking company. Such a model requires two special capabilities: the ability to locate any given address in the service area and the capability to accurately estimate the distance between any given pair of points, reflecting local traffic conditions.

Carey and his colleagues discuss their study of freight usage patterns of technology-based firms in the Austin, Texas, area. The study results confirm the heavy reliance of these firms on air freight and courier services for both inbound and outbound freight shipments.

An Econometric Analysis of Produce Truck Transportation Supply

N. DEVADOSS AND T. H. MAZE

The research described in this paper involves the supply of truck services to haul fresh fruits and vegetables (produce) from the Southwest region of the United States to domestic markets. The researchers made use of the U.S. Department of Agriculture's data base of produce shipments, produce unloadings, truck rates, and truck costs, as well as subjective measures of the adequacy of truck service supply. The importance of the research lies in its ability to show that truck service providers allocate efficiently in response to competitive price signals from truck service customers.

The spatial distribution of agricultural commodity producers and consumers in the United States creates a demand for agricultural commodities to be transported. More than half of these agricultural commodities by weight are fresh fruits and vegetables (FFV, also commonly called produce) (*1, 2*). The cost of transportation forms a sizable portion (~20 percent) of the overall retail price of FFV (*1,3*).

Generally, the movement of produce is difficult to manage for many reasons (*4, 5*). The two major causes are the dramatic seasonal fluctuations of produce transportation needs and the characteristics of the types of produce transportation available to the shippers. The seasonality of the harvesting of agricultural produce intensifies peaking, and the inability to store most kinds of produce prohibits shippers from dissipating shipping peaks.

These problems can be understood clearly by considering the example of a single agricultural region. The U.S. produce-growing regions have been divided according to common seasonality and geographic location by Maze (*6*), as shown in Figure 1. In this paper, the Southwest region (New Mexico, Oklahoma, and Texas) is the focus. The dramatic fluctuations in volumes of shipments of produce for this region is illustrated graphically in Figure 2. The figure shows a graph of the number of truckloads of produce shipped from the region in 1983. During the fourth week of May, 4,476 truckloads of produce were shipped from the Southwest. During the last week of September, however, shipments from the region dropped to fewer than 300 truckloads per week. This type of peaking, in the Southwest and in other regions, creates great adjustment problems for the allocation of trucks.

Trucking tends to dominate the transportation of fresh produce because of its flexibility and other qualitative characteristics. Over the last few decades, the Southwest region has become almost totally reliant on trucking for produce shipments. The increase in truck shipments of produce relative to rail shipments since the 1950s illustrates this tendency. By 1984, 99.73 percent of all produce shipments in the Southwest were made by truck. Fewer than 0.10 percent were made by rail car, and fewer than 0.17 percent by piggyback (all data from USDA, *Fresh Fruits and Vegetables: Shipments and Arrivals* and *Fresh Fruit and Vegetable Unloads* for the applicable years). Although there are alternatives to trucking that may present excellent options in the future, trucking is presently almost the only mode used to move Southwestern produce within the United States. Wyckoff and Master identified the most likely reason for this dominance when they found that truckload options are generally no more costly than rail and provide better-quality service (*7*).

To serve the special demands placed on truck carriers who ship raw agricultural commodities, these truckers were exempted from interstate economic regulations by the Motor Carrier Act of 1935 (*8*). Furthermore, to allow greater participation by agricultural carriers in traditionally regulated truck service markets, the Motor Carrier Act (MCA) of 1980 relaxed restrictions placed on carriers without Interstate Commerce Commission (ICC) certification (*9–12*). Unregulated agricultural commodity carriers are free to migrate and follow the harvesting season across the country. The ability to migrate has been widely considered to be a source of competition for truck service between regions with harvest peaks that overlap in time (*1, 6, 13*), although there is some evidence to the contrary (*14*).

The primary objective of the research described in this paper is to better understand the supply and demand of produce truck services, and possibly that of truck services in general. The research investigates the allocation of providers of produce truck service in response to price signals and in response to other related market variables. The importance of the research is twofold. First, it provides an example of the response of truck service suppliers to the demands (prices bid) of truck service consumers in a competitive environment, and second, it provides a better understanding of the mechanics of the produce truck market.

N. Devadoss, Oklahoma Highway and Transportation Engineering Center, University of Oklahoma, Norman, Okla. 73019. T. H. Maze, Local Transportation Information Center, Iowa State University, Ames, Iowa 50010.

FIGURE 1 Produce-growing regions in the continental United States.

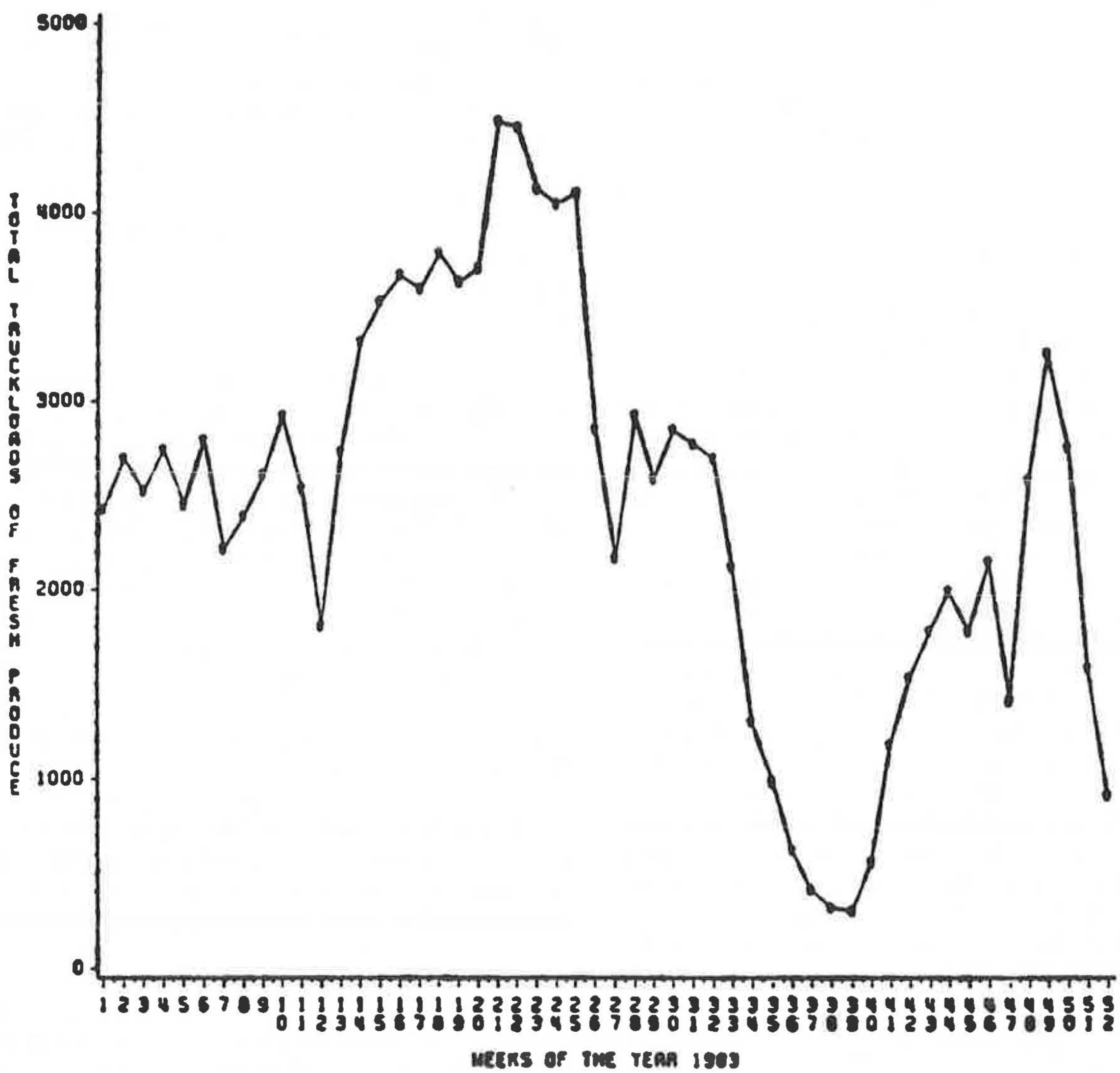

FIGURE 2 Weekly produce shipments by truck from the Southwest region.

This second factor will offer aid to the U.S. Department of Agriculture (USDA) and state departments of agriculture in advising shippers of market conditions for produce transportation.

Although there have been many studies of unregulated agricultural truck transportation, these studies are usually devoted to determining whether the quality and cost of unregulated truck services are comparable to those of regulated markets (*15–25*). Generally, the answer is that the average performance of unregulated truck service markets is superior to the average performance of their regulated counterparts. Studies of unregulated agricultural truck service markets, however, seldom focus on market issues. Specifically, these studies seldom examine whether truck service suppliers respond efficiently to competitive price signals from truck service consumers. Additionally, the issue of the magnitude of the possible relationship is rarely considered.

The dearth of research in this area is probably attributable to the past lack of data on the produce truck transportation market. Conditions have changed, however, and data on the produce truck service market are currently being collected. In June 1979, USDA began collecting produce truck service market data on a weekly basis (published as *Fruit and Vegetable Unloads Truck Rate and Cost Summary* and *Fruit and Vegetable Unloads Truck Rate Report*). In this paper, the truck produce service market from the Southwest region to six major domestic market destinations (Atlanta, Chicago, Dallas, Denver, New York, and Los Angeles) is analyzed. In this research, the USDA data are used to conduct an empirical econometric analysis of produce truck transportation services. Seemingly unrelated regression (SUR) models of the truck service models are developed for each destination, for each of the growing subregions within the Southwest region, and for each of the major types of produce grown in the Southwest.

The models developed in this paper indicate that exempt truckers allocate their trucks with respect to rate signals, so that the market follows the traditional micro-economic theory of the market. It has also been found that the availability (adequacy) of trucks at a shipping region and the truck operating costs play an important part in setting rates. Although the scope of this research is limited to the Southwest region, the findings can be extended to other regions.

DATA DESCRIPTION

A major resource for this research is the data base that is being collected by the Market News Branch, Fruit and Vegetable Division, Agricultural Marketing Service and Office of Transportation, of the U.S. Department of Agriculture, as mentioned earlier. Five years of data (1979–1984) are coded and stored in a form that is compatible with a standard statistical package (i.e., the Statistical Analysis System, or SAS). The prepared data base includes the following elements.

Shipment Data

The raw data of the Market News Branch are listed as thousands of pounds of each commodity on a weekly basis. In all, 39 different types of produce are reported. Because the focus of this research is truck transportation services and not the produce types themselves, the USDA data are converted from 1,000-lb lots to truckloads.

Unloading Data

The raw data of the Market News Branch are listed as thousands of pounds of each commodity unloaded at a major consuming city. Originally, the unloading data were collected for 42 major U.S. cities. Subsequently, because of a reduction in the funding level, USDA reduced the number of cities to 21. The unloading data for the six major destinations used in this study, however, are included in all the years under consideration. Unloadings are reported on a monthly basis. To convert unloading volumes to weekly data, to be compatible with weekly shipment data, the unloadings made each week are assumed to be proportional to the month's volume.

Freight Rate Data

Freight rates (prices) for trucking services from major producing subregions to the six major destinations mentioned previously are collected on a weekly basis by USDA. The rates are normally quoted as a typical truckload carrying 40,000 pounds of produce. The weekly rate is given on a range basis, with minimum and maximum values, and in some cases only one value is reported (normally the maximum rate).

Truck Availability (Adequacy) Data

For each area, a truck adequacy scale, ranging from surplus to shortage, is reported to the Market News Branch. The scale is defined as follows:

- Surplus (supplies of trucks exceed shippers' needs),
- Slight surplus (supplies of truck slightly exceed shippers' needs),
- Adequate (supplies of trucks are generally in good balance with shippers' needs),
- Slight shortage (supplies of trucks are short of shippers' needs), or
- Shortage (supplies of trucks are far below shippers' needs).

Operating Cost Data

Operating cost information is reported by the Office of Transportation, USDA. The USDA report supplies information on both truck fleet costs and truck owner-operator costs. Because the majority of produce is hauled by exempt truck owner-operators, the corresponding truck owner-operator costs (in cents per mile) are considered in the analysis. The cost is reported as the summation of fixed costs (interest, insurance, and license), variable costs (depreciation and driver wage), and operating costs (fuel, maintenance, and miscellaneous expenses). The cost of fuel, which accounts for approximately 20 percent of the overall operating costs, is generally more variable than other costs. The truck-operating cost per mile is reported on a monthly basis, and it is assumed that weekly operating costs are equal to the cost reported for the entire month.

Price Index

The truck rates and operating costs are adjusted to derive constant dollar values. The Transportation Consumer Service Price Index is used to deflate monthly dollar values to constant dollars (1967 dollars are indexed at 100). The Transportation Consumer Price Index is given in the Consumer Price Index *Detailed Report* (published by the Bureau of Labor Statistics, U.S. Department of Labor) on a monthly basis. The weekly figures obtained from the monthly values are based on the assumption that inflation increases or decreases uniformly within each month.

Auxiliary Data

State-level reports published by several state agencies are also used to arrive at volumes of shipments from produce-growing subregions within each state of the Southwest (*26–31*). *The Census of Agriculture* is also used to supplement data whenever necessary (*32*).

METHODOLOGY

Before an empirical aggregate model is constructed, an abstract conceptual model is hypothesized to provide direction for the specification of the empirical model. The rates may be viewed as being determined by the interaction of the regional supply and demand curves of transportation services. In the analysis, the truck rate is therefore hypothesized to measure the supply of truck service to various destinations. Moreover, it is also hypothesized that trucking firm decision makers (suppliers of truck services) respond to the expected profit per unit of time when they allocate their trucks. The expected profit is actually the difference between the rate (revenue) and the cost of operation. In some instances the expected revenue would be almost equal to or less than the operating cost, which means zero profit (breaking even) or even a loss.

The cost of operating trucks involves not only the costs given in the USDA report but also other incidental expenses, such as the costs associated with delays of multiple load pickups, waiting time while the produce is packed, and multiple deliveries. These expenses may vary from destination to destination and from time to time, depending on the season. Sometimes truckers are compensated for these special services, but most truckers bear these expenses without added compensation (*23*). These special services lead to inefficiencies, and they reduce the profits earned by truckers.

It should be noted that the supply of truck service has to be considered as the interaction of two parties, the buyer and the supplier. As buyers of truck services (buyer broker, truck broker, or both) want more trucks to haul produce, they increase rates to attract more trucks. The suppliers (truckers) then compare the different rates offered to them, the costs of providing the service or not providing the service, and the cost of offering service to one destination as compared to that for other possible destinations. Moreover, as the operating costs increase, the suppliers are likely to seek a higher truck rate, if it is assumed that all other factors remain constant (*13*).

The rate offered for truck service from a produce-growing area to a destination city can be considered as the appropriate proxy value for the supply of truck services. As the rate offered for truck service to a particular destination increases, more truckers should be attracted to that particular destination, if it is assumed that costs remain constant.

If decision makers at trucking firms allocate their trucks to different destinations on the basis of anticipated profits per unit time, then the quantity of truck service supplied (the quantity of produce truck loads actually shipped) to the Southwest to haul a specific type of produce is dependent on the rate (revenue) offered for one truckload of that type of produce, if it is assumed that the cost of operation is relatively constant over a short time (i.e., 1 week). Furthermore, the rate is hypothesized to be dependent on the total quantity of produce (all types of produce) shipped from the growing area, quantity of competing produce (other produce types) shipped from within the same growing area, truck rates in competing growing areas, relative availability of trucks, and the operating costs of trucks. The hypothesized model of truck service supplied to the Southwest (measured by a proxy variable, truck rate) is expressed by the following equation:

$$\mathrm{MTR}_{ijkt} = F(\mathrm{TRSH}_{ijkt}, \mathrm{TCSH}_{ijt}, \mathrm{TWSH}_{ijt}, \mathrm{ADECOD}_{ijkt}, \mathrm{OPCOST}_{t})$$

where

i = producing (growing) area,
j = destination city,
k = produce type,
t = time period,
MTR = mean truck rate,
TRSH = total regional quantity shipped,
TCSH = total competing area quantity shipped,
TWSH = total competing produce quantity shipped within the area,
ADECOD = adequacy of trucks,
OPCOST = operating cost of trucks, and
F = abstract aggregate supply function.

EMPIRICAL ANALYSIS

The modeling process is divided into two stages. In the first stage the data set is prepared, and a list of candidate variables is chosen by using preliminary analysis. In the second stage, a seemingly unrelated regression (SUR) technique is considered for the final model development, using the set of chosen variables.

Data Set Development

The numerous variables included in the data set compiled for the analysis must be reduced to a reasonable number. For example, the USDA shipment reports include 39 different types of produce. An attempted model for the truck service supplied to carry each commodity would be unmanageable. Instead, variables are classified into categories. Produce, for example, is classified into four major varieties. Data are classified by subregions within the Southwest, by shipping destinations, by produce type, and by time period, as follows.

Producing Subregions

The produce-growing subregions are classified as follows:

- Lower Rio Grande Valley, Texas;
- Winter Garden, Texas;
- Panhandle/Hereford, Texas; and
- New Mexico.

The USDA report did not list any shipment data for the state of Oklahoma.

Competing Subregions

The competing subregions can be classified by reference to the subregion that is being studied. For example, if the truck service is supplied to the Lower Rio Grande Valley, then the remaining subregions (Winter Garden, Panhandle/Hereford, and New Mexico) are considered to be competing subregions.

Destination Cities

Not all of the available fresh fruits and vegetables are shipped to all six major destination cities every year. For instance, the Panhandle/Hereford subregion shipped FFV consistently to New York, Chicago, Atlanta, and Dallas during 1979–1984. In contrast, shipments from the Panhandle/Hereford subregion to Los Angles and Denver are only recorded during 1979 and 1980. Models are actually estimated only if there is a long enough data record to allow the estimation of model parameters with an ample number of degrees of freedom.

Types of Produce

On the basis of the produce types listed in the USDA truck rate reports, the produce types are consolidated into a manageable number of categories. Produce shipped from the Southwest regions is grouped into one of the following categories:

- Citrus,
- Vegetables,
- Dry onions, or
- Lettuce.

Time Periods

The time period considered in the analysis is from July 1979 to December 1984. It should be noted that a few types of FFV are shipped only during certain portions of the analysis period. For example, USDA only reported vegetable shipments during 1979 and 1980 from the Winter Garden subregion.

Model Development

The abstract conceptual model identifies the variables that determine exempt truck service supply to the Southwest region. By using the abstract model for guidance, an empirical model is specified to account for the truck service supply from the produce-growing subregion (i) to a destination city (j) for a particular type of produce (k) during a specific time period (t).

The mean truck rate is used as the dependent variable, and independent variables are sought to describe its behavior. The "best" independent variables are selected by reviewing two-dimensional plots, correlation coefficients, and partial correlation coefficients between the dependent variable and the candidate independent variables and their common transformations.

Because of the short (weekly) observation periods, serial correlation should be present in the empirical model. The resulting empirical model specification is presented in the following equation:

$$\begin{aligned} \text{MTRD}(i, j, k, t) = P_0 &+ P_1 * \text{TRSH}(i, k, t) \\ &+ P_2 * \text{TCSH}(i, t) \\ &+ P_3 * \text{TWSH}(i, k, t) \\ &+ P_4 * \text{ADECOD}(i, j, k, t) \\ &+ P_5 * \text{OPCOSTD}(t) \\ &+ U(i, j, k, t) \end{aligned}$$

where

i = origin (growing/producing subregion, e.g., Lower Rio Grande, Texas);
j = destination (consumer area, e.g., Atlanta);
k = produce type (e.g., citrus, vegetables);

t = time period (weeks of a year);
MTRD = mean truck rate (indexed to 1967 dollars);
OPCOSTD = cost of production inputs of truck (i.e., fuel price, wage rate, etc.) per mile in cents (indexed to 1967 dollars);
ADECOD = truck availability at a growing subregion (i), to a destination (j) for a produce type (k) at time (i) [adequacy code is a qualitative variable ranging from surplus (1) to shortage (5)];
TRSH = total shipments of produce type (k) from a growing subregion;
TCSH = total shipments of all produce types from a competing subregion;
TWSH = total shipments of competing produce types within the growing subregion (all types of produce other than k);
$P_0, P_1, P_2, P_3, P_4, P_5$ = regression parameter estimates;
$U(i, j, k, t) = Q_0 * U(i, j, k, t-1) + V(t)$ (autocorrelated error term);
Q_0 = autoregression coefficient;
$U(i, j, k, t-1)$ = lagged autocorrelated error term (LRS); and
$V(t)$ = random error term.

Analysis Procedure

The SAS routine "Autoregression" (AUTOREG) (*33*) is used with the best independent variables to estimate the parameters for single-equation models for each combination of producing area, produce classification, and destination city. The residuals are then obtained from the AUTOREG procedure for each destination, after correcting the first-order autocorrelation. Then the first order lagged values of the residuals are deduced from each model's residuals.

A SUR system model is run on the combined data set of the original best variables and the lagged first order residuals to obtain the coefficients of the system. The SUR procedure was introduced by Zellner, and it is preferred for situations in which there are omitted variables that are common to a system of equations (*34*). Beilock and Shonkweiler used SUR to model truck service supply under similar conditions (*35*). A system of simultaneous equations is used to model truck rates from each producing subregion for each commodity classification to the six destinations as a seemingly unrelated system to allow information to be transmitted between equations through the error structure. The estimation of parameters is done through the maximum likelihood method (*36*). The model that best fits the data is chosen by repeated experimentation with the available data on the basis of logical and statistical criteria (*37*).

As indicated earlier, one of the main problems is the lack of uniformity in the data, a condition that leads to an unequal number of missing observations. This problem has been addressed by many researchers (*38–44*). The SAS procedure used for modeling here takes the missing data into account through the MISS/NOMISS option (*33*).

EMPIRICAL MODELS

An equation system is estimated for each origin to all six destinations and for each produce classification for which there is a data set of sufficient size. In the following material, general interpretations for the system model estimated are provided. A more lengthy discussion of each equation within the system is provided elsewhere by Devadoss (*45*).

Lower Rio Grande Valley: Truck Rate Analysis for Vegetables

The Lower Rio Grande Valley is the predominating major produce-growing subregion in the Southwest and is the only citrus-growing subregion in the region. Hence citrus and vegetable producers compete with each other to attract truck services during certain periods of the year.

The model specifications developed for truck rates for Lower Rio Grande Valley vegetables to each of the major destination cities are given in the following equations. The estimated parameters, their standard errors, t values, and corresponding probability values for each equation and the entire system are presented in Table 1.

New York

$$\text{MTRD} = A_0 + A_1(\text{OPCOSTD}) + A_3(\text{TCSH}) + A_4(\text{ADECOD}) + A_5(\text{LRS})$$

Chicago

$$\text{MTRD} = B_0 + B_1(\text{OPCOSTD}) + B_2(\text{TRSH}) + B_3(\text{TCSH}) + B_4(\text{ADECOD}) + B_5(\text{LRS})$$

Atlanta

$$\text{MTRD} = C_0 + C_1(\text{OPCOSTD}) + C_2(\text{TRSH}) + C_3(\text{TCSH}) + C_4(\text{ADECOD}) + C_5(\text{LRS})$$

Denver

$$\text{MTRD} = D_0 + D_1(\text{OPCOSTD}) - D_2(\text{TRSH}) + D_4(\text{ADECOD}) + D_5(\text{LRS})$$

TABLE 1 ESTIMATED SUR COEFFICIENTS FOR TRUCK RATES: VEGETABLES FROM THE LOWER RIO GRANDE VALLEY

Destination	Variables	Parameter Estimate	Standard Error	t-Ratio	Prob>|t| (alpha)
New York City	INTERCEPT(Ao)	472.275	20.13	23.46	0.0001
	OPCOSTD(A1)	5.014	0.411	12.19	0.0001
	TCSH(A3)	0.298	0.008	3.86	0.0007
	ADECOD(A4)	12.371	3.163	3.91	0.0006
	LRS(A5)	0.202	0.067	3.01	0.0056
Chicago	INTERCEPT(Bo)	280.543	16.32	17.19	0.0001
	OPCOSTD(B1)	5.014	0.411	12.19	0.0001
	TRSH(B2)	0.011	0.003	3.84	0.0007
	TCSH(B3)	0.0089	0.003	3.06	0.0050
	ADECOD(B4)	3.788	1.249	3.03	0.0053
	LRS(B5)	0.202	0.067	3.01	0.0056
Atalanta	INTERCEPT(Co)	168.036	17.19	9.77	0.0001
	OPCOSTD(C1)	5.014	0.411	12.19	0.0001
	TRSH(C2)	0.014	0.004	3.34	0.0025
	TCSH(C3)	0.0209	0.004	5.04	0.0001
	ADECOD(C4)	8.647	1.727	5.01	0.0001
	LRS(C5)	0.202	0.067	3.01	0.0056
Denver	INTERCEPT(Do)	199.979	19.38	10.32	0.0001
	OPCOSTD(D1)	5.014	0.411	12.19	0.0001
	TRSH(D2)	-0.0158	0.007	-2.13	0.0421
	TCSH(D3)	N.S	N.S	N.S	N.S
	ADECOD(D4)	9.783	3.064	3.19	0.0036
	LRS(D5)	0.202	0.067	3.01	0.0056
Los Angeles	INTERCEPT(Eo)	252.753	19.29	13.10	0.0001
	OPCOSTD(E1)	5.014	0.411	12.19	0.0001
	TRSH(E2)	N.S	N.S	N.S	N.S
	TCSH(E3)	0.010	0.007	1.44	0.1625
	ADECOD(E4)	7.332	2.822	2.59	0.0150
	LRS(E5)	0.202	0.067	3.01	0.0056
Dallas	INTERCEPT(Fo)	N.S	N.S	N.S	N.S
	OPCOSTD(F1)	5.014	0.411	12.19	0.0001
	TRSH(F2)	N.S	N.S	N.S	N.S
	TCSH(F3)	0.0099	0.0038	2.59	0.0154
	ADECOD(F4)	8.590	1.614	5.32	0.0001
	LRS(F5)	0.202	0.067	3.01	0.0056

System weighted M.S.E is 1.15442 with 172 degrees of freedom.
System weighted R-square is 0.6267.
N.S - Not Significant

Los Angeles

$$\text{MTRD} = E_0 + E_1(\text{OPCOSTD}) + E_3(\text{TCSH}) + E_4(\text{ADECOD}) + E_5(\text{LRS})$$

Dallas

$$\text{MTRD} = F_1(\text{OPCOSTD}) + F_3(\text{TCSH}) + F_4(\text{ADECOD}) + F_5(\text{LRS})$$

From the analysis, it can be seen that the truck rate is mainly dependent on operating cost and on total shipments of produce from this subregion.

Lower Rio Grande Valley: Truck Rate Analysis for Citrus

The model developed for truck rates for carrying citrus from the Lower Rio Grande Valley subregion to various destinations, and their estimated parameters, standard errors, t values, and the corresponding probability values for each equation and the entire system are presented in Table 2. In general, the citrus truck rates are dependent on the operating costs of the trucks and on volumes of shipments from competing subregions. The dependence on the volume of shipments from the competing subregion may be due, in part, to the relatively nonperishable nature of citrus fruit in comparison to other fruits and vegetables. For example, when there is a shortage of truck services, vegetable shippers must bid up the rate so that they can immediately attract a large enough number of truckers to haul the highly perishable fresh vegetables to the market destinations. Citrus shippers can postpone shipping for a few days and wait for a more favorable truck service market.

The system model specification for Lower Rio Grande Valley citrus truck rates is as follows:

New York

$$\text{MTRD} = A_0 + A_1(\text{OPCOSTD}) + A_2(\text{TWSH}) + A_3(\text{TCSH}) + A_4(\text{ADECOD}) + A_5(\text{LRS})$$

Chicago

$$\text{MTRD} = B_0 + B_1(\text{OPCOSTD}) + B_4(\text{ADECOD}) + B_5(\text{LRS})$$

Atlanta

$$\text{MTRD} = C_0 + C_1(\text{OPCOSTD}) + C_2(\text{TWSH}) + C_3(\text{TCSH}) + C_5(\text{LRS})$$

Denver

$$\text{MTRD} = D_0 + D_1(\text{OPCOSTD}) + D_2(\text{TWSH}) + D_3(\text{TCSH}) + D_5(\text{LRS})$$

Los Angeles

$$\text{MTRD} = E_0 + E_1(\text{OPCOSTD}) + E_2(\text{TWSH}) + E_3(\text{TCSH}) + E_5(\text{LRS})$$

Dallas

$$\text{MTRD} = F_0 + F_1(\text{OPCOSTD}) + F_5(\text{LRS})$$

From the analysis, it may be seen that the truck rates are mainly dependent on the operating cost and on volumes of produce shipments from this subregion. Truck rates are also generally dependent on the total volume of shipments from competing subregions (outside the Lower Rio Grande Valley) and on the volume of competing vegetable shipments within the subregion.

Lower Rio Grande Valley: Truck Rate Analysis for Dry Onions

Shipments of dry onions from the Lower Rio Grande Valley subregion to the six major destinations are only reported for 1982 and 1983. Because of the limited number of observations, the results of this analysis should be interpreted cautiously. The statistically significant variables and their estimated parameters, standard errors, t values, and corresponding probability values are presented in Table 3.

From the analysis it should be noted that the supply of truck services (truck rate) depends on the operating cost, adequacy code, volume of shipments from the Lower Rio Grande Valley subregion, and volume of shipments from competing subregions. The final system model specification is as follows:

New York

$$\text{MTRD} = A_0 + A_1(\text{OPCOSTD}) + A_4(\text{ADECOD}) + A_5(\text{LRS})$$

Chicago

$$\text{MTRD} = B_0 + B_1(\text{OPCOSTD}) - B_2(\text{TRSH}) - B_3(\text{TCSH}) + B_4(\text{ADECOD}) + B_5(\text{LRS})$$

Atlanta

$$\text{MTRD} = C_0 + C_1(\text{OPCOSTD}) + C_5(\text{LRS})$$

TABLE 2 ESTIMATED SUR COEFFICIENTS FOR TRUCK RATES: CITRUS FROM THE LOWER RIO GRANDE VALLEY

Destination	Variables	Parameter Estimate	Standard Error	t-Ratio	Prob≤|t| (alpha)
New York City	INTERCEPT(Ao)	581.00	80.24	7.24	0.0002
	OPCOSTD(A1)	3.109	1.173	2.65	0.0329
	TWSH(A2)	0.044	0.028	1.58	0.1581
	TCSH(A3)	0.073	0.032	2.29	0.0556
	ADECOD(A4)	N.S	N.S	N.S	N.S
	LRS(A5)	0.271	0.107	2.53	0.0390
Chicago	INTERCEPT(Bo)	390.055	65.06	5.995	0.0005
	OPCOSTD(B1)	3.109	1.173	2.65	0.0329
	TWSH(B2)	N.S	N.S	N.S	N.S
	TCSH(B3)	N.S	N.S	N.S	N.S
	ADECOD(B4)	9.866	4.162	2.37	0.0496
	LRS(B5)	0.271	0.107	2.53	0.0390
Atlanta	INTERCEPT(Co)	270.740	60.19	4.498	0.0028
	OPCOSTD(C1)	3.109	1.173	2.65	0.0329
	TWSH(C2)	0.040	0.014	2.790	0.0269
	TCSH(C3)	0.051	0.017	3.070	0.0181
	ADECOD(C4)	N.S	N.S	N.S	N.S
	LRS(C5)	0.271	0.107	2.53	0.0390
Denver	INTERCEPT(Do)	242.654	59.82	4.056	0.0048
	OPCOSTD(D1)	3.109	1.173	2.65	0.0329
	TWSH(D2)	0.040	0.014	1.703	0.1323
	TCSH(D3)	0.035	0.016	2.139	0.0698
	ADECOD(D4)	N.S	N.S	N.S	N.S
	LRS(D5)	0.271	0.107	2.53	0.0390
Los Angeles	INTERCEPT(Eo)	322.131	67.00	4.808	0.0019
	OPCOSTD(E1)	3.109	1.173	2.65	0.0329
	TWSH(E2)	N.S	N.S	N.S	N.S
	TCSH(E3)	0.043	0.022	1.917	0.0968
	ADECOD(E4)	N.S	N.S	N.S	N.S
	LRS(E5)	0.271	0.107	2.53	0.0390
Dallas	INTERCEPT(Fo)	123.025	53.13	2.315	0.0493
	OPCOSTD(F1)	3.109	1.173	2.65	0.0329
	TWSH(F2)	N.S	N.S	N.S	N.S
	TCSH(F3)	N.S	N.S	N.S	N.S
	ADECOD(F4)	N.A	N.A	N.A	N.A
	LRS(F5)	0.271	0.107	2.53	0.0390

System weighted M.S.E is 1.5300 with 53 degrees of freedom.
System weighted R-square is 0.3985
N.S - Not Significant
N.A - Not Applicable

TABLE 3 ESTIMATED SUR COEFFICIENTS FOR TRUCK RATES: DRY ONIONS FROM THE LOWER RIO GRANDE VALLEY

Destination	Variables	Parameter Estimate	Standard Error	t-Ratio	Prob≤|t| (alpha)
New York City	INTERCEPT(Ao)	499.185	24.37	20.49	0.0001
	OPCOSTD(A1)	3.866	0.328	11.79	0.0001
	TRSH(A2)	-0.018	0.011	-1.63	0.1420
	TCSH(A3)	-0.018	0.011	-1.63	0.1427
	ADECOD(A4)	6.371	3.163	3.91	0.0006
	LRS(A5)	0.488	0.143	3.42	0.0091
Chicago	INTERCEPT(Bo)	317.369	17.23	18.43	0.0001
	OPCOSTD(B1)	3.866	0.328	11.79	0.0001
	TRSH(B2)	-0.021	0.0055	-3.76	0.0055
	TCSH(B3)	-0.020	0.0054	-3.66	0.0064
	ADECOD(B4)	5.171	1.143	4.52	0.0019
	LRS(B5)	0.488	0.143	3.42	0.0091
Atalanta	INTERCEPT(Co)	208.267	17.19	12.11	0.0001
	OPCOSTD(C1)	3.866	0.328	11.79	0.0001
	TRSH(C2)	N.S	N.S	N.S	N.S
	TCSH(C3)	N.S	N.S	N.S	N.S
	ADECOD(C4)	N.S	N.S	N.S	N.S
	LRS(C5)	0.488	0.143	3.42	0.0091
Denver	INTERCEPT(Do)	196.761	15.50	12.69	0.0001
	OPCOSTD(D1)	3.866	0.328	11.79	0.0001
	TRSH(D2)	N.S	N.S	N.S	N.S
	TCSH(D3)	N.S	N.S	N.S	N.S
	ADECOD(D4)	N.S	N.S	N.S	N.S
	LRS(D5)	0.488	0.143	3.42	0.0091
Los Angeles	INTERCEPT(Eo)	229.562	54.05	4.25	0.0028
	OPCOSTD(E1)	3.866	0.328	11.79	0.0001
	TRSH(E2)	N.S	N.S	N.S	N.S
	TCSH(E3)	N.S	N.S	N.S	N.S
	ADECOD(E4)	N.S	N.S	N.S	N.S
	LRS(E5)	0.488	0.143	3.42	0.0091
Dallas	INTERCEPT(Fo)	69.424	14.199	4.89	0.0009
	OPCOSTD(F1)	3.866	0.328	11.79	0.0001
	TRSH(F2)	N.S	N.S	N.S	N.S
	TCSH(F3)	-0.0012	0.0009	-1.366	0.2050
	ADECOD(F4)	N.A	N.A	N.A	N.A
	LRS(F5)	0.488	0.143	3.42	0.0076

System Weighted M.S.E is 2.1348 with 59 degrees of freedom
System weighted R-squre is 0.8697
N.S - Not Significant
N.A - Not Applicable

Denver

$$MTRD = D_0 + D_1\,(OPCOSTD) + D_5\,(LRS)$$

Los Angeles

$$MTRD = E_0 + E_1\,(OPCOSTD) + E_5\,(LRS)$$

Dallas

$$MTRD = F_0 + F_1\,(OPCOSTD) + F_5\,(LRS)$$

Winter Garden:
Truck Rate Analysis for Produce

USDA reported truck service rates for vegetables shipments from the Winter Garden subregion to only four of the six destination cities: New York, Chicago, Atlanta, and Dallas. No rates were reported for shipments to Denver or Los Angeles. Because of the low number of observations, a separate analysis of truck rates for each type of produce is not feasible. A combined analysis that did not distinguish among types of produce was therefore carried out. The statistically significant explanatory variables and their estimated parameters, standard errors, *t* values, and corresponding probability values are presented in Table 4.

From the analysis, it can be observed that the truck rate is dependent on the operating costs of the trucks, volume of shipments from competing subregions, and total volume of shipments from the subregion itself. The final system model modification is as follows:

New York

$$MTRD = A_0 + A_1\,(OPCOSTD) + A_3\,(TCSH)$$

Chicago

$$MTRD = B_1\,(OPCOSTD) + B_2\,(TRSH) + B_3\,(TCSH)$$

Atlanta

$$MTRD = C_1\,(OPCOSTD) + C_2\,(TRSH) + C_3\,(TCSH)$$

TABLE 4 ESTIMATED SUR COEFFICIENTS FOR TRUCK RATES: FFV FROM WINTER GARDEN

Destination	Variables	Parameter Estimate	Standard Error	t-Ratio	Prob>|t| (alpha)
New York City	INTERCEPT(Ao)	428.172	21.69	19.75	0.0003
	OPCOSTD(A1)	2.075	0.251	8.27	0.0037
	TRSH(A2)	0.287	0.149	1.93	0.1486
	TCSH(A3)	0.063	0.019	3.33	0.0449
	LRS(A5)	0.054	0.284	0.19	0.8612
Chicago	OPCOSTD(B1)	2.075	0.251	8.27	0.0037
	TRSH(B2)	0.934	0.208	4.49	0.0109
	TCSH(B3)	0.145	0.025	5.69	0.0047
	LRS(B5)	0.054	0.284	0.19	0.8612
Atalanta	OPCOSTD(C1)	2.075	0.251	8.27	0.0037
	TRSH(C2)	0.521	0.176	2.96	0.0415
	TCSH(C3)	0.165	0.028	7.57	0.0016
	LRS(C5)	0.054	0.284	0.19	0.8612
Dallas	OPCOSTD(F1)	2.075	0.251	8.27	0.0037
	TRSH(F2)	0.175	0.074	2.37	0.0771
	TCSH(F3)	0.055	0.010	5.50	0.0053
	LRS(F5)	0.054	0.284	0.19	0.8612

System weighted M.S.E is 9.6497 with 21 degrees of freedom.
System weighted R-square is 0.8455.
Note the Non-significant Intercept terms have been omitted.

Dallas

$$MTRD = F_1(OPCOSTD) + F_2(TRSH) + F_3(TCSH)$$

Panhandle/Hereford Truck Rate Analysis

The Panhandle/Hereford subregion shipped vegetables in 1979 and 1980. Potatoes and dry onions were shipped during 1981–1984. In 1984, potato and dry onion shipments were reported from the Hereford region alone. Because Hereford is located within the Panhandle subregion, the Hereford data are assumed to be part of the data for the Panhandle/Hereford subregion. There were very few observations in each category, so all types of produce were combined together in modeling the truck rates.

The rates for Denver and for Los Angeles were not consistently reported (especially those for Los Angeles), so these destinations were eliminated from the analysis. The statistically significant explanatory variables and their estimated parameters, standard errors, t values, and corresponding probability values are presented in Table 5.

From the analysis, it can be observed that the truck rates are dependent on the operating costs of the trucks, the total volume of shipments from the subregion itself, and on the volume of shipments from competing subregions. The final system model modification is as follows:

New York

$$MTRD = A_1(OPCOSTD) + A_2(TRSH) + A_3(TCSH) - A_5(LRS)$$

Chicago

$$MTRD = B_1(OPCOSTD) + B_2(TRSH) + B_3(TCSH) - B_5(LRS)$$

Atlanta

$$MTRD = C_1(OPCOSTD) + C_2(TRSH) + C_3(TCSH) - C_5(LRS)$$

Dallas

$$MTRD = F_1(OPCOSTD) + F_2(TRSH) + F_3(TCSH) - F_5(LRS)$$

TABLE 5 ESTIMATED SUR COEFFICIENTS FOR TRUCK RATES: PRODUCE FROM HEREFORD/PANHANDLE

Destination	Variables	Parameter Estimate	Standard Error	t-Ratio	Prob≤|t| (alpha)
New York City	OPCOSTD(A1)	4.957	0.140	35.31	0.0001
	TRSH(A2)	0.339	0.044	7.80	0.0001
	TCSH(A3)	0.245	0.008	31.09	0.0001
	LRS(A5)	-0.145	0.043	-3.42	0.0051
Chicago	OPCOSTD(B1)	4.957	0.140	35.31	0.0001
	TRSH(B2)	0.162	0.021	7.78	0.0001
	TCSH(B3)	0.106	0.004	22.82	0.0001
	LRS(35)	-0.145	0.043	-3.42	0.0051
Atalanta	OPCOSTD(C1)	4.957	0.140	35.31	0.0001
	TRSH(C2)	0.160	0.026	6.15	0.0001
	TCSH(C3)	0.110	0.005	20.66	0.0001
	LRS(C5)	-0.145	0.043	-3.42	0.0051
Dallas	OPCOSTD(F1)	4.957	0.140	35.31	0.0001
	TRSH(F2)	N.S	N.S	N.S	N.S
	TCSH(F3)	-0.015	0.004	-3.95	0.0019
	LRS(F5)	-0.145	0.043	-3.42	0.0051

System weighted M.S.E is 29.2999 with 54 degrees of freedom.
System weighted (modified) R-square is 0.9596
N.S - Not Significant
Note the Non-significant Intercept terms have been omitted.

New Mexico: Truck Rate Analysis for Dry Onions and Lettuce

The major commodities shipped from the New Mexico subregion are dry onions and lettuce. Because the USDA rate data do not explicitly distinguish between these two crops, they are not analyzed separately. In general, produce shipments have been reported from New Mexico to all of the major destinations, but not for all years. For example, truck rates were not reported for service from New Mexico to Los Angeles for 1982 or 1983, and truck rates to Denver are not available for 1981 or 1982. Because there was a negligible number of observations for Los Angeles, that destination was omitted from the analysis. The statistically significant explanatory variables and their estimated parameters, standard errors, *t* values, and corresponding probability values are presented in Table 6.

In general, the truck rates to the various destinations depend mainly on the operating costs of the trucks and the volume of shipments from competing subregions. To increase the supply of trucks, the truck rates offered in New Mexico must be increased in comparison to the rates offered in the Texas subregions. As the volume of shipments from Texas increases (Texas accounts for ~95 percent of all produce shipments from the Southwest), the supply of trucks to New Mexico can generally be expected to decrease, if all other factors remain constant.

The final specification for the system of equations for various shipments to destinations from the New Mexico subregion is as follows:

New York

$$\text{MTRD} = A_0 + A_1(\text{OPCOSTD}) - A_3(\text{TCSH}) - A_5(\text{LRS})$$

Chicago

$$\text{MTRD} = B_0 + B_1(\text{OPCOSTD}) - B_3(\text{TCSH}) - B_5(\text{LRS})$$

Atlanta

$$\text{MTRD} = C_0 + C_1(\text{OPCOSTD}) - C_3(\text{TCSH}) - C_5(\text{LRS})$$

Denver

$$\text{MTRD} = D_1(\text{OPCOSTD}) - D_3(\text{TCSH}) - D_5(\text{LRS})$$

TABLE 6 ESTIMATED SUR COEFFICIENTS FOR TRUCK RATES: DRY ONIONS AND LETTUCE FROM NEW MEXICO

Destination	Variables	Parameter Estimate	Standard Error	t-Ratio	Prob>|t| (alpha)
New York City	INTERCEPT(Ao)	606.692	72.67	8.34	0.0011
	OPCOSTD(A1)	13.243	0.829	15.98	0.0001
	TCSH(A3)	-0.271	0.048	-5.55	0.0052
	LRS(A5)	-1.632	0.091	-17.93	0.0001
Chicago	INTERCEPT(Bo)	339.418	52.63	6.45	0.0030
	OPCOSTD(B1)	13.243	0.829	15.98	0.0001
	TCSH(B3)	-0.249	0.031	-8.07	0.0013
	LRS(B5)	-1.632	0.091	-17.93	0.0001
Atalanta	INTERCEPT(Co)	288.229	43.21	6.67	0.0026
	OPCOSTD(C1)	13.243	0.829	15.98	0.0001
	TCSH(C3)	-0.228	0.021	-10.87	0.0004
	LRS(C5)	-1.632	0.091	-17.93	0.0001
Denver	OPCOSTD(D1)	13.243	0.829	15.98	0.0001
	TCSH(D3)	-0.132	0.022	-5.93	0.0041
	LRS(D5)	-1.632	0.091	-17.93	0.0001
Dallas	OPCOSTD(F1)	13.243	0.829	15.98	0.0001
	TCSH(F3)	-0.169	0.027	-6.15	0.0035
	LRS(F5)	-1.632	0.091	-17.93	0.0001

System weighted MSE is 11.8426 with 28 degrees of freedom.
System weighted R-square is 0.8328.

Dallas

$$MTRD = F_1(OPCOSTD) - F_3(TCSH) - F_5(LRS)$$

Summary of Model Interpretation

The results of this research demonstrate that the determinants of truck supply are not uniform across all the destination cities. Furthermore, truck rates within a single region tend to be more sensitive to trucking volumes in competing subregions when the commodity that is being shipped is not highly perishable. The strong relationship between price and quantity of truck services supplied (as measured by truckloads of produce shipped) indicates that in a competitive market, truckers seem to allocate their equipment efficiently in response to rate signals. Unregulated truck service supply appears to respond to fluctuations, thus confirming that the truck service market follows the traditional micro-economic model of a market. This result implies that in the existing unregulated truck service market, buyers can purchase services efficiently through competitive price signals.

CONCLUSIONS

The determination of the responsiveness of the supply of produce transportation providers to price signals provides a better understanding of the transportation system at the regional and, possibly, at the national level. The insight into the transportation service market supplied by this research should provide transportation policy makers with knowledge of the relative health of competitive transportation markets. Similar research on a national level is also likely to reinforce these findings on the allocation of truck services in the Southwest region.

Other policy implications are related to USDA's continuous attempts to improve agricultural transportation systems. Better knowledge of the mechanics of the market will aid USDA and state departments of agriculture in advising produce shippers of the national transportation picture.

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Freight Flow and Attitudinal Survey for Arizona

A. Essam Radwan, Mushtaqur Rahman, and Sylvester A. Kalevela

A mail survey of randomly selected carriers was used to collect data about freight flows on Arizona's primary and secondary highways and about carriers' perceptions of certain freight related problems. The data obtained included commodities shipped, tonnage, origins and destinations, Arizona routes used in the travel, and attitudinal information on several transportation issues and concerns. The route-specific freight flow information was needed to run a simulation model that had been developed for the Arizona Department of Transportation. The sample was drawn as a three-stage stratified random sample of 2,100 carriers from a prepared list of population of 12,900 carriers (16.28 percent sample size). The rationale for using the mail survey technique, the design of survey forms, the procedures used in follow-up, and the various strategies adopted to achieve better response rate are described. A summary of some of the data analysis results is given. The survey results indicate that Interstate highways are the routes most used for freight movements in Arizona. Furthermore, the attitudinal questions revealed that carriers consider insurance costs to be their major future concern and pavement condition to be the most significant problem that may affect the trucking industry.

The Arizona Department of Transportation (ADOT) recently realized that there was a need for a planning model to evaluate the performance of Arizona's highway system for freight movement. In response, the Arizona Freight Network Analysis (AFNA) research project was undertaken in February 1986 (*1*). Data collection for the project was accomplished with a self-administered survey that was designed to gather data on highway freight movements and carrier attitudes toward certain issues related to freight transportation. The goals, methodology, design, sampling plan, and results of the survey are presented in this paper.

The data collection vehicle selected for the AFNA project was a mail survey with multiple follow-ups. The focal points of this data collection effort were freight movements on and carrier attitudes about the Arizona highway network. The data on highway freight movements were necessary to drive a network-type simulation planning model that had been developed as part of the AFNA project to simulate freight traffic flow on Arizona highways. Attitudinal data from the carriers were required as part of an effort to understand the respondents' perceptions of various freight issues and concerns. The survey instrument was therefore designed with two parts: a freight movement survey (FMS) and a carrier attitudes survey (CAS).

Before the decision was made to conduct the self-administered survey, secondary data sources were investigated for possible use in data compilation. The commodity flow data provided in the current census reports of the Commodity Transportation Survey were found to be too aggregated for application in a state-level freight analysis, especially for a simulation model that requires freight movement information in terms of intercity trips and by commodity groups. In addition, the census reports provided information only on manufacturing and related industries.

In previous efforts to develop a data base for nationwide commodity flows on the basis of 173 Bureau of Economic Analysis (BEA) economic areas, it was noted that there were no independent data sources that could provide a measure of flows of individual commodities carried by trucks between the BEA economic areas (*2*, p. 233). This lack of disaggregated commodity flow data for the highway mode poses a difficulty in freight modeling. Reebie and Associates of Greenwich, Connecticut, have developed a national freight data base called Transearch (*3*) that contains intercity freight traffic flows. The existing summary reports for Transearch did not meet the requirements of the AFNA model, however. The possibility of getting special tabulations from the Transearch data base was examined and found to be too expensive because the process would qnvolve extensive programming tasks for the vendor.

Some of the computer-readable data bases, like Wharton Econometric and DRI, were also examined. These data bases do not provide the necessary data for flow modeling either: they mainly contain international financial and credit statistics and macroeconomic data.

Given this background, the AFNA researchers believed that it was necessary to employ survey research methods for data collection. The main reason for selecting mail survey as the collection method was its cost-effectiveness and convenience when compared to an on-the-road intercept survey at ports of entry. Moreover, the intercept survey method is not suitable for capturing "internal-internal" trips, which are intercity movements by carriers within the Arizona state boundary.

The mailed surveys were addressed only to freight carriers, mainly because of the type of freight movement data that were required for the simulation model. The AFNA

Center for Advanced Research in Transportation, Arizona State University, Tempe, Ariz. 85287.

model needed route-specific origin-destination (O-D) data on commodity flows. Shippers and receivers are not likely to have route specific O-D data on commodity flows. Because carriers are directly involved in hauling goods on the roads, they generally maintain such information. Also, because the goal of the AFNA project was to evaluate the performance of the Arizona highway system, the carriers' responses to the attitudinal questions were considered more important than those of shippers or receivers.

The issue of nonresponse bias—that is, the bias associated with nonrespondents who voluntarily do not participate in the survey—was not examined empirically in this research because all of the traditional methods for dealing with nonresponse bias have been demonstrated to have significant disadvantages (*4*, p. 37). Instead, multiple follow-up procedures were undertaken to achieve a better response rate and thereby reduce the nonresponse bias.

SAMPLING PROCEDURE

The researchers selected 2,100 carriers to receive survey questionnaires. A random stratified sampling technique was applied to the total population of 12,900 carriers, ranked by the total annual miles driven in Arizona. Thus a relatively large sample size (16.28 percent) was drawn for the survey. The population list was prepared with 1985 tax accounts data from the ADOT Motor Vehicle Division (MVD). The stratified sampling plan that was used in the survey was as follows:

- Top 1,200 carriers (1,200 sampled, or 100 percent),
- Carriers from 1,201 to 1,900 (350 sampled, or 50 percent), and
- Carriers from 1,901 to 12,900 (550 sampled, or 5 percent).

SURVEY METHODS

Mail-Back Questionnaire

After the attributes of the mail survey were considered in relation to the precise survey objectives, scattered carrier population to be surveyed, and budgetary constraints, a mail-back questionnaire technique with multiple follow-up procedures was chosen to collect data on freight movements and carrier attitudes. A comprehensive literature review of mail surveys and response rates can be found elsewhere (*5*).

In the survey that was used for the AFNA project, sampling was performed from a prepared population list. This may have introduced some bias in the representativeness of the sample. That is, each unit of the population may not have had an equal opportunity of being included in the sample. Efforts were made to overcome this problem by

- making the list relevant (for example, the original MVD list of 13,049 carriers was brought down to 12,900 by sorting for passenger carriers and leasing firms),
- obtaining the latest information available (for example, the list of carriers that was gathered from MVD was current as of January 1985), and
- minimizing the duplication of carriers in the list (for example, one out-of-state carrier may have local offices in Phoenix, and both offices may be listed with MVD for accounting purposes; only one office was included in the final list).

One problem in conducting mail surveys is that of selection of appropriate respondents. This problem arose in the current study because the sampling units were business firms or other organizations for which there were no available contact names. As a result, the first wave of questionnaires was directed to the attention of "Transportation Director," and the follow-up mailings were sent to the president of the firm (by title). This procedure was chosen under the assumption that the surveys would be passed on to the appropriate person within the target company.

Because the sampling list contained freight carriers that were located all over the United States, the mail questionnaire was probably the best method for reaching all the respondents. Another advantage was that no additional cost was incurred in contacting respondents who had moved to a new location and left a forwarding address.

Survey Strategies

The first mailing package contained six items. The first page was a cover letter typed on Arizona State University letterhead, signed by two university faculty members. Because no contact names were available for the target firms, the letter began impersonally, with "Dear Sir." The letter was carefully worded to explain to the respondents the goals and benefits of the survey and to assure them of the confidentiality of the data that were requested. The carriers were asked to provide commodity shipment information for a "recent representative week" of 7 days. The second page was the instruction sheet, which contained some hypothetical examples to assist respondents in filling out the forms. The third page was the freight movement survey form, and the fourth page was a duplicate copy of the same. The fifth page was the attitudinal survey.

The 7-day period for the representative sample should not be misconstrued as the sample size. It actually characterizes the sample period. This characterization was considered important in determining truck traffic variation within a week. Also, it was determined that a request for data for periods longer than a week would reduce the survey return rate.

Follow-Up Procedures

Second Wave of Questionnaires

The second wave of questionnaires was sent out to the group that did not respond to the first wave. Minor revisions were made to the original FMS form to clarify a few issues that appeared to cause confusion, judging from the first returns. For example, the explanation "(total weight of vehicle + commodity)" was provided after the "Gross Weight" heading. The only major change made to the CAS form was the addition of more items to the list of "current and future concerns and problems."

The second mailing was conducted with a change in survey sponsorship. Arizona Motor Transport Association (AMTA) letterhead was used for the cover letter, which was signed by the Executive Vice President. This change was meant to increase the interest of the respondents and emphasize the importance of the surveys.

Third Wave of Questionnaires

The forms used in the third wave were identical to the second wave forms. The survey sponsorship was changed to make the survey instrument more authoritative. In this wave, the cover letter was sent by the Transportation Planning Division of the Arizona Department of Transportation. Although the carrier code was not included in the forms, as it had been in the first two waves, the cover letter requested the respondents to write the code on the returned form. It was decided that the code was not critical at this point because no additional follow-up effort was planned.

Telephone Calls

After mailing out the third wave of questionnaires, telephone calls were made to the Arizona-based carriers that belonged to the "top 200" group of the sampling plan. The decision to make this follow-up effort was mainly based on availability of financial resources and the importance of the work to Arizona highway network usage. The phone calling was time consuming and difficult to pursue because of the lack of contact names. People in the higher echelon of company management, like the vice president or president, were not available most of the time, and lower-level executives were hesitant to take any responsibility. Even so, many successful contacts were made with these larger carriers. These contacts were helpful in encouraging the carrier company representatives to respond to the survey, even though response involved a large effort for them in terms of record and data base sorting and summarizing.

DESIGN OF SURVEY FORMS

Freight Movement Survey (FMS)

The goal in designing this form was to make it precise and simple, yet capable of capturing the important data needed for the study. The freight movement survey form requested information on the following:

- carrier code,
- contact person,
- date,
- carrier type,
- shipping date,
- commodity shipped,
- gross weight,
- shipment's origin city and state,
- shipment's destination city and state,
- Arizona routes taken in travel, and
- comments.

Meetings with Carriers

As part of the design process for the survey forms, several visits were made to meet with representatives of various types of carriers. The goals of the meetings were to make contacts with the operating personnel and get their suggestions and reactions to a proposed form and data collection procedures, reaffirm the researchers' understanding of operating procedures of carriers in the Phoenix area, and learn more about the availability of automated data within the industry. The on-site visits covered six different categories of carriers:

- common carriers of general freight that serve both interstate and intrastate traffic,
- common carriers of general freight that serve primarily interstate traffic,
- private carriers that serve both interstate and intrastate,
- common carriers of specific commodities and general freight that serve primarily interstate,
- private carriers of special commodities that serve Arizona only, and
- private carriers of food products that serve Arizona primarily.

The following facts emerged from the visits:

- Specific statistical information would generally be available from existing records or computerized data bases, with some adjustments or additions needed from other records in some instances.
- Most carriers would be hesitant to supply information unless they were assured of its confidentiality.
- Specific shipment or trip weights are usually estimated or averaged. Individual truckloads are not weighed because the weight-distance tax forms allow reporting by weight classification.
- Weight data are not usually recorded into data bases but could be determined from invoices or loading reports.
- Route-specific data are available because most carriers schedule a given number of trips from an origin city to various destinations in a given time period on a given route. For those cases in which specific schedules were not available, O-D data could be derived from shipping documents.

As a result of the visits, the researchers came to the following conclusions:

• To maintain confidentiality, the survey form should not contain names and addresses of carriers; a code would be used instead.

• The form should not ask for mileage between origins and destinations because supplying such data would only complicate the reporting process and would merely reflect map miles, which are readily available by use of a state highway map.

• The tonnage data available would not be strictly accurate but would be adequate for modeling.

• Route-specific data would be available from for-hire carriers but could only be approximated for truckload and special commodity carriers. Also, route-specific data over city streets would not be available and were outside the scope of this research.

Carrier Attitudes Survey (CAS)

The CAS questionnaire contained both questions in multiple-choice format with ranking and questions in "yes/no" answer format. The five questions used in the CAS section covered the following topics:

• issues that adversely affect the operation and safety of the carrier (e.g., geometric design, pavement condition, etc.),

• seasonal variations in carrier operations,

• current and future concerns in the transportation industry (e.g., insurance, labor issues, public safety, etc.),

• primary carrier markets (e.g., farms, manufacturing, wholesale and retail trade, etc.), and

• interfaces with other carriers modes (rail, air, pipelines, or water).

RATE OF SURVEY RETURNS

Figure 1 shows weekly return rates for the three waves. It can be seen that the weekly rate of return increases during the first three weeks, then decreases, to become almost nonexistent by the end of the seventh week. The timing for mailing the second and the third waves was determined on the basis of having reached a negligible rate of return (the eighth week, as can be seen in the figure).

Table 1 presents a summary of response rates by wave for the two surveys. The table also shows the number of "genuine" nonresponses found in the survey. The genuine

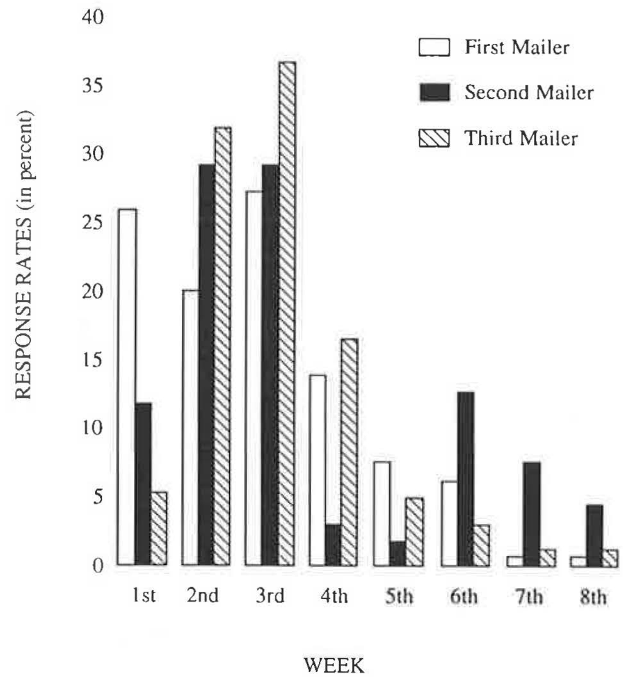

FIGURE 1 Weekly response rates of the three mailing waves.

nonresponses include carriers that had gone out of business or packages that were sent back due to change of address or incomplete address. This type of nonresponse is called "genuine" because "it can be assumed generally to be a random or quasi-random occurrence that adds no significant bias to the survey data" (*4,* p. 35). As a result, these nonresponses were subtracted from the sample size for calculation of response rates. The other kind of nonresponses, called "nongenuine," usually introduces bias in the survey data (*6*). The nongenuine nonresponses include carriers whose representatives declined to participate in the survey (with or without specifying a reason), carriers whose surveys were returned blank or incomplete, and carriers whose representatives did not respond at all.

It can be noted from the table that a response rate of 25 percent was achieved in three waves for the freight movement survey and a rate of 28 percent for the carrier attitudes survey. If the two surveys are treated as a single survey entity, the response rate is computed to be 29 percent. Table 1 also presents the effect of follow-up efforts and survey sponsorship on the overall response rates. It is evident from the results that the follow-up efforts were effective. The ADOT sponsorship may be one reason for the relatively higher response rate in the third wave.

TABLE 1 RESPONSE RATES BY MAILING WAVE

	First Wave		Second Wave		Third Wave		Three Waves Combined	
	Number of Responses	Percent of Sample	Number of Responses	Percent of Sample	Number of Responses	Percent of Sample	Number of Responses	Percent of Sample
Freight Movement Survey	147	7.5	109	5.5	229	11.6	485	24.6
Carrier Attitudes Survey	145	7.3	147	7.5	256	13.0	548	27.8

NOTE: Respondents (R): freight carriers; population: 12,900 carriers; sample: $S = 2{,}100$ carriers; sampling technique: stratified random sampling; genuine nonresponse: $G = 127$; percentage of response: $P = 100\,[R/(S - G)]$.

ANALYSIS OF SURVEY DATA

Freight Movements Survey (FMS) Data

In this section, the results of statistical analysis on several types of data are presented.

Trip Calendar

Most of the first data sample was recorded in September and October. The second data sample was from November and December, and the third data sample was from January and February. There is likely to be bias in the results because of the time of year that the data were collected. This was anticipated in the study, and the time period was selected because it was considered typical. Future data may need to be examined closely for any peak or off-peak behavior during the year.

The data indicated that freight movement occurs on all 7 days of the week. Most trips occurred during the weekdays, and they were distributed roughly uniformly over the business week. Saturdays had about 50 percent and Sundays 25 percent of the number of trips recorded during a weekday. This finding suggested the inclusion of weekend activity in the simulation model.

Carrier Type

Roughly 20 percent of the trips recorded were of unspecified carrier type, 26 percent were common carrier, 24 percent were for-hire carrier, 21 percent were private carrier, and 8 percent were contract carrier.

Commodity Type

The data indicate that the manufacturing and agricultural commodity groups were most prevalent and that mining, services, and unclassifiable were least. It appears that extrapolation based on these data may be statistically supportable. The unclassifiable code is not recorded often, and the distribution appears to be filled out. Additional data would help to determine the appropriateness of scaling and forecasting these data.

Gross Weight

It was observed that roughly 50 percent of the trucks weighed between 75,000 and 85,000 pounds. A few higher values (for multiple-axled vehicles) were also recorded. The extremely low values that were recorded represented net weight instead of gross weight and have been modified by adding a typical vehicle tare weight.

Origins and Destinations

Trips that originated outside Arizona were coded with ports of entry into Arizona as their origin cities, and trips terminating outside Arizona were coded with exit ports as their destination cities. This coding scheme was adopted to place boundaries on the Arizona highway network that was to be used in the freight traffic simulation. The five cities used as ports of entry into Arizona (Lupton, San Simon, Yuma, Ehrenberg, and Topock) make up the majority of the trip origins and destinations. This further emphasizes the use of the state highways for through trips. Most of the other trips recorded in the survey are from major cities in Arizona, such as Phoenix, Tucson, and Flagstaff. Many small cities have no originating or terminating trips at all. From statistical analysis, it is evident that extrapolation cannot be performed with these data in their present form. Data for major cities may be satisfactory, but data for smaller cities and highway junctions do not have sample sizes large enough to allow proper statistical extrapolations.

Route Use

It was observed that Interstate highways in Arizona are the most heavily used for freight movements. Many of the other routes had no trips recorded in the survey data. The sample size of the route use data is too small, and additional data are needed for proper use. This problem could be addressed by using a smaller highway network that consists of the Interstate highways.

The collected survey data set is characterized by directional flow of truck traffic. Attempts to correlate this data set with highway traffic counts failed because the available average daily traffic counts are of mixed vehicular composition and do not provide directional flow (*7*).

Highway Carrier Attitudes Survey (CAS) Data

Trucking Operation and Safety Issues

Table 2 summarizes the responses obtained for the questions on trucking operation and safety issues, ranked in order of importance according to the responses. It can be observed that almost 24 percent of respondents listed inadequate highway geometric design as the most important problem, and 30 percent considered this to be a problem that may affect their trucking operations. The problem of bad pavement condition appeared to be most critical, given that 53 percent of the respondents listed this problem as most important, and 5 percent mentioned it as the second most important. Only 6 percent of the respondents considered inappropriate location of intermodal terminals to be one of their concerns. This last result was expected because few of these carriers are involved with intermodal freight

TABLE 2 TRUCKING OPERATION AND SAFETY ISSUES

Issues	Responses (%)	Breakdown of Responses in Order of Importance (%)				
		1[a]	2	3	4	5
Inadequate highway geometric design standards	30	24	4	2	–	–
Bad pavement condition	58	53	5	–	–	–
Inappropriate location of intermodal terminals	6	4	1	1	–	–
Stop areas needed for fatigued drivers	18	11	4	2	1	–
Inadequate warning sign system	13	8	3	1	1	–
Other[b]	13	12	1	–	–	–

[a] Most important.
[b] Examples of "others": not specified; conditions are fine; bridge decks misaligned and abutting too rough pavement; more freeways needed; lack of truck stops with service facilities between San Simon, Wilcox, and Tucson; use of off ramps and signal lights instead of cloverleafs; left turn signals needed.

operation in addition to their common or for-hire operation.

Only 17 percent of all the respondents indicated that their operations interface with other modes of transportation (air, rail, and pipeline). The remainder operate independently. In addition, 68 percent of all respondents stated that their operations had no seasonal variations, and 31 percent mentioned variations.

Current and Future Concerns in the Transportation Industry

Table 3 presents a summary of the responses about current and future freight concerns. The first column lists the issues that respondents were to rate according to importance and whether the issues were of concern to the transportation industry. The second column presents the rate of affirmative responses. Respondents were asked to attach an index of importance to each affirmative response. An index of 1 indicates issues that were rated as the most or among the most important concerns, whereas an index of 5 index indicates issues of least importance. Among the respondents, 86 percent stated that insurance was among their current and future concerns. Of these 86 percent, 74 percent noted that insurance was among their most serious concerns, 9 percent rated it as second most important, 2 percent believed that insurance was a third-level concern, and only 1 percent rated it as a fourth-level concern. The rate of affirmative responses for the rest of the issues in the list is given in the second column of the table.

TABLE 3 CURRENT AND FUTURE CONCERNS IN FREIGHT TRANSPORTATION

Current and Future Concerns	Responses (%)	Breakdown of Responses in Order of Importance (%)				
		1[a]	2	3	4	5
Insurance	86	74	9	2	1	–
Labor issues	7	4	1	1	1	–
Public safety	34	24	6	3	1	–
Tax collection	40	23	11	4	2	–
Economic conditions	45	30	5	7	3	–
Government control	35	26	5	3	1	–
Bad vehicle conditions	22	16	2	2	2	–
Bad drivers	37	27	4	4	2	–

[a] Most important.

Commodity Hauled

Table 4 summarizes the results obtained for this query. On the basis of the total number of returned survey forms, the column of responses (second column) gives the proportion of carriers who haul a given commodity. For instance, farm produce is transported by some 20 percent of all carriers. The order of importance in column three indicates whether a given commodity is hauled as a primary, secondary, or tertiary item. For example, of the 20 percent of the carriers who haul farm produce, 18 percent stated that farm produce is their primary cargo.

CONCLUSIONS

The combined response rate of the first, second, and third waves amounted to 25 percent for the freight movements survey and 28 percent for the carrier attitudes survey. From

TABLE 4 COMMODITIES HAULED BY CARRIERS

Commodity Hauled	Responses (%)	Breakdown of Responses in Order of Importance (%)				
		1[a]	2	3	4	5
Farms	20	18	1	1	–	–
Mining	6	5	1	–	–	–
Agricultural services, forestry, and fisheries	13	12	1	–	–	–
Construction	18	17	1	–	–	–
Manufacturing	28	25	3	–	–	–
Transportation, communications, and utilities	4	4	–	–	–	–
Wholesale and retail trade	37	33	3	1	–	–
Finance, insurance, and real estate	1	1	1	–	–	–
Services	5	4	1	–	–	–
Government	4	3	1	–	–	–
Other[b]	20	20				

[a] Most important
[b] Examples of "other": food products, livestock, U.S. Postal Service, garbage, freight of all kinds, chemicals and petroleum products in bulk, hazardous waste, caskets, liquid asphalt and asphalt products, scrap metal, records/tapes/videotapes, paper, not specified.

a statistical analysis of the freight movements survey data, the following conclusions were drawn.

- Although weekend freight trips are less frequent than weekday, the weekend activity needs to be included in simulations of freight traffic on Arizona highways.
- About 50 percent of the trucks traveling on Arizona highways weighed between 75,000 and 85,000 pounds.
- Haulage of agricultural, construction, and manufacturing commodities dominates freight transportation in Arizona.
- Five ports of entry and several major cities in Arizona were almost the only locations given as trip origins and destinations.
- Freight movements in Arizona occur primarily on Interstate highways.

The following conclusions were drawn from the carrier attitudes survey.

- Bad pavement condition received the highest concern rating from the carriers, followed by inadequate highway geometric design standards.
- Insurance costs, economic conditions, tax collection, bad drivers, government control, and public safety are the current and future concerns of the freight carrier industry.
- Freight transported on Arizona highways consists mainly of commodities related to wholesale and retail trade.
- Most of the carriers surveyed do not have seasonal variations in their trucking operations.

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Abridgment

A Decision Support System for Freight Transport in Arizona

A. ESSAM RADWAN, JEFFREY COCHRAN, AND MARTIN FARRIS

In this paper, the tasks and major findings of a freight transportation study conducted in Arizona are briefly described. The main goal of the study was to assess the freight movement performance of Arizona's highway network. A complete freight carrier modal directory, containing information on carriers that operate in the state, was developed. Freight movement surveys and attitudinal surveys were mailed to a sample of those carriers, and an information base about freight shipments on Arizona's primary and secondary highways was developed. A description of a decision support system, its structure, and components is provided, and discussions are presented of how this interactive computer-based system can be used by managers to apply both data and models effectively in decision making.

The study described in this paper was funded by and developed at the request of the Arizona Department of Transportation (ADOT). ADOT is concerned about the performance of the state highways and their ability to meet existing and future freight demands. Freight transportation is a relatively new focus, and currently ADOT does not have enough of the analytical tools and relevant freight data needed for comprehensive planning.

STUDY OBJECTIVES

The main goal of the study was to assess the freight movement performance of Arizona's highway network. The objectives were to develop tools to allow highway planners and decision makers to assess the effectiveness, efficiency, and economy of alternative highway policy decisions in serving the needs of Arizona citizens. The first objective of the study was to develop a freight carrier modal directory that would contain information on carriers that operate in the state, including company name, address, telephone number, carrier type (private, common, for hire), rank in terms of total mileage driven in the state, and account number with the ADOT Motor Vehicle Division (MVD). The second objective was to collect information on freight shipments on Arizona's primary and secondary highways. The third objective was to develop the Arizona Freight Network Analysis Decision Support System (AFNA DSS). This system was to have three major components:

- A preprocessor that converts the freight shipment data into a form that can be used by a simulation model,
- A model that simulates the movements of trucks on highway links between cities and collects statistics on system performance, and
- A planning module that allows "what if" analysis of the effects of freight movement on traffic congestion on highways, highway safety, and pavement maintenance.

The work for this study was divided into four modules (Figure 1):

- Modal freight directory,
- Freight movement information forecasting,
- Freight network analysis, and
- Management and strategic planning.

FREIGHT CARRIER MODAL DIRECTORY

Mail surveys addressed to freight carriers were selected as the most appropriate vehicle for data collection under the given budget constraints of the study. Two types of surveys were identified as necessary: freight flow surveys and attitudinal surveys. The surveys were designed by using statistical procedures to ensure reliable results (see the companion paper by Radwan et al. in this Record). A modal directory of freight carriers that serve the state of Arizona was found to be necessary to attain a successful sampling procedure.

A computerized data base management system (DBMS) was developed on a microcomputer to include the top 2,000 carriers (in terms of mileage covered on Arizona highways) of the 13,049 motor carriers registered in the state. The system was programmed with dBase III and contained information on the carriers' names, addresses, telephone numbers, MVD account numbers, type, and miles driven in Arizona. A statistical analysis of these 2,000 carriers made with the dBase III sorting utilities revealed that some 27.6 percent of these carriers are based in Arizona and that the top 200 carriers represent about 56 percent of the 983,237,200 mi driven by all 2,000 carriers.

A. E. Radwan, Center for Advanced Research in Transportation, College of Engineering, Arizona State University, Tempe, Ariz. 85287. J. Cochran, Industrial Engineering and Management Systems Department, College of Engineering, Arizona State University, Tempe, Ariz. 85287. M. Ferris, Department of Purchasing, Transportation, and Operations, College of Business, Arizona State University, Tempe, Ariz. 85287.

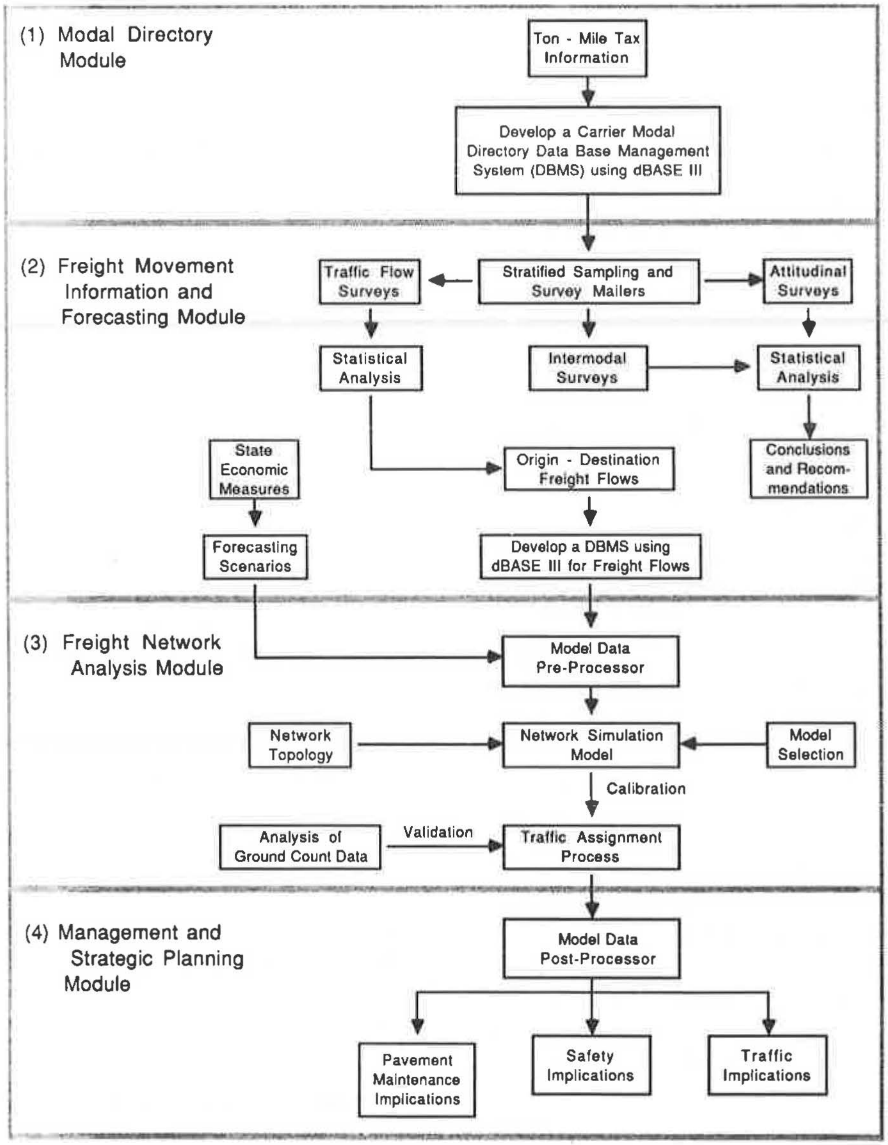


FIGURE 1 Research modules and tasks.

FREIGHT FLOW DATA

A stratified sampling technique was applied to the total population of carriers, and a sample size of 2,100 carriers was obtained. Three mailings of surveys were sent to these 2,100 carriers over a 6-month period. Follow-up telephone calls were made to the nonrespondents among the top 200 carriers.

Each mailing contained forms to be filled out and a self-addressed stamped envelope. The freight flow information requested on these forms was

- Name of contact person,
- Date,
- Carrier type (common, contract, or private),
- Shipping date,
- Commodity shipped,
- Gross weight,
- Shipment's origin (city, state),
- Shipment's destination (city, state),
- Routing through Arizona (highways used), and
- Comments.

Freight carriers that operate from intermodal facilities in Arizona (air terminals, pipeline outlets, and railroad facilities) also received mail surveys. In all, 254 carriers were surveyed, and the results are documented elsewhere (*1*) (see also companion paper by Radwan et al.).

AFNA DECISION SUPPORT SYSTEM

Today, managers are constantly challenged to make difficult decisions so that their companies may survive and succeed. Consequently, increasing numbers of managers are turning to decision support systems (DSSs) for aid in making these decisions. A DSS is an interactive computer-based system that allows managers to effectively use both data and models in decision making.

As mentioned before, the third objective of this project was to design and develop a DSS for freight movements, to be used by ADOT. The system incorporates the AFNA data base and a computer simulation model as its basis. The simulation model has been developed to simulate the movement of each truck on the highway and to collect statistics on traffic performance. A prime consideration in the development of the AFNA DSS was to create a program with all the best DSS characteristics: user friendliness, interactivity, and the capabilities of supplying various solutions from a model library and accessing relevant information from the data base. The AFNA DSS was designed to be used in freight movement planning to provide decision makers with information that is derived from the simulation model of the state highway network system. The data base and models that it contains will be used by the ADOT Transportation Planning Division to determine the statewide impacts of their decisions.

AFNA SYSTEM STRUCTURE

The general structure of the AFNA system and the flow of data files are depicted in Figure 2. There are five modules in the AFNA software environment: user-system interface, dBase III data base, model data preprocessor, SLAM II Arizona highway simulation model, and transportation planning.

The user-system interface module provides the control mechanism that allows the user to access the AFNA system. The menu-driven and question-answer on-screen dialogue provides the interface between user and system. In addition, the data base component (dBase III and data preprocessor) and the model base component (simulation and planning module) are linked by this same interface module, establishing the unification of the AFNA DSS architecture.

The dBase III data base module allows users the capability of retrieving data on freight carriers on the Arizona state highway network and flow, as desired. This module's primary function is the organization and preprocessing of the survey data on a trip-by-trip basis. The dBase III data base module has also been "taught" a portion of the route-link relations between key origins and destinations on the AFNA network so that a minimum of input work is required to handle the survey results as they arrive. The topological knowledge and raw survey data are combined to produce an output file, DB.OUT, that contains a summary of the date, carrier, weight, commodity, origin, destinations, and link information for each trip that was listed on a survey form.

The preprocessor module for the model data is designed to combine trips from common origins into an appropriate probability distribution on the basis of date, carrier code, weight, commodity code, and truck branching conditions. The resulting file, STD.DAT, is the driver for the AFNA simulation model. The STD file allows easy modifications to be made for conducting "what if" scenarios for many kinds of planning activities.

The Arizona highway simulation model processes the data file (STD.DAT) by creating entities (trucks) with appropriate attributes (commodity, weight) and controlling the flow of these entities through the AFNA network. The simulation model is used to conduct the experiments required for analyzing a planning scenario and provides a summary report for each run. By making simple changes to the input files (STD.DAT and NET.DAT), a planner can easily delete or upgrade links in the network being studied.

The transportation planning module uses the simulation output (SLAM.OUT) and combines it with other information, such as existing pavement conditions, base year cumulative loading, and accident statistics, to produce planning reports. These reports include such considerations as pavement maintenance and safety implications.

MANAGEMENT AND STRATEGIC PLANNING

Planning Functions Overview

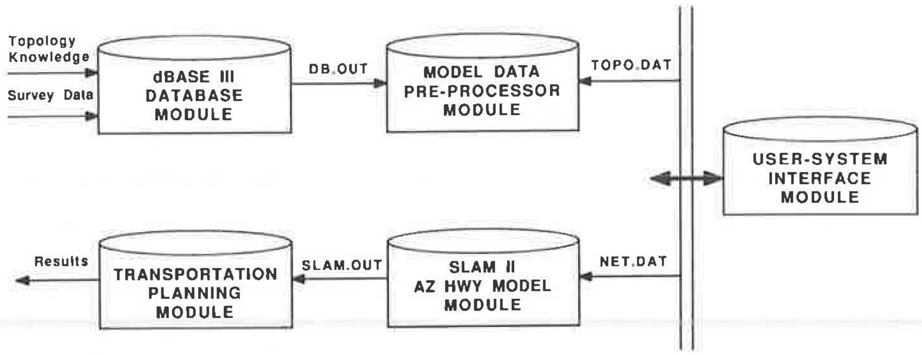
The AFNA simulation model is driven by survey data. This makes the static data become dynamic representations of truck flow on the Arizona freight highway network. This characteristic is a useful tool in planning tasks, especially the "what if" analyses.

If the user wants to run a simulation on a network of a different size than the provided STD file, all the changes need only be made in the data files because the simulation program has been designed as a generic model that does not contain any topology information. Even so, addition or subtraction of links may be performed on an individual basis, although the process may be tedious and time-consuming.

The user can apply various loading factors to the model to perform some forecasting functions. The total truck numbers in the current model are considered to be loaded with a global loading factor of 1.0. If the user predicts that in 1995 the total number of trucks will increase by 60 percent and assumes that the conditional branching probabilities remain the same, the user can apply a global loading factor of 1.60 to the current model, run the simulation, and study the results.

Safety Submodule

The function of the safety submodule is to compute annual estimates of the number and cost of traffic accident systemwide. The input data for this submodule include such variables as accident rates (accidents per million vehicle miles) for various types of highways and percentages of fatal accidents, injury accidents, and property damage only accidents. Current default values for these variables were obtained from the *Arizona Traffic Accident Summary* (*25*). The costs of accidents were estimated separately for each of the three categories (fatal, injury, property damage only) (*6*, pp. 120–121). The output of the safety module includes



FILE	DESCRIPTION
DB.OUT	Trip-by-trip record from survey data including O-D & link
STD.DAT	Aggregated node-based travel data
TOPO.DAT	Network topology, link and node relationships
NET.DAT	Network link data
SLAM.OUT	Simulation results for transportation planning

FIGURE 2 AFNA system and file structure.

- Input echo and comments,
- Table containing estimates of total number of accidents by severity class for each link,
- Table containing estimates of total accident costs by severity class for each link,
- Table containing the maximum, average, and minimum accident costs during the plan period for each link, and
- Accident cost summary for the whole system, given as totals for the entire network.

Pavement Maintenance Submodule

The pavement maintenance submodule is used to provide cost information for selected maintenance options. The maintenance options that can be selected for analysis are pavement replacement, pavement rehabilitation (resurfacing), and regular annual corrective and preventative pavement maintenance.

After the user inputs the cost data, the machine prompts for inputting the code numbers of the links that contain segments that are to be considered for a given maintenance plan. A maintenance plan is considered to be a combination of maintenance options whereby a set of highway segments that is scheduled for maintenance is broken down into subsets that are assigned to various maintenance options. So that a record of the locations of the various segments can be kept, the user is expected to input arbitrary reference code numbers (as integers) for all segments. Although the segment numbers are arbitrary, the code numbers for the links (mentioned previously) refer specifically to the link numbers assigned to the links in the standard network topological system.

To make the input procedure for this submodule easier, the user should decide in advance which subsets of segments are to be assigned to pavement replacement or pavement rehabilitation and which will be assigned to regular maintenance only. The length of the segments must also be determined. An interactive input routine is provided for input of a set of mixed data subsets: segment list for replacement, segment list for pavement rehabilitation, and segment list for regular maintenance.

The output of this submodule is in four parts:

- List of all links and segments subject to pavement replacement and the costs associated with the action,
- List of all links and segments subject to pavement rehabilitation and the costs associated with the action,
- List of links subject to regular maintenance, and
- Cost summary for the entire maintenance plan.

The numerical output of this submodule is used to give the planner-user cost estimates that can be quoted when maintenance plans are being analyzed.

STUDY FINDINGS

The DSS proved to be a useful framework for this study (7). The modular software integration approach incorporated the separate programs developed by the AFNA project team into a unified package. A main-line dialogue-generation and control program was the keystone of the integration because it serves as a common interface among the system modules and the AFNA user.

To execute a large-scale transportation simulation model, a communication network between microcomputer and mainframes is needed. The AFNA simulation model runs on a mainframe, but the model data preparation, output analysis, and presentation are done on a personal computer to take advantage of that machine's excellent user interface.

The model developed for the AFNA system is data driven. The data-driven modeling approach is different from the traditional approach to simulation modeling, which combines data, knowledge, and control in its programming. The data-driven approach treats the data and control logic as distinct parts. The resulting model can thus be used in many different applications, without modifying the actual program (*8*).

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Computerized Vehicle Routing for Home Delivery Operations

J. AUGUSTINE HSU, T. P. KIM, AND KEVIN BOTT

Vehicle routing models have been widely used for LTL (less than truckload) trucking operations on interurban highways. These models take into consideration various operational as well as contractual constraints and attempt to minimize the total costs (or maximize the total profit, if that is the goal of the operation). To make these models useful for home delivery services, at least two additional capabilities are needed. The first is the ability to locate (or assign coordinates to) any given address in the service area. The second is the ability to accurately estimate the distance between any given pair of points. In other words, estimated distances have to reflect local traffic conditions, such as one-way streets, locations of freeway interchanges, locations of bridges, and so on. In addition to these two abilities, an interactive graphic capability is useful to ease the task of manually refining results. In this paper, the development of such a vehicle-routing model for the home delivery operations of a major trucking company is presented.

Computerized routing and scheduling systems have been used in less than truckload (LTL) trucking operations on interurban highways for many years. Successful practices reported in the early 1980s (*1, 2*) helped to convince many trucking operators of the feasibility of computerized truck dispatching. Meanwhile, the capabilities of microcomputers are continuously being enhanced, and their costs are continuously being reduced. The emergence of many microcomputer-based vehicle-routing systems in the mid-1980s (*3*) makes this kind of application cost-effective, even for a small trucking operation.

Applications of these vehicle-routing systems to a truck operation within a metropolitan area, however, is much more difficult. The primary reason for this difficulty is the accuracy required in estimating the location of any given stop and the distance between any given pair of stops. In a store delivery operation, in which there are only a limited number of customers, each customer's location can be predefined. Distance between any two customers can be preestimated and built into a data base. Estimation of distances thus becomes a routine table lookup procedure. In a home delivery operation, however, the number of potential customers is so large that it becomes impractical to precode the customer locations or to prebuild a distance data base. In this case, accurate estimation of stop locations and distances becomes the key issue in the successful operation of a home delivery operation.

In this paper, the development of such a system for the home delivery operations of a major trucking company is described. A brief discussion on the vehicle-routing problem is presented first. This is followed by the description of a vehicle-routing system called RouteAssist (developed by the same trucking company) on which the development of the home delivery routing system is based. Finally, the development and implementation of the home delivery routing system are described.

VEHICLE-ROUTING PROBLEM

In this paper, only a brief and general description of the vehicle-routing problem will be given. An excellent review of this problem can be found in a paper by Bodin et al. (*4*), and future research perspectives have been discussed in several recent publications (*5, 6*).

As an operations research problem, a vehicle-routing problem can be described as follows. Given

- A set of delivery or pickup orders,
- A set of available vehicles,
- All relevant cost information, and
- Various operational constraints,

find solutions for

- Assigning orders to vehicles, and
- Sequencing orders on each route

to achieve the objective of

- Minimization of total costs.

Solution strategies to this problem can be classified into the following approaches (*7*):

1. Cluster first, route second;
2. Route first, cluster second;
3. Savings and insertion;
4. Improvement and exchange;
5. Mathematical programming;
6. Interactive optimization; and
7. Exact procedures.

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The first five strategies represent various heuristic procedures to achieve good (but not necessarily optimal) solutions efficiently. The sixth strategy takes advantage of interactions between human knowledge and modeling procedures. The last strategy attempts to solve the problem by various optimization algorithms.

Because of the complexity of the operational environment, most of the vehicle-routing systems are developed on the basis of one or more heuristic methods. In the next section, a vehicle-routing system will be described to illustrate the implementation of these solution strategies. This vehicle-routing system is the basic framework on which the home delivery–routing system is developed.

DESCRIPTIONS OF A VEHICLE-ROUTING SYSTEM

The previously mentioned vehicle-routing system is designed to assist a fleet dispatcher in the daily routing and scheduling of deliveries and pickups from a central depot, routed over interurban highways. It can also be used as a decision-support tool for management in planning controlled transportation systems. In a multistop environment in which a private or contract carrier is being used, it is used to

- Design routes and schedules that minimize fleet costs,
- Select the demand points that can be most economically served by the private or contract fleet,
- Select the points whose deliveries should be shipped via common carrier, and
- Determine the minimum number of tractors, trailers, and drivers required.

The system is capable of analyzing different transportation conditions, such as a single driver or sleeper team, with realistic constraints about operation, equipment, and union agreements. It can be used to design pickup routes, delivery routes, and backhaul (pickup and delivery) routes. Savings can accrue in many ways, including

- Reduction of the number of miles driven, which results in lower fuel costs, lower maintenance costs, and reduced driver costs;
- Possibility of more stops per route;
- Reduction of the number of vehicles used;
- Assignment of backhauls to the most appropriate route;
- Reduction of the labor force;
- Improved assignment of equipment and drivers to routes; and
- Determination of the best mix of private and common carriers.

The system prepares three basic reports. The first is a schedule that tells drivers what time to leave the depot, the scheduled arrival time at each stop, total route timing, and even their lunch break schedules. The second is a summary route report that provides the dispatchers with an overview of the entire fleet operation. Timing, performance, and costs for every route are presented in a clear, easily understandable format. The third report, which is the driver and equipment scheduling report, identifies the minimum number of tractors, trailers, and drivers needed to serve the scheduled routes throughout the planning horizon.

The development of this vehicle-routing system, along with one of its earliest implementations, was described by Bott (*8*). The system was based on the savings approach developed by Clarke and Wright (*9*). Then, through one of its early installations, a greedy insertion algorithm based on a knapsack-type approach was designed (*10*). Later, a limited fleet version of the system was developed in which the problem was solved by using a heuristic that was based on a column generation procedure (*11*).

Currently, the system has been implemented at 28 sites and is used to dispatch some 330 tractors every day. The average savings of the fleet operating cost range from 5 to 15 percent. In one case, an increase of 28 percent in total revenue per mile was reported (*12*).

APPLICATIONS TO HOME DELIVERY OPERATIONS

So that the previously described system could be applied to home delivery operations, much effort was put into the development of an accurate address locator and an accurate distance estimator. The graphics capability of the original routing system was also enhanced so that detailed street maps could be interactively displayed to help the dispatcher refine the routing results. The design concept of this system is presented in Figure 1.

Address Locator

Given an address written by a sales clerk on a sales slip and typed into the system by a data entry clerk, a good address locator has to be able to recognize the various components of an address and assign the accurate coordinates accordingly (Figure 2). The first part of the address-locating process is an address recognizer, which breaks down a given

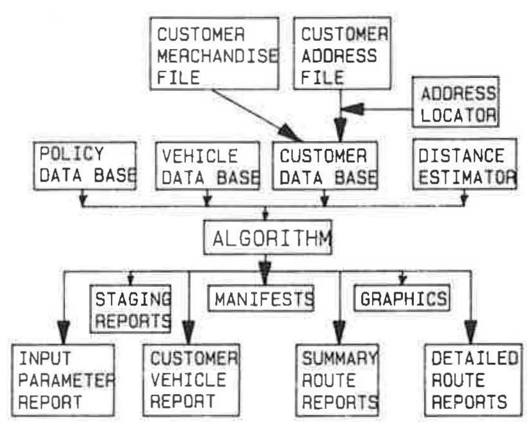

FIGURE 1 Overview schematic of home delivery–routing system.

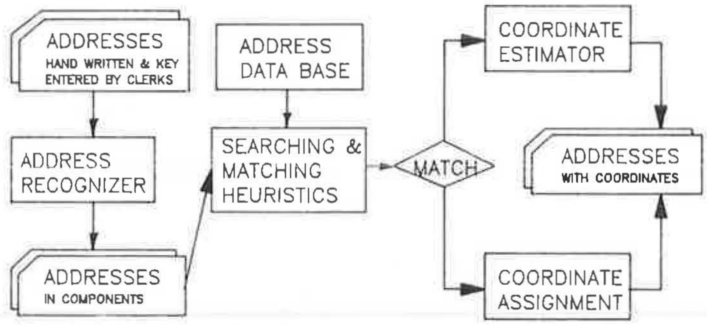

FIGURE 2 Address locator.

address into the following components: street number, directional prefix, street name, street type or street type abbreviation, directional suffix, supplemental street number information (e.g., apartment number), city name, state name or state name abbreviation, and zip code. After an address is broken down into these components, it is ready to be matched against the address data file. In the home delivery system under discussion, the address data file is composed of two types of data files, DIME files and street index files.

GBF/DIME stands for Geographically Based Files created through the Dual Independent Map Encoding technique. A DIME file is basically a collection of street segment records, as well as records of nonstreet features such as railroads, rivers, and boundaries of political units. Each street segment record contains identifiers (e.g., coordinates) for the end points (nodes) of the segment, the low and high address numbers, and other information, such as census blocks, tracts, zip code, and so on. Each DIME file was processed so that only the desired fields and the desired records were retained.

Because these DIME files generally reflect the street conditions in the late 1970s, they have to be updated by a supplemental source of data: street index files produced by map publishers. These street index files usually include the fields of street name, street type, and map index information (such as grid number and page number), as well as directional prefix and suffix. Through digitization, each grid number can be converted to a coordinate consistent with the coordinates used in the DIME files. New residential streets, which tend to be short in length, can be located accurately by using these street index files.

To match a given address to the address data base, two devices are essential: an efficient searching heuristic and a smart spelling checker. It is also important to be able to assign the coordinates for a new street address that is not found in the data base and to update the data base accordingly. When a given address has been matched against a record in the data base, the system estimates the coordinates for the address.

Distance Estimator

In general, there are three different approaches to estimating distances in a vehicle-routing system: distance matrix, shortest path within a network data base, and coordinates and circuities. The first approach is most accurate but is only applicable in cases for which the number of stops is fixed and small. The second approach requires a network data base and an algorithm to find the shortest path between two nodes. The network could be a complete street network, a major highway network, or even just a skim tree network in which each link does not necessarily represent a physical road facility. The third approach uses the coordinates of the two points to calculate the direct line distance and then adjusts it by a circuity factor. The key in a successful application of this last approach is the accuracy of the circuity factors.

During the development of this home delivery–routing system, both the first and second approaches were determined to be impractical because of the effort required to prepare and maintain the necessary data files. Efforts were then concentrated on developing an accurate circuity file. The original vehicle-routing system uses a circuity file at the three-digit zip code level. Even though these circuities yield a satisfactory result for routing along interurban highways, this file was not found to be precise enough for routing within a metropolitan area.

Traffic zone data was used to develop a more accurate five-digit zip code circuity file. Because traffic zones are the basic geographical units used in the urban transportation planning process, there is a great deal of zone-based data available from various metropolitan planning organizations (MPOs). To develop this circuity file, the following information is required: zone to zone distance, travel time matrices, or both; zone to zip code correspondence table; and zone centroid coordinates. Each zone centroid is treated as a sample origin or destination, and a five-digit zip code–based circuity file is developed accordingly.

Further refinements are usually required to accommodate local traffic conditions, which are not reflected in the zone to zone distance matrices. Circuity files can also be revised so that "barriers" can be built in to reflect operational or other requirements.

Interactive Graphics Capabilities

The original vehicle-routing system had many graphics capabilities that were found to be helpful in reviewing and refining the routing solutions. Some of these capabilities include adding or deleting a stop from a route, requesting stop or route information, joining two routes into one, splitting one route into two, resequencing stops on a route, and overlaying various geographical information, such as roads, water, zip code boundaries, and so on.

For the home delivery–routing system, an additional capability was developed so that streets could be displayed on the screen. This ability was found to be extremely useful in reviewing the sequencing of a cluster of stops close together. By combining these graphics capabilities and an editing screen, stops can be easily swapped between routes or resequenced within the same route.

RESULTS AND BENEFITS

The home delivery–routing system was implemented at two sites in 1987. The two implementations had different degrees of sophistication in their data base design. The first implementation has a detailed data base for the address locator and distance estimator. This system is used solely for assisting dispatchers in routing and scheduling. The second implementation is part of a home delivery system that includes comprehensive vehicle routing, warehousing, and accounting features. The first phase of this second implementation employed a more aggregated data base for its address locator and distance estimator. The detailed data base will be included in the second phase of implementation. Some results of the parallel processing for the first implementation are presented in Table 1. The three solutions used in the parallel processing are as follow:

- Manual solutions by dispatchers or routers,
- System solutions by resequencing orders that were previously grouped as just described, and
- System solutions consisting of both grouping the orders into routes and sequencing the orders on each route.

It was found that system solutions are better than manual solutions by 16 to 26 percent in total mileages. Even the more primitive system solutions are better than manual solutions by 11 to 20 percent.

To make system-generated routes acceptable to dispatchers, route feasibility is as important as mileage reduction. Again, the system solution was judged by drivers and dispatchers as good as, if not better than, the manual solution. In addition, the implementation of the system provides management with standards for measuring the performance of dispatchers and drivers. As a result, management efficiency has improved, and performance has become much more consistent.

Finally, it was found that service to customers was also improved because of the availability of better information and the consistency of performance.

TABLE 1 RESULTS OF PARALLEL PROCESSING, BY SOLUTION

Case	No. of Stops	No. of Routes			Total Miles		
		A	B	C	A	B	C
1	144	9	9	8	570	445	421
2	157	8	8	8	1214	1078	1013
3	130	7	7	7	695	586	532

NOTE: Solutions were as follows: A, manual routing; B, resequencing of manual routes; and C, computerized routing.

IMPLEMENTATION ISSUES

Successful implementation of any decision support system takes more than just a good computerized system (*6, 8, 13*). Several important issues emerged through the implementation of this home delivery–routing system. First of all, not all home delivery operations are the same, and the local data bases are not the only difference. Each delivery system client may have different requirements for serving customers and delivering their goods. Furthermore, local management and local labor often have their own requirements. It is most important to make sure that all the operational details are understood and correctly implemented.

Second, use of a computerized dispatching system inevitably involves changes in operating procedures. Each home delivery operation has its own procedural "traditions." Many of these are valid and are necessary to cope with unique local conditions. Some of the others, however, are in reality superficial, and these should be reviewed and changed as needed.

Third, operators, especially dispatchers, should be involved in the implementation from the beginning. Dispatchers are usually the people who are most knowledgeable about local conditions. If they realize that the system is there to free them from routine tasks rather than to replace their jobs, then they will be motivated to use the system effectively.

Fourth, local conditions will keep changing, and so will the operating requirements. The system has to be adaptive so that new requirements can be taken into consideration easily. Local data bases have to be updated on a regular basis, and ideally this task should be performed by the dispatching staff.

SUMMARY AND CONCLUSIONS

The development of a home delivery–routing system for the home delivery operations of a major trucking company is described in this paper. In addition to reducing operating costs and providing better management controls, many other benefits can be realized by implementing a computer vehicle-routing system for home delivery operations. For example, the address locator helps the dispatcher make early detection of any problems that may have been caused by incorrect addresses and provides sufficient time for corrective actions to be taken. Consequently, the computer-generated manifests provide easy-to-read, error-free addresses that reduce driver guesswork. The schedule generated by the system also provides a much more precise estimate of delivery windows. As a result, retailers are able to give their customers a delivery window of ~1–2 hours rather than half a day. The routing system can also be easily tied into an automated warehousing system and can become an integrated part of a complete home delivery operation.

Given the continuing improvement of microcomputer technology, it is expected that the application of computerized routing systems for home delivery operations will become much more cost-effective. It is hoped that this paper provides some insight into understanding the problems of these systems and supplies at least a partial framework for further development in this area.

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Air Freight Usage Patterns of Technology-Based Industries

DAVID E. CAREY, HANI S. MAHMASSANI, AND GRAHAM S. TOFT

Freight usage patterns for technology-based firms are documented through a case study of the Austin, Texas, area. The results confirm the heavy reliance of these firms on air freight and courier services for both inbound and outbound freight. These services are used on a routine basis as the principal mode for receiving inputs to the manufacturing processes and delivering products to market. A limited sample of shipments is examined in terms of the weight, size, and value characteristics of the items shipped. The results generally point to the need for incorporating the special freight transportation considerations of these firms into comprehensive economic development programs. The conclusions can also aid service providers as indicators of the potential of strategic marketing efforts to serve the emerging special requirements of technology-based industries and their growing influence on manufacturing processes in otherwise "conventional" industries.

Technology-based industries continue to be the target of economic development efforts in many locations in the United States and abroad. Overviews of the many public and private initiatives to sponsor such development can be found elsewhere (*1–4*). Although the availability and quality of air transportation for both passengers and freight have not been widely recognized in the earlier initiatives, these factors have been identified as important considerations for high-technology ("high-tech") development (*5, 6*).

The propensity of these industries to use freight modes that offer high service quality, particularly air and courier services, varies from one firm to another, depending on the principal products and activities of a given firm at a particular location. For example, use of air and courier service by firms engaged in research and development, or in early commercialization activities, can be attributed to any combination of the following factors: great time sensitivity of the shipments, generally high value of the transported objects (e.g., prototypes, documents, or specialized components), or "perishability" of the shipments in terms of being either physically fragile or subject to economic or technological obsolescence. On the other hand, the more significant factor for firms engaged in mass manufacturing of more mature product lines (at branch plants, for example) is the increasing tendency to select air transportation as an integral component of the firm's logistics strategy. The choice is made on the basis of an analysis of total distribution costs, which include the value of capital tied up in transit or in inventories, transport cost, penalties due to loss, damages, and potential disruptions. In addition to the previously mentioned high-value, low-bulk, and time-sensitive nature of the associated products and inputs, the following trends conducive to air usage in "high-tech" manufacturing have been noted (*5*):

- The advent of firms that use decentralized manufacturing and are multilocational, often beyond national boundaries.
- The tendency toward a high degree of modularization, whereby defects can be corrected through replacement of a complete module (*7*). Although this characteristic is particularly prevalent in the electronic and allied industries, it is not limited to high-tech products. It is also compatible with high-tech manufacturing processes (e.g., robotics) in the more traditional industries.
- Use of barely timely ("just-in-time") component delivery strategies. This procedure appears to be favored by many of these industries because it reduces in-process inventories, freeing capital and allowing greater flexibility in responding to rapidly evolving market forces (*8*).

This increased preference for using air and special delivery services was recently documented by Toft and Mahmassani in an analysis of the 1977 Census of Transportation Commodity Survey data files (*6*). Air mode shares for what could be considered high-tech products were found to be substantially higher than for general commodities. In addition, a listing of such commodities was developed in the interest of greater specificity in planning for the requirements of high-tech manufacturing (*6*). In general, however, there is little information available on the patterns of air freight (and other special services) usage by technology-based industries to guide and support efforts to incorporate transportation needs within comprehensive economic development programs. Such information would also be useful to airport authorities, as well as to carriers and other freight service providers. This increased usage by high-tech firms is not limited to air transport because comparable levels of service may be achievable using trucks or intermodal carriers.

D. E. Carey, JHK & Associates, 2828 North 44th Street, Phoenix, Ariz. 85008. H. S. Mahmassani, Department of Civil Engineering, University of Texas at Austin, Austin, Tex. 78712. G. S. Toft, Indiana Economic Development Council, 1 North Capitol, Indianapolis, Ind. 46204.

The case study that is presented in this paper involves Austin, Texas, a city that has experienced considerable growth in high-tech activities over the past decade. The results of a survey of air freight usage patterns among high-tech firms in the Austin area are also summarized. Although the study is limited in scope, it helps illustrate the joint growth of high-tech employment and air freight activity in a particular area and provides useful and heretofore unavailable information on a variety of air freight usage parameters associated with high-tech firms.

The definition of high-tech industries that is used in this study is presented next, followed by an overview of the characteristics of high-tech industrial development in the Austin area. Then the survey is described, the results are discussed, and conclusions are presented.

DEFINITION OF HIGH-TECHNOLOGY INDUSTRIES

Efforts to define high-tech firms usually rely on two principal characteristics that are thought to reflect "knowledge intensity": a large proportion of professional and technical employees (40–60 percent of the total) and a significant proportion of sales revenues devoted to research and development (5–20 percent). Three definitions of high-tech industries, in terms of the three-digit Standard Industrial Classification (SIC) code, are included in Table 1. One is from the Department of Labor's Bureau of Labor Statistics, which recognizes three broad categories: manufacturers of high-tech products such as computers, technology-intensive companies such as chemical or turbine manufacturers, and high-tech services such as data processing and software companies (*3*). The second definition is from the University of Texas's Bureau of Business Research (BBR) and is somewhat narrower, although it still recognizes three categories: electrical and electronic machinery (SIC 36), instruments (SIC 38), and high-tech services (SIC 73) (*9*). A comparison of other definitions in terms of implications for air freight preference can be found elsewhere (*6*).

The third column of Table 1 corresponds to the operational definition adopted in this study (AUS, for Austin) and consists of the SIC codes of companies or organiza-

TABLE 1 DEFINITIONS OF HIGH-TECHNOLOGY INDUSTRIES

SIC	Industry Classification	BLS	BBR	AUS
132	Natural gas liquids	×	–	–
281	Industrial inorganic chemicals	×	–	×
282	Plastic materials and synthetics	×	–	×
283	Drugs	×	×	×
284	Soaps, cleaners, and toilet preparations	×	–	–
285	Paints and allied products	×	–	–
286	Industrial organic chemicals	×	–	×
287	Agricultural chemicals	×	–	–
289	Misc. chemical products	×	–	–
291	Petroleum refining	×	–	–
344	Fabricated structural metal products	–	–	×
348	Ordnance and accessories	×	×	–
349	Misc. fabricated metal products	–	–	×
351	Engines and turbines	×	–	–
353	Construction, mining, and material-handling machinery	–	–	×
355	Special industrial machinery	×	–	–
357	Office, computing, and accounting machinery	×	×	×
361	Electric transmission and distribution equipment	×	×	×
364	Electric lighting and wiring equipment	–	×	×
365	Radio and TV receiving equipment	×	×	–
366	Communication equipment	×	×	×
367	Electronic components and accessories	×	×	×
369	Micellaneous electrical machinery	×	×	×
372	Aircraft and parts	×	–	–
376	Guided missiles and space vehicles	×	×	–
379	Misc. transportation equipment	–	×	–
381	Engineering, laboratory, scientific, and research instruments	×	×	×
382	Measuring and controlling instruments	×	×	×
383	Optical instruments and lenses	×	×	×
384	Surgical, medical, and dental instruments	×	×	×
385	Ophthalmic goods	–	×	–
386	Photographic equipment and supplies	×	×	–
387	Watches and clocks	–	×	–
506	Wholesale trade, electrical goods	–	–	×
737	Computer and data processing services	×	×	×
739	Research and development laboratories	×	×	×
892	Noncommercial educational, scientific, and research organizations	–	–	×

NOTE: BLS = U.S. Department of Labor, Bureau of Labor Statistics; BBR = University of Texas, Bureau of Business Research; AUS = classifications used in this study (Austin).

TABLE 2 EVOLUTION OF HIGH TECHNOLOGY IN AUSTIN, BY SIC CATEGORY

Two-Digit SIC Code and Description	Year 1945	1955	1965	1975	1984
28 Chemicals and Allied Products	0	1	2	2	5
29 Petroleum Refining and Related Industries	0	1	1	1	1
34 Fabricated Metal Products	0	0	0	1	1
35 Machinery	0	0	0	2	13
36 Electrical and Electronic Machinery	0	2	4	14	34
37 Transportation Equipment	0	0	0	0	1
38 Measuring and Analysis Equipment	2	2	4	13	22
39 Miscellaneous Manufacturing	0	0	0	2	2
50 Wholesale Electrical	0	0	0	0	1
73 Computers and Data Processing, Plus Research and Development	0	0	0	0	6

tions contacted for information. It should be noted that several SIC categories included in the other two definitions are not used in the current listing because there were no such companies in Austin at the time of the study. On the other hand, several categories not present in either of the other two definitions are included in our definition because these products or services, which were represented by several Austin firms, were considered to have a strong technological orientation or exhibited many of the same characteristics of high-tech firms in other SIC categories.

CHARACTERISTICS OF HIGH-TECHNOLOGY DEVELOPMENT IN AUSTIN

The first firms that would be considered high-tech by today's standards came to Austin in the late 1940s and early 1950s. These early firms were primarily manufacturers of electrical filters and other electrical components and measuring instruments. The field of high technology continued to grow in the 1960s at an increasing rate that accelerated dramatically in the late 1970s and 1980s. Table 2 presents a breakdown by two-digit SIC code of the number of technology-oriented firms located in Austin, at 10-yr intervals between 1945 and 1984. The category "Machinery, including selected electrical and electronic machinery" (SIC 35), which includes computers, calculating machines, and office machines, experienced the fastest relative growth during this period. The greatest total increase during this time occurred in category SIC 36 (Electrical and electronic machinery, equipment and supplies), which includes electronic components and communications equipment.

This growth is best illustrated graphically, as in Figure 1. The growth of air freight traffic and Austin's Robert Mueller Airport is shown in Figure 2 in terms of annual inbound and outbound tonnage for 1979–1984. Further characterization of high-tech development in the Austin area will be given in the section on survey results.

SURVEY PROCEDURE

The nature of the transportation requirements of high-tech firms does not appear to have been documented in available sources. To better understand the makeup of these

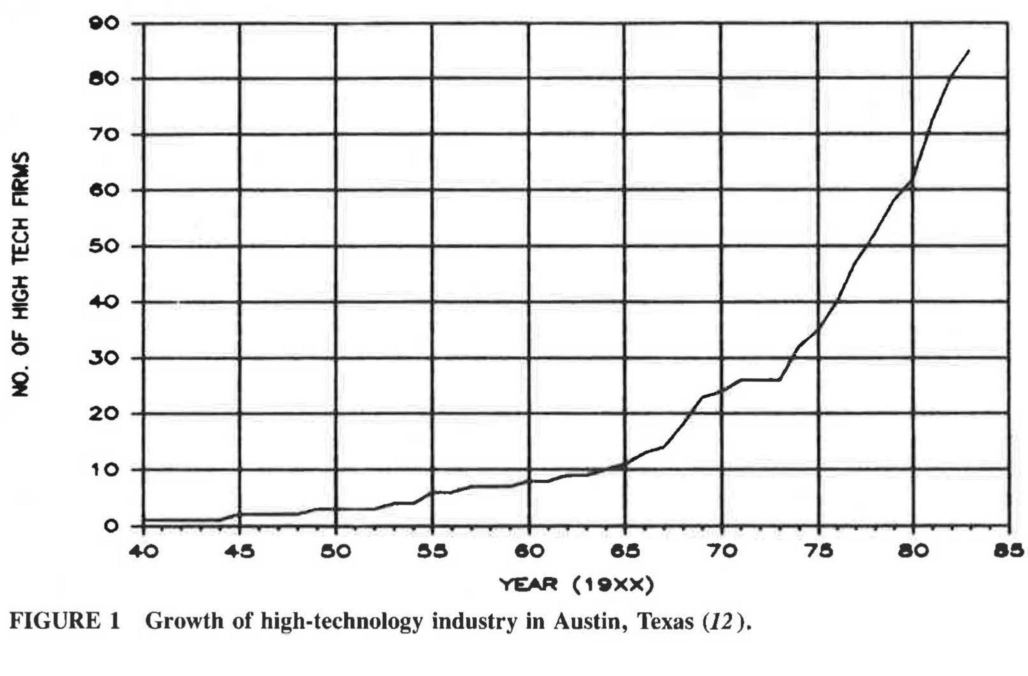

FIGURE 1 Growth of high-technology industry in Austin, Texas (*12*).

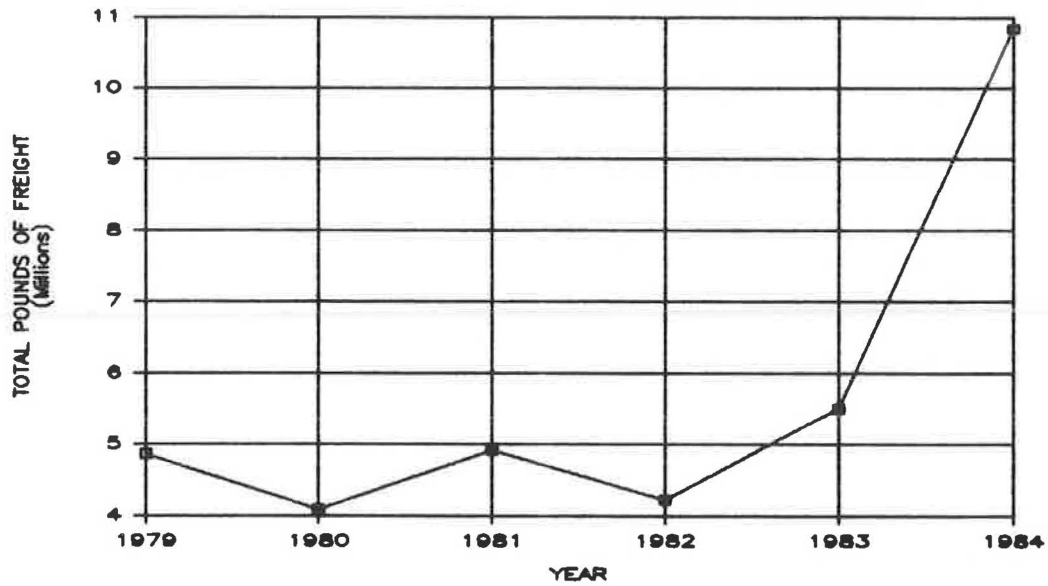

FIGURE 2 Air freight, Austin Municipal Airport (Source: Aviation Department of the City of Austin).

requirements, a survey was conducted about the actual use of air transportation and other modes by these firms. In this section, the survey procedure and questionnaire are described, and the data that were obtained from the firms that responded to the survey are introduced. In the next section, the data pertaining to freight transport are discussed. Data on air passenger travel were also obtained and are discussed elsewhere (*10, 11*).

Each of the firms surveyed was located in the Austin area at the time of the survey and is categorized by one of the SIC codes listed in Table 1 under the heading AUS. The information requested was designed to provide data on the characteristics of the freight flows generated in the high-tech industries. Specifically, we wished to determine, for both outbound and inbound ships, the following:

- Origin and destination of shipment,
- Description of items shipped,
- Weight and size characteristics of shipment,
- Approximate value of shipment,
- Frequency,
- Mode, and
- Nature of shipment (routine, irregular, or emergency).

In addition, the survey asked for details about the firm, including the following:

- Name and address of company,
- Name and position of person completing the survey,
- Classification of operation of the plant or office,
- Address of the parent company,
- Year of incorporation,
- Major business activities of the company,
- Major product (service) lines of the company,
- Product or service market,
- Change in geographical markets,
- Breakdown of number of employees at plant or office,
- Corporation revenues,
- Number of offices or plants, and
- Locations of other offices or plants.

The firms were identified with the aid of the *1983 Directory of Austin Area Manufacturers* (*12*), which includes such information as the size of the firm, length of time in Austin, marketing areas, type of organization, and chief products of the firm by SIC code. In effect, we aimed at all the listed firms to obtain a mixture of large and small companies and high-tech manufacturing, research, and service organizations. In all, 86 firms were contacted for information, and replies were received from 33 of these. A complete list of the companies contacted can be found elsewhere (*11*).

Each of the 86 firms was contacted initially in person or by mail and was requested to complete a rather lengthy and detailed questionnaire that had been pretested through several in-person interviews. Only 13 of the firms returned completed questionnaires. Because of this low response rate, we decided to sacrifice some detail in the interests of obtaining a greater representation. A new, shortened, easy-response questionnaire was developed and mailed to all the firms that did not respond to the first query. This second questionnaire included fewer questions about details of the company itself and asked for estimates instead of actual figures. Detailed descriptions of each shipment were not requested this time. Instead, the number of shipments to and from various aggregated regions was sought, as well as the "usual" mode for these shipments. This streamlined approach greatly reduced the human resources required to supply the requested information, and this reduction was a major factor in eliciting the cooperation of these busy organizations.

In all, 20 completed forms were returned from the second mailing, resulting in a total of 33 replies for the overall survey out of a population of 86, for a return rate of 38.4 percent. Of the respondents, only 18 out of 33 supplied freight data. In many of the nonmanufacturing firms, especially the smaller ones, information on freight shipments is not easily accessible nor particularly well monitored.

Comparison of the responding and nonresponding firms on the basis of SIC codes, years in Austin, and number of employees did not suggest any systematic difference between the two groups. We were therefore reasonably satisfied that the sample of responses was representative of high-tech firms in Austin at the time of the study. Nevertheless, it should be stressed that the study was exploratory and not intended to support formal statistical inferences.

A list of the responding firms, sorted by SIC code, appears in Table 3, along with the number of employees (as of the first quarter of 1984) and the year that the office or plant was established in Austin. The table illustrates the range of industries included in the study: the companies represent manufacturing as well as research and service industries and include some firms that have been located in Austin for 40 years, as well as more recent arrivals. The size of the organizations represented ranges from small outfits with four employees to international corporations employing more than 1,000 people (7,000 employees at the largest).

SURVEY RESULTS

In interpreting the results, it should be noted that "air transportation" was viewed as a modal option distinctly different from parcel or special delivery services. The latter are thought to include firms offering a high level of service quality in terms of speed, reliability, and care in handling, such as Federal Express, Emery, Airborne, United Parcel Service (UPS), and others. This distinction is a confusing one in this context, however, because many of these firms are actually air freight carriers themselves (e.g., Federal Express) or primarily air freight forwarders who operate their own aircraft in addition to using other airlines (e.g., Emery). Others, such as UPS, use a mixture of modes to provide service options that ensure an agreed-on quality and often involve air transportation at some stage. Because of this apparent ambiguity in modal definitions, the responses involving these modes are not readily distinguishable. For example, some users of Federal Express might have indicated "air" when others would have indicated "parcel." The issue is primarily one of product differentiation and brand identification in the users' perceptions of these services. For the purposes of this study, the difference is not essential because both so-called modes are in most cases substitutable and reflect the same need for high-quality service for which shippers are willing to pay a premium.

TABLE 3 CHARACTERISTICS OF RESPONDING FIRMS

SIC Code	Industry	Year Established in Austin	No. of Employees
2819	Industrial inorganic chemicals	1960	11
2821	Plastics materials	1978	4
2869	Industrial organic chemicals	1949	200
3572	Typewriters and parts	1977	89
3573	Electronic computing equipment	1967	7,000
3573	Electronic computing equipment	1979	40
3573	Electronic computing equiment	1981	190
3613	Switchgear and switchboard apparatus	1979	85
3616	Electric transmission and distribution equipment	1981	155
3622	Industrial controls	1970	30
3662	Radio and TV communication equipment	1955	1,500
3662	Radio and TV communication equipment	1962	160
3662	Radio and TV communication equipment	1982	1,500
3670	Electronic components and accessories	1982	50
3674	Semiconductors and related devices	1978	450
3674	Semiconductors and related devices	1979	10
3677	Electronic inductors	1953	35
3679	Electronic components, NEC[a]	1974	39
3679	Electronic components, NEC	1976	55
3679	Electronic components, NEC	1978	16
3693	X-ray apparatus and tubes	1969	130
3811	Engineering, laboratory, scientific, and research instruments	1968	10
3811	Engineering, laboratory, scientific, and research instruments	1971	5
3811	Engineering, laboratory, scientific, and research instruments	1977	7
3823	Industrial measuring and controlling instruments	1957	20
3825	Electronic measuring instruments	1976	20
3829	Measuring and controlling devices, NEC	1945	20
5065	Wholesale trade, electrical goods	1981	12
7391	Research and development laboratories	1983	45
7391	Research and development laboratories	1983	150

[a] NEC = not classified elsewhere.

The survey results point to a strong reliance by the responding firms on air transportation and parcel delivery services. Only one of the responding firms did not indicate the use of these modes for either inbound or outbound freight, and most firms indicted exclusive or dominant use of these modes. Air is the predominantly reported mode of transportation for high-tech freight into Austin from the Northeast, Midwest, South, and Mountains and Plains regions. Parcel services are reported most often as the mode for freight into Austin from the Southeast and Far West states. The same heavy reliance on air and parcel is also present for outbound freight, and although data in this regard are extremely limited, most overseas outbound freight was reported to have been shipped by air or parcel.

The percentage of shipments by each mode is presented in Table 4, aggregated on the basis of the shipping or receiving firm's two-digit SIC code. Interestingly, the category with the largest percentage of truck usage, SIC 35 (Machinery), includes those firms engaged in the heaviest manufacturing of all respondents.

Most of the firms that provided information on the nature of the items shipped as inbound freight described shipments to their plants or offices as "electronic parts." The items described as outbound freight included partially or fully assembled electronic equipment, which was further specified to include computer terminals, test equipment, disk drives, microchips, personal computer boards, and cable harnesses and assemblies.

The reported values of the outbound shipments ranged from a $2.00 cable harness to a $60,000 electric power converter. Outbound shipments ranged in weight from 1-lb packages of microchips to an 8,600-lb piece of test equipment. The reported sizes of the outbound shipments ranged from 54 in.^{3} of microchips to 1,000 ft^3 of electronic instruments. Parcel services tended to carry the smallest and lightest items, air freight services handled the items of moderate size and weight, and trucks handled the bulky and heavy items. However, it is notable that many items in the greater size and weight categories are also going by air instead of exclusively by truck, most likely because of their high value or time sensitivity, or a concern for their breakability.

The Mountains and Plains and the Far West regions dominated as the origins of the inbound air shipments (Table 5). The Southwest was reported to be the leading destination for outbound domestic shipments, whereas the Mountains and Plains received the smallest number of these shipments. The asymmetry between inbound and outbound flows from and to the various regions is interesting. The pattern demonstrates a clear distinction between the sources of inputs for the high-tech activities in Austin and the major markets for the high-tech goods and services offered by Austin firms, thereby clarifying Austin's role in the national high-tech development scene at the time of the study.

The analysis just mentioned is further strengthened by an examination of the principal destinations of air passenger trips taken by the employees of Austin's high-tech firms. Table 5 presents a comparison of the inbound and outbound air freight shipments and air passenger trips to and from each regional destination. The Southwest emerges as the most frequent destination for both outbound air freight shipments and air passenger trips, followed by the South (for air freight only). These results suggest that these regions are important markets for Austin's technology-oriented firms. On the other hand, only a small percentage of inbound air shipments arrive in Austin from the Southwest, in contrast to the percentages from the Far West and the Mountains and Plains. These latter regions account for the largest shares of inbound freight but few of the outbound shipments.

As reported elsewhere (*10*) and earlier, the most prevalent air passenger destination for Austin high-tech firms is the Southwest, followed by the Far West. This can be explained in part by noting the many high-tech firms located in these areas, particularly in California's Silicon Valley. In addition, Austin appears to be assuming a growing role as a leading high-tech link between the Southwest and the rest of the nation, particularly the West Coast. Therefore, although the South and the Southwest provide major markets for Austin's technological products and services, much of the technological exchange and interaction (as well as component parts) needed for the production of these goods and services involves the high-tech concentrations in the Far West.

TABLE 4 PERCENT OF SHIPMENTS USING EACH MODE

Two-Digit SIC Code	Mode (%) Air	Parcel	Truck	No. of Responding Firms
28	–	100.0	–	1
35	53.8	–	46.2	3
36	45.1	33.3	21.6	8
38	71.0	29.0	–	5
50	100.0	–	–	1
Total				18

TABLE 5 AIR FREIGHT AND AIR PASSENGER TRIPS SUMMARY, BY REGION

Region	Total Passenger Trips/ Month[a] (%)	Total Freight[b] (%) Inbound	Outbound
New England	8.7	6.0	3.6
Mideast	8.4	6.5	5.5
Midwest	12.4	15.7	6.9
South	7.7	8.9	21.6
Southwest	29.6	12.5	35.2
Mountains & Plains	6.8	28.5	3.2
Far West	3.1	19.0	9.1
Canada	1.1	1.6	4.1
Europe	1.4	1.4	4.0
Latin America	0.05	0.0	2.1
South America	0.34	0.0	2.2
Asia	0.14	0.0	2.4
Other	0.29	0.0	0.17

[a] Data from D. E. Carey (*11*).
[b] Based on the responses of 18 firms.

CONCLUSION

Our case study of Austin's high-tech firms demonstrates the strong dependence of these firms on air freight and package delivery services. This conclusion confirms earlier concerns that the availability and quality of air freight transportation may be important considerations in regional economic development plans aimed at attracting and fostering technology-based activities in a given region. In addition, this information should supply air freight suppliers with indications about potential markets for their services, thereby guiding their resource deployment and other supply decisions. The primary determinants for this demand, as confirmed through an analysis of shipment characteristics, are time sensitivity, relatively low bulk, and high value. That these determinants need not be exclusively within the realm of air transport was demonstrated by the current use of trucks for some of the shipments that were surveyed, as well as by the use of parcel delivery services that may be using trucks for at least some segments of the shipment's ultimate route. More importantly, the results of this study suggest potentially lucrative market niches for specialized common carrier trucking services, which would recognize the principal considerations governing the shipping mode decisions of high-tech firms. Strategic marketing efforts to provide for these specialized needs will assume an even greater importance as otherwise "conventional" industries continue to adopt high-tech manufacturing processes, which result in an increased capability to achieve the savings associated with just-in-time logistics strategies.

The analysis of origins and destinations of shipments to and from Austin is consistent with Austin's status as an emerging high-tech center. In this role, the city interacts strongly with other national centers, particularly on the West Coast, but also plays a strong regional part in the surrounding markets for high-tech products and services.

As we have emphasized throughout the paper, the results presented here are primarily illustrative in nature and do not provide an adequate basis for forecasting freight patterns. Naturally, this case study of Austin firms provides only a limited perspective on the air freight patterns associated with high-technology development. It would be highly desirable to include a broader range of firms in a wider variety of locations, as well as more complete information on both freight transport patterns and firm characteristics. In addition to providing more definitive information, these inclusions would allow development of formal multivariate models to capture the principal determinants of freight generation and modal choice of high-tech firms.

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