Impacts of Highway Congestion
on Freight Operations:
Perceptions of Trucking Industry Managers

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Abstract

To better understand how road congestion adversely affects trucking operations in California, we surveyed approximately 1,200 managers of all types of trucking companies operating in California. More than 80% of these managers consider traffic congestion on freeways and surface streets to be either a "somewhat serious" or "critically serious" problem for their business. A structural equations model is estimated on these data to determine how five aspects of the congestion problem differ across sectors of the trucking industry. The five aspects were slow average speeds, unreliable travel times, increased driver frustration and morale, higher fuel and maintenance costs, and higher costs of accidents and insurance. The model also simultaneously estimates how these five aspects combine to predict the perceived overall magnitude of the problem. Overall, congestion is perceived to be a more serious problem by managers of trucking companies engaged in intermodal operations, particularly private and for-hire trucking companies serving airports and private companies serving rail terminals. Companies specializing in refrigerated transport also perceive congestion to be a more serious overall problem, as do private companies engaged in LTL operations. The most problematic aspect of congestion is unreliable travel times, followed by driver frustration and morale, then by slow average speeds. Unreliable travel times are a significantly more serious problem for intermodal air operations. Driver frustration and morale attributable to congestion is perceived to be more of a problem by managers of long-haul carriers and tanker operations. Slow average speeds are also more of a concern for airport and refrigerated operations.

Introduction

Our aim is to understand to how congestion affects the trucking industry from the point of view of the operations managers of these companies. A survey was conducted in which managers of approximately 1,200 trucking companies with operations in California were asked how serious they thought each of five potential congestion-related problems was to their operations. They were also asked how serious they thought the overall problem of congestion was for their business.

One of our objectives was to determine how perceptions of congestion problems differ across types of operations, such as for-hire carriers versus private carriers, truckload versus less-than-truckload (LTL) operations, various specialized services (tank, bulk, refrigerated), various lengths of loaded movements, and provision of service to inter-modal facilities (airports, seaports, and rail terminals). A second objective was to determine which aspects of congestion have the greatest perceived impact on trucking operations. Aspects examined include slow average speeds, unreliable travel times, increased driver frustration and morale, higher fuel and maintenance costs, and higher costs of accidents and insurance. In order to accomplish these two objectives, a structural equations model (SEM) is used to estimate the influences of each of nine operating characteristics on each of five perceived problems, while simultaneously estimating how the five problems combine to explain the perceived level of the overall problem of congestion. The method used to estimate the SEM is designed for use with ordinal-scale (attitudinal) endogenous variables, and tests are conducted to determine differences between responses of for-hire and private trucking companies.

This study offers a rich set of data because carriers surveyed represent every industry segment: national, regional and local truckload and less-than-truckload (LTL) carriers, private and for-hire fleets, specialized carriers and those serving rail, maritime and air intermodal terminals. The survey is restricted to carriers with operations in California, but many of the companies in the sample operate outside California as well. Therefore results should be directly applicable to other geographic regions.

This research extends an earlier study that had as its focus carrier perceptions of the benefits of congestion mitigation strategies available to public agencies (Golob and Regan, 1998). This work is intended to complement traditional analysis of roadway congestion and to provide policy makers with input from the commercial vehicle operators' perspective. It comes at a time when California government leaders and transportation policy analysts are struggling with key resource allocation issues that will impact the short and long term future of goods movement in the state. To the greatest extent possible, insights of commercial vehicle operators should be included in the policy analysis process.

Related Studies

The authors are unaware of any previous studies of how the trucking industry views congestion problems based on large-scale surveys of industry managers. However, insights into perceived congestion problems can be gained from several recent studies of the potential benefits of intelligent transportation systems (ITS) and information technology (IT) for freight operations.

Scapinakis and Garrison (1993) conducted a small survey regarding carriers' perceptions of a use of communications and positioning systems, and Kavalaris and Sinha (1995) surveyed trucking companies with a focus on their awareness of and attitudes towards ITS technologies. Ng *et al.*(1995) reported results from two nationwide surveys of dispatchers and commercial vehicle operators to determine characteristics that would determine likely acceptance of Advanced Traveler Information Systems (ATIS) technologies, including route guidance, navigation, road and traffic information, roadside services and personal communication. Regan *et al.* (1995) surveyed 300 companies to determine carriers' propensity to use new technologies, particularly two-way communication and automatic vehicle location/identification technologies. Holguin-Veras and Walton (1996) and Holguin-Veras (1999) also investigated the use of IT in port operations through interviews with port operators and a small survey of carriers. Crum *et al.* (1998) studied the use of electronic data interchange (EDI) technology, and Hall and Intihar (1997) studied IT adaptation through a series of interviews with trucking terminal managers, focus group meetings with representatives of the trucking industry, and telephone interviews with technology providers.

Preferences of freight industry managers regarding alternative strategies to relieve congestion were surveyed and analyzed by Hensher, *et al.* (1996) and Hensher and Golob (1998). The survey sample was 150 organizations in New South Wales, Australia, stratified by freight-industry sector: manufacturing, utilities, services, retailing, warehousing and distribution, contract distribution, freight hauling, and freight forwarding, and the survey collected views on road infrastructure changes, new road infrastructure, non-road infrastructure needs, and transport policies. Hensher and Golob (1998) used an optimal scaling method to identify which transportation policies for relieving congestion were favored by each of the industry sectors.

The Survey

Protocol and Sample

During the Spring of 1998, a survey of California based (corporately located) for-hire trucking companies, California based private trucking fleets and national carriers was carried out by a private survey research company for the Institute of Transportation Studies at the University of California, Irvine. Potential respondents were drawn from a

set of 5258 freight operators, from three strata: (1) 804 California based for-hire trucking companies, with annual revenues of over $1 million, (2) 2129 California based private fleets of at least 10 vehicles (power units) and (3) 2325 for-hire large national carriers not based in California with annual revenues of over $6 million. The list of companies and individual contact information was drawn from a database of over 21,000 for-hire carrier and 25,000 private fleets maintained Transportation Technical Services Inc.

Questions were posed to the logistics or operations manager in charge of operations in California. The survey was conducted as a computer-aided telephone interview (CATI), with an average interview time of just over 18 minutes. The managers were asked if they were willing to participate in a survey and then the survey began, often at a later time suggested by the manager. The content of the survey was not described before the survey began. An overall response rate of 22.4% was obtained, with many of the national carriers excluded on the basis of insufficient operations in the state of California. After eliminating the contacts with no operations in California and invalid telephone numbers, the effective response rate was approximately 35%.

Non-response analyses were conducted for each of the three strata from which the sample was drawn. Golob and Regan (1998a) report that there are no statistically significant differences between survey respondents and other companies on any of three criteria available in the database from which the sample was drawn: revenue, overall size of fleet, and number of years in business. Shown in Table 1 are the fleet sizes for all for-hire companies (California-based companies and large national companies combined). The difference in mean fleet size between respondents and non-respondents is not statistically significant at the p = .05 level. The sample appears to be representative of for-hire trucking companies operating in California in 1998.

Table 1: Fleet sizes of For-hire Companies Surveyed and Those Not Surveyed

	N	Mean	Std. Dev.	Median	F-stat.	Prob.
Respondents	767	264.8	1332.2	81	1.327	0.249
Non-respondents	2362	205.0	1218.6	78		

Fleet sizes for private companies are listed in Table 2. Once again, there is no significant difference between the mean fleet sizes of companies surveyed and those not surveyed. The database from which the sample of private fleets was drawn also contained the standard industrial classification (SIC) codes of the companies. A comparison of the SIC code distributions for our sample of private trucking companies and their complement of non-surveyed companies is shown in Figure 1.

Table 2: Fleet sizes of Private Companies Surveyed and Those Not Surveyed

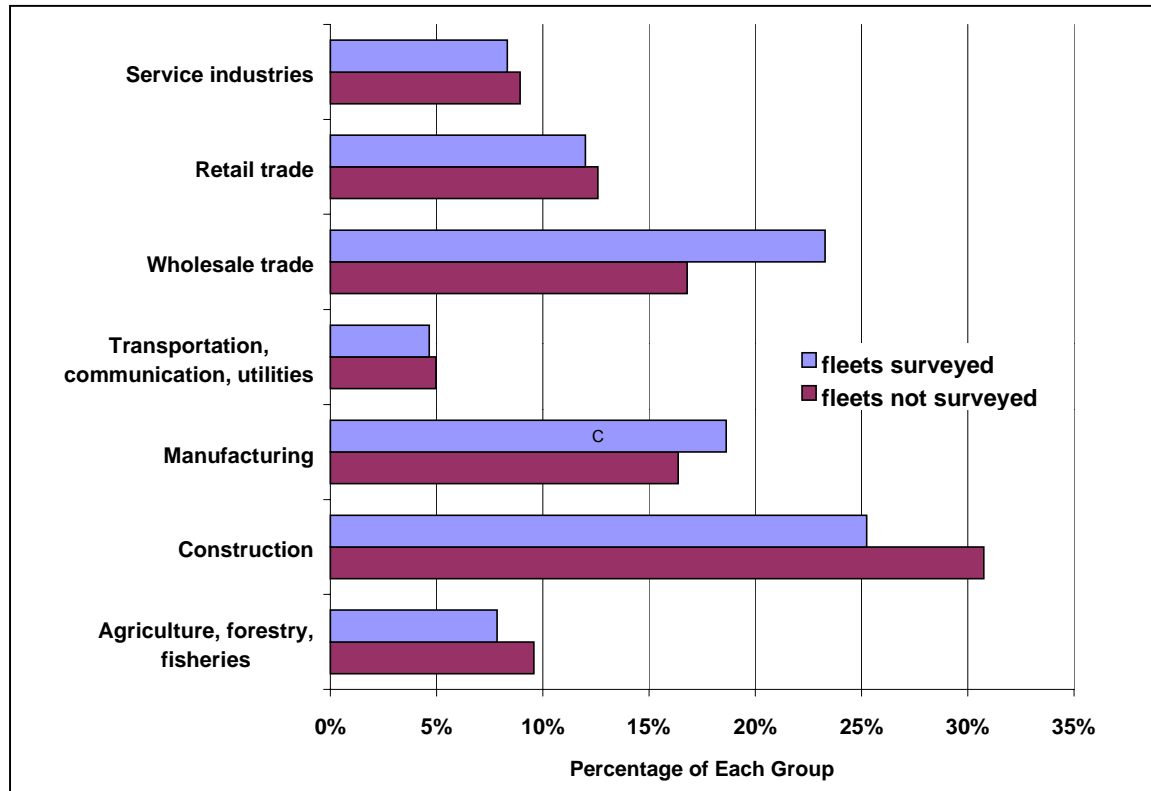|	N	Mean	Std. Deviation	Median	F-statistic	Prob.
Respondents	410	58.6	131.0	28		
Non-respondents	1718	70.5	263.4	29	0.792	0.374

Figure 1: Distributions of Standard Industrial Classifications of Private Companies Surveyed and Those Not Surveyed in the 1998 ITS California trucking Industry Survey

The chi-square statistic for the contingency table corresponding to Figure 1 is 13.37 with 6 degrees of freedom (p = 038). Our sample over-represents trucking operations from the wholesale trade sector, and under-represents those from the construction sector. The distribution of the sample is quite close for all the other sectors. Because the sample is not biased in terms of fleet size, and because and the overall deviation in terms of SIC codes for the private operators in the sample is not significant at the p = .01 level, we judge that the private fleet component of the sample is a good representation of private trucking companies operating in California in 1998.

Survey Content

The survey dealt with four main topics: (1) traffic congestion, (2) use and usefulness of information technologies, (3) use and efficiency of intermodal terminals in California, and (4) operational characteristics. . A summary of survey results can be found in Regan and Golob (1999a).. Each of the four main sections of the survey is briefly described below.

Traffic congestion

This section included questions about carriers' perceptions about the impact of traffic congestion on their operations, followed by questions about the effectiveness of potential means of reducing congestion. This presention is concerned with analysing these perceptions of traffic impacts. An analysis of carrier perceptions of the effectiveness of congestion mitigation strategies available to public agencies is provided in Golob and Regan (1999a)

Use of Technologies

Questions were asked to elicit information on carriers' use of technologies including mobile communication devices, EDI, automatic vehicle location (AVL) devices, and automatic vehicle identification (AVI) devces, such as the PrePass$_{TM}$ electronic clearance system. Questions were also asked about dispatchers' and drivers' means of accessing publicly available traffic information updates. In addition, respondents were asked to rate the usefulness of various technologies and information sources.   A model of demand for information technologies is presented in Golob and Regan (1999b).

Use of and satisfaction with intermodal facilities in California

Carriers' use of maritime, rail and air intermodal facilities was investigated. Questions were asked about typical delays and the predictability of the time required for pickup and delivery of loads to these facilities. Respondents were also invited to describe the types of problems they face in operating at intermodal facilities. Carrier perceptions of problemsencountered in intermodal maritime operations are explored in Regan and Golob (1999b).

Operational characteristics

The remaining questions asked about the operational characteristics of the companies. Of interest are the types of services offered, the average length of haul, time sensitivity of the operations, the locations of the main terminals and the fleet size. We were careful in this section not to ask questions that involved company proprietary information. The broad goal of this study was to obtain information on all of the subjects listed above from a large enough sample of the California trucking companies so that no industry segments would be left out.

The Data

Perceptions of Problems Caused by Congestion

Survey respondents were asked to rate five congestion problem areas in terms of the impact of each area on the operations of their companies. Responses were collected on a four-point ordinal scale, with the categories described as "not a problem," "minor problem," "significant problem," and "major problem." Aggregate ratings of the significance of these five problem areas are shown in Figure 2. On the basis of rating as a "major problem," driver frustration and morale and accidents and insurance costs stand out, with between 25% and 30% of the sample rating these two areas as a major problem.

1. Higher costs because of slow average speeds
2. Scheduling problems due to unreliable travel times
3. Driver frustration and morale
4. Increased fuel and maintenance costs
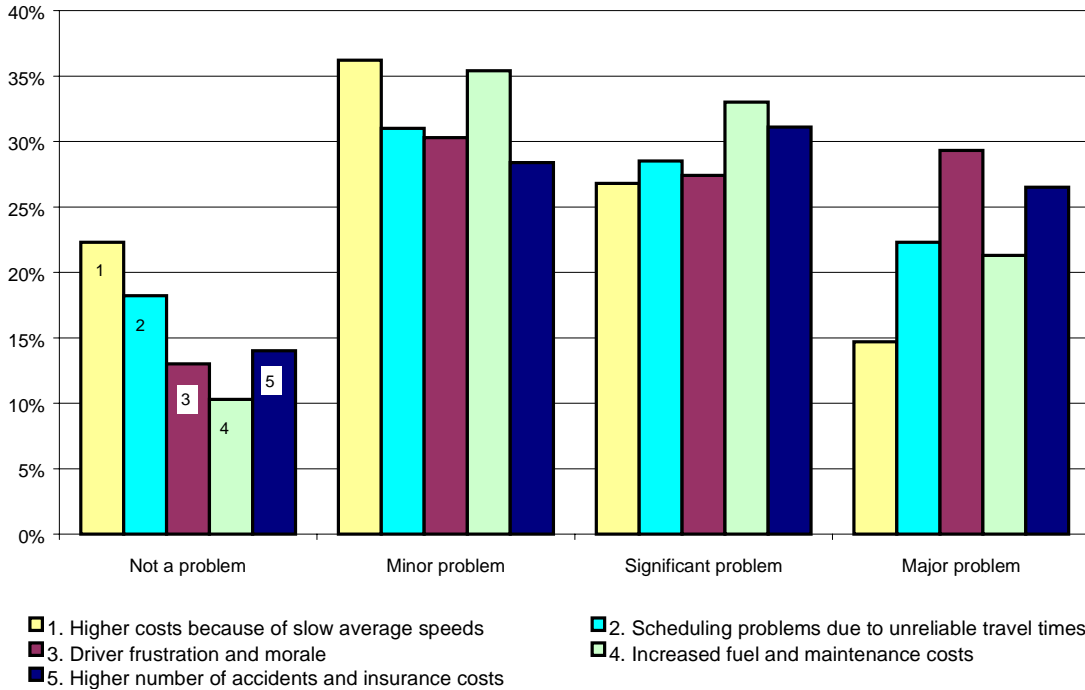5. Higher number of accidents and insurance costs

Figure 2: Ratings on a Four-Point Scale of Five Potential Problems Caused by Congestion (N = 1177)

Increased <u>fuel</u> <u>and</u> <u>maintenance</u> <u>costs</u> (due to stop and go driving) receives the lowest "not a problem" rating. Ninety percent of all respondents consider such costs to be a problem of some degree. Compared to the other four problem areas, <u>higher</u> <u>costs</u> <u>due</u> <u>to</u> <u>slower</u> <u>average</u> <u>speeds</u> is the least burdensome consequence of road congestion. An objective of our research is to determine how the ratings of these five congestion-related problem areas differ across trucking operations.

Trucking company managers were also asked to rate how serious the overall problem of congestion is for their business, using a three-point ordinal scale: "not serious," "somewhat serious," and "critically serious." The majority of respondents (64.4%) reported that congestion was a "somewhat serious problem." The remainder of the sample was split evenly between "not serious" and "critically serious" (17.8% each). Thus, over 82% of all trucking company managers consider road congestion to be a somewhat serious or critically serious problem for their California operations.

Figures 3 through 8 examine the differences in responses given by for-hire carriers and private and contract carriers. We refer to for-hire carriers as all for-hire carriers except carriers who have contract operations only, because we found that, in terms of perceptions of congestion problems, contract-only carriers are more like private carriers than they are like typical common (for-hire) carriers. We examine these two market segments because there is likely to be some differences in their responses due to operational differences. Our sample of 1177 trucking companies is broken down into 611 for-hire carriers and 566 companies which operate as private or contract-only carriers. Statistically significant differences in responses between the segments were found for most of the congestion problem areas.

A breakdown of ratings of <u>higher</u> <u>costs</u> <u>due</u> <u>to</u> <u>slow</u> <u>average</u> <u>speeds</u> is shown in Figure 3. There is no statistically significant difference (at the $p = .05$ level) between for-hire and private or contract-only carriers in terms of their ratings of the seriousness of this aspect of road congestion. Only about 40% of companies in each segment consider this aspect of congestion to be either a significant or major problem.

A breakdown of ratings of <u>scheduling</u> <u>problems</u> <u>due</u> <u>to</u> <u>unreliable</u> <u>travel</u> <u>times</u> is charted in Figure 4. This is perceived to be a more serious problem for for-hire carriers than for private/contract carriers (the Kendall τ_b rank-order correlation is .073, corresponding to $p = .023$). Almost 25% of managers of for-hire carriers rate unreliability to be a major problem, compared with less than 20% of private/contract carriers.
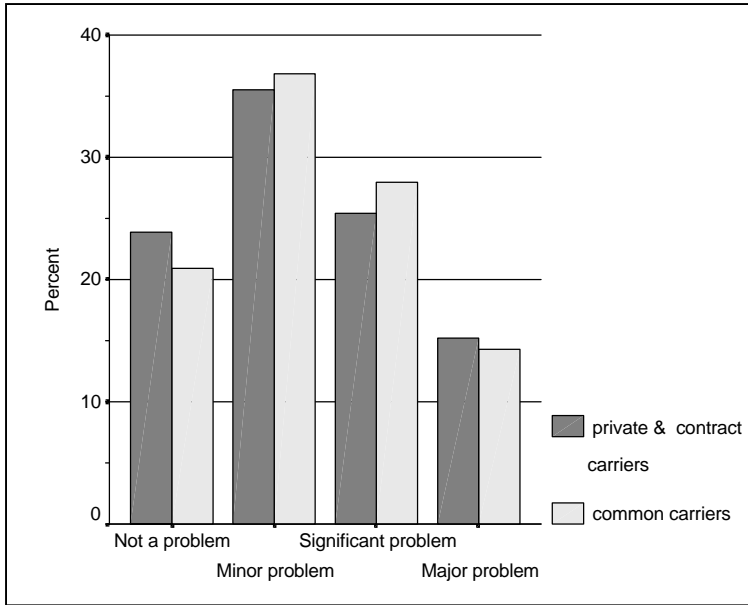
Figure 3: Ratings of the Problem of Higher Costs due to Slow Average Speeds, Broken Down by For-hire Versus Private and Contract-only Carriers
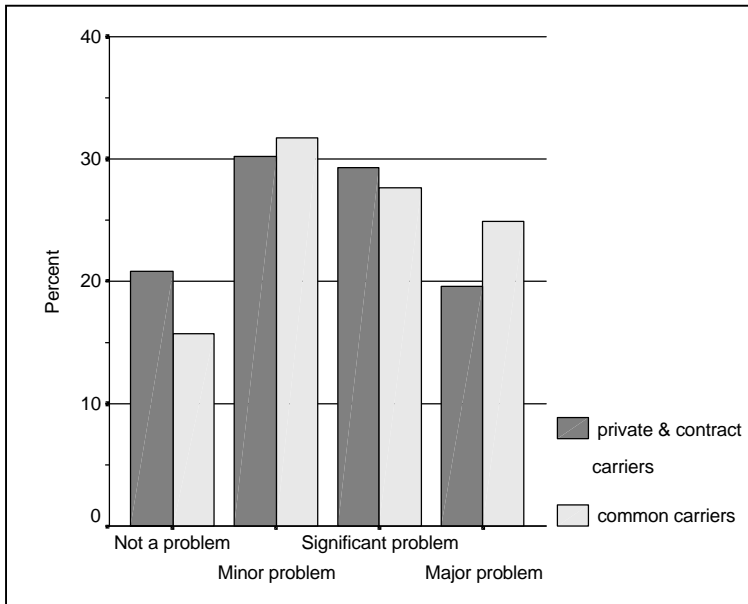
Figure 4: Ratings of the Scheduling Problem due to Unreliable Travel Times, Broken Down by For-hire Versus Private and Contract-only Carriers

A breakdown of ratings of the congestion-related problem of <u>driver</u> <u>frustration</u> <u>and</u> <u>morale</u> is shown in Figure 5. This is perceived to be a more serious problem by for-hire carriers (τ_c = .154, corresponding to p = .000). The direction of the differences between for-hire and private carriers is similar to that in the previous case of unreliability due to congestion between for-hire. Driver frustration and morale is rated as being not a problem by almost 19% of private/contract carriers, versus only about 8% of for-hire carriers. Fully a third of representatives of for-hire carriers rated this to be major problem, the highest proportion given to any congestion-related problem. This is likely a reflection of the differences in labor issues between private and for-hire carriers. Managers in for-hire companies are keenly aware of the difficulty associated with keeping drivers. Turn over among drivers in private companies tends to be lower (Hamelin, 1992).
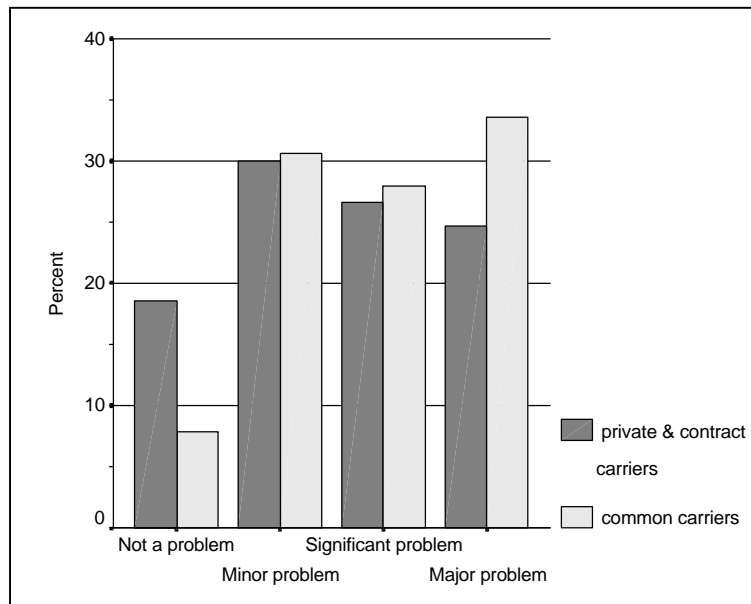

Figure 5: Ratings of the Problem of Driver Frustration and Morale, Broken Down by For-hire Versus Private and Contract-only Carriers

A breakdown of the fourth potential problem due to congestion, <u>increased</u> <u>fuel</u> <u>and</u> <u>maintenance</u> <u>costs</u> <u>due</u> <u>to</u> <u>stop</u> <u>and</u> <u>go</u> <u>driving</u>, is shown in Figure 6. Once again, for-hire carriers perceive increased fuel and maintenance to be a more serious problem (τ_c = .079, corresponding to p = .013), but the strength of the ordinal relationship with segmentation is less than in the case of driver frustration and more similar to the relationship characterizing unreliability.
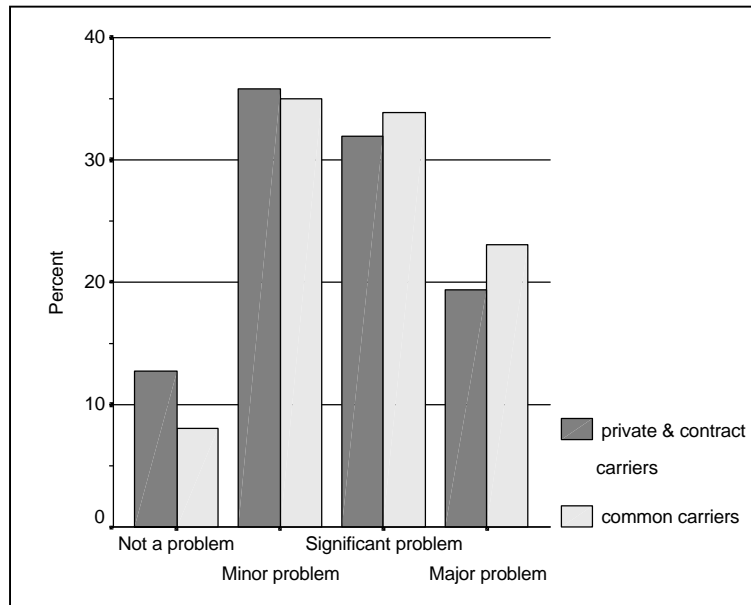
Figure 6: Ratings of the Problem of Higher Fuel and
Maintenance Costs due to Stop and Go Driving, Broken
Down by For-hire Versus Private and Contract-only
Carriers

A breakdown of the fifth and final aspect of the congestion problem, higher numbers of accidents and insurance costs, is shown in Figure 7. Once again, for-hire carriers consider this to be a more serious problem (τ_c = .088, corresponding to p = .007). However, this difference in perception is mostly confined to the "not a problem" and "significant problem" categories, as shown in Figure 7. Similar percentages of the two segments rated safety in this sense to be a major problem.

Finally, segment differences in terms of the perceived seriousness of the overall problem of congestion are depicted in the breakdown in Figure 8. Congestion is perceived to be more of an overall problem by for-hire carriers, but the differences between the segments, while significant at the p = .05 level, is relatively weak (τ_c = .066, corresponding to p = .022). One of our objectives was to determine if there are representatives of specific types of for-hire carrier or private and contract trucking operations who view congestion as a more critical problem than others
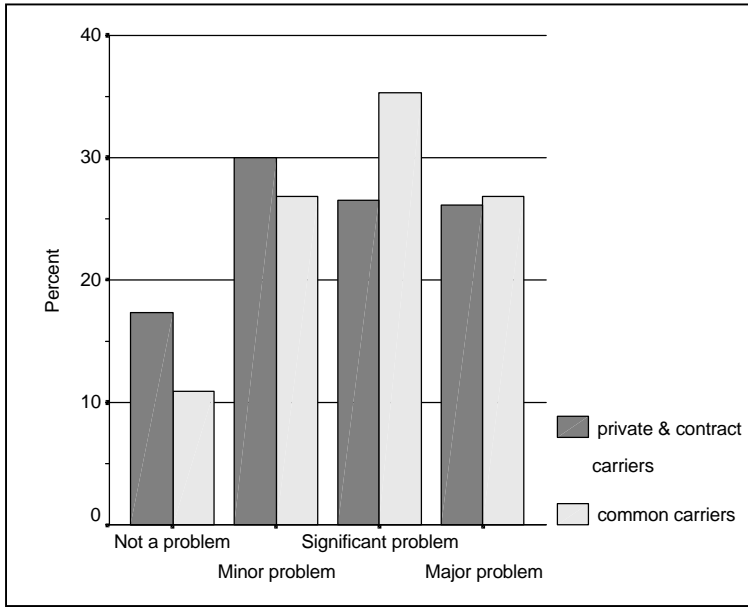
Figure 7: Ratings of the Problem of Higher Numbers of accidents and Insurance Costs, Broken Down by For-hire Versus Private and Contract-only Carriers
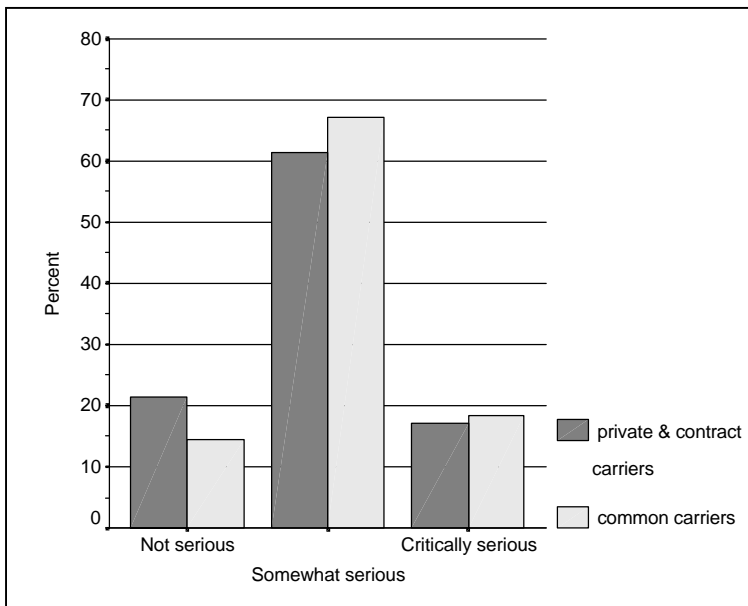

Figure 8: Ratings of the Seriousness of the Overall Problem of Congestion, Broken Down by For-hire Versus Private and Contract-only Carriers

Operational Characteristics

Next we examined other company characteristics in order to identify which ones appear to inform company perceptions of congestion. Nine characteristics were identified as having a statistically significant impact on company responses. These are companies with less than truckload operations; companies whose primary services are tank, refrigerated or bulk transport; companies with long average loaded moves (over 500 miles); and companies serving air, maritime or rail intermodal facilities.   The distributions of the nine variables for the two segments are shown in Table 3.

Table 3: The Exogenous Variables, Showing % in "yes" State for Each Dummy Variable (bar charts are scaled in 5% increments)

Characteristic	For-hire carriers (n = 611)	Private and contract-only carriers (n = 566)
Conducts some contract operations	■■■■■■■■■■■■■63.1%	■■■■■■28.1%
Carrier engages in LTL operations	■■■■■■■■40.1%	■■■■■■■■■45.6%
Primary service: tank transport	■6.9%	■3.5%
Primary service: refrigerated transport	■■■13.4%	■■9.9%
Primary service: bulk transport	■7.4%	■■■14.0%
Averaged loaded movement > 500 mi.	■■■■■■■■■45.7%	■■■■■22.6%
Delivers to or picks up at rail terminals	■■■■17.5%	■■9.4%
Delivers to or picks up at airports	■■■■21.8%	■■■16.1%
Delivers to or picks up at seaports	■■■■■■■■■■47.5%	■■■■■27.4%

Methodology

Overview

Methodological details are reviewed below. First, we present an overview for readers unfamiliar with structural equation models (SEM). The hypothesis examined by the model is that operational characteristics affect managers' perceptions of the extent and primary causes of traffic congestion problems. The operational characteristics serving as exogenous (independent) variables are listed in Table 3. We also use the model to test whether the relationships between operational characteristics and perceived problems are different for for-hire operations, versus private or contract-only operations.

There are six endogenous (dependent) variables in our model system. The first five of these are ratings of the seriousness of each of the aspects of the congestion problem identified in the previous Section: (1) higher costs because of slow average speeds, (2) scheduling problems due to unreliable travel times, (3) driver frustration and morale, (4) increased fuel and maintenance costs due to stop and go driving, and (5) higher number of accidents and insurance costs. Each of these first five endogenous variables are specified as regression functions of the nine exogenous variables. The sixth endogenous variable is the seriousness rating of the overall problem of congestion. This sixth endogenous variable is specified as a linear function of the first five endogenous variables.

With the SEM we can find which congestion problems are perceived to be most problematic by different types of companies. By using multi-group SEM methodology, we can test for differences between for-hire and private/contract-only carriers in terms of connections between operational characteristics and perceived problems and in terms of how the five aspects of congestion combine to explain the overall rating of the seriousness of the road congestion problem.

Our model system is divided into two sub-models of the form shown in the flow diagram of Figure 9. Each box in Figure 9 represents a variable and each arrow indicates a nonzero effects of one variable on another. The six boxes in the middle column of Figure 9 symbolize the endogenous variables, and the nine boxes on the sides symbolize the exogenous variables. The sub-models in the SEM are solved simultaneously. The values attached to the links shown in the figure represent, for each of the two industry segments, the extent to which the characteristics identified as significant affect the carriers' estimation of the significance of the individual and overall congestion problem. The links between the individual congestion problems and the overall congestion problem represent the extent to which the estimation of the extent of congestion overall is determined by responses to individual congestion related problems. The model cannot be rejected at the 0.05 level. We present the model specification details for interested readers in the next section. Readers wishing to begin with the results are encouraged to skip ahead to the Model Results Section.
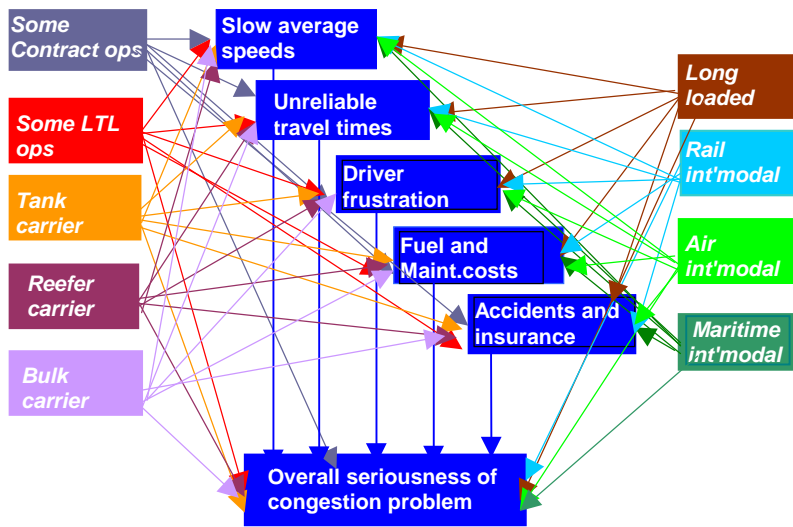
Figure 9: Flow Diagram of the Strucural Equation Models Illustrating the Sub-Model Structure

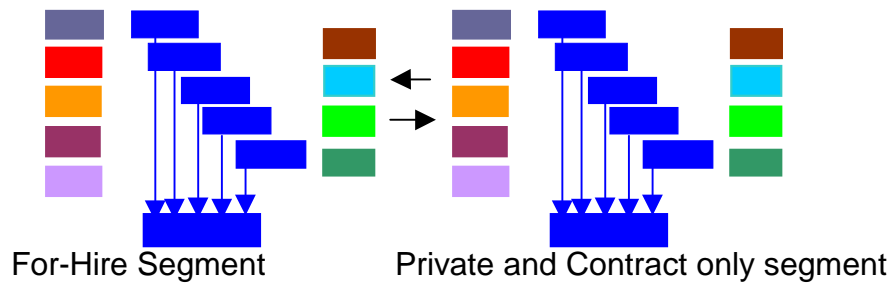For-Hire Segment   Private and Contract only segment

Figure 10: Overall Model Structure of Multi-Group Structural Equation Model Used to Test Equality of Structural Parameters Between For-Hire and Private Companies

Model Specification

The endogenous variables are all measured on ordinal (ordered categorical) scales. Consequently, the first step in the modeling is to convert the ordinal scales to continuous latent variables. For each observed ordinal variable y with c categories, we assume that there is a corresponding latent continuous variable y* which is normally distributed with mean zero and unit variance. Category k of the ordinal variable is observed if the latent variable is within a specific range defined by threshold (or, cut-points) on the distribution of the latent variable:

$$y = k \qquad iff \qquad \alpha_{k-1} < y^* \le \alpha_k \tag{1}$$

where $\alpha_0 < \alpha_1 \ldots < \alpha_c$, and $\alpha_0 = -\infty$ and $\alpha_k = \infty$. Our first five of the endogenous variables are measured in terms of four categories, so there are k = 3 thresholds, and the remaining endogenous variable has three categories and two thresholds.

The ordered-response probit model was designed just for such a problem. It was developed simultaneously by Aitchison and Silvey (1957) and Ashford (1959) as an extension of the binomial probit model used in discrete choice modeling (Maddala, 1983). The ordered probit model describes the probability of observing category j for observed variable y, conditional on the exogenous (**x**) variables:

$$
\begin{aligned}
P(y = k \,|\, x) \quad &= P(\alpha_{k-1} < y^* \le \alpha_k) \\
&= \Phi(\alpha_k - \omega' x) - \Phi(\alpha_{k-1} - \omega' x)
\end{aligned} \tag{2}
$$

where Φ denotes the standard cumulative normal distribution function and ω is a vector of reduced-form regression coefficients defining the conditional mean. The parameters are estimated using maximum likelihood (Maddala, 1983).

The latent variables can then be specified as simultaneous functions of themselves and of the exogenous variables. Our model requires that the first five endogenous variables are (regression) functions of the exogenous variables alone, but we must allow for the possibility that the error terms of these regression functions are correlated. The last endogenous variable, the seriousness of the overall problem of congestion, is specified as a function of the other five endogenous variables and the exogenous variables.

Our system can be defined in terms of a SEM without measurement models:

$$y^* = B\,y^* + \Gamma\,x + \zeta \tag{3}$$

where y* is the (6 by 1) vector of latent endogenous variables, x is the (9 by 1) vector of exogenous variables, and ζ is a (6 by 1) vector of errors in the equations. The variance-covariances matrix of these errors is defined as Ψ.

The structural parameters to be estimated are the elements of the B, Γ and Ψ matrices. The vector of all parameters is commonly denoted by θ. For identification of system (3),

the free parameters in matrix B must be chosen such that (I - B) is non-singular, where I denotes the identity matrix. A necessary and sufficient condition for identification is that the rank of the matrix given by

$$C = \left[(I - B) \mid -\Gamma \right] \tag{4}$$

must be equal to the number of endogenous variables minus one (here, the rank of C must be five).

The parameter matrices are specified to have the following forms. The beta matrix of causal links between the endogenous variables is specified as

$$\underset{(6\times6)}{B} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \beta_{6,1} & \beta_{6,2} & \beta_{6,3} & \beta_{6,4} & \beta_{6,5} & 0 \end{bmatrix} \tag{6}$$

where the elements $\beta_{I,j}$ represent free parameters which capture the relative contributions to overall seriousness of the congestion problem from each of the five specific problem areas. Because these parameters are to be estimated simultaneously with the parameters of the other matrices, the estimates of the relative contributions of the problem areas will be conditioned on the exogenous regression effects and on any non-zero error-term correlations.

As long as there are sufficient free parameters to satisfy the rank condition for identification (2), the gamma matrix of direct (regression) links from each of the observed exogenous variables to each latent endogenous variable is specified to have all non-zero elements which have coefficients that are significantly different from zero. It is logical to begin the search for an optimal gamma matrix by initially specifying as zero only those parameters that are found to be insignificant in the six separate ordered probit models, one for each of the six endogenous variables.

Because the last endogenous variable is specified as a function of the other endogenous variables the direct regression effects on each of the first five endogenous variables also affect the last endogenous variable via these paths. The total effects of the exogenous variables on the endogenous variables in a SEM of this type are given by

$$\Omega = (I - B)^{-1} \Gamma \tag{7}$$

which are known as the parameters of the reduced-form equations.

Finally, the matrix of error-term variance-covariances is specified to have free variance parameters on the main diagonal and non-zero covariance terms as are required to fit the model. It was anticipated that all covariances involving the errors of the equation for the last endogenous variable would be zero because of the postulated direct effects in the beta matrix. The variances of the ordered probit latent variables are defined as unity, so the estimated error-term variances for each of the variables must be bounded between one and zero if the model fits. Percentage of variance accounted for can be calculated as one minus the estimated error variances.

In multi-group structural equations modeling, used here, all of the parameter matrices are partitioned along a third, grouping or segmentation, variable, which in the present case is of order three, representing the four mode dependency segments described in Table 3. The default form of the model postulates that all structural parameters in the B, Γ and Ψ matrices are equal across the three segments. The equality restrictions are released where warranted by significant improvements in model goodness-of-fit. Multi-group modeling is a particularly powerful technique for finding statistically significant interactions between individual segmentation groups and structural parameters. An overview is provided by Bollen (1989).

Estimation Method

SEM systems of this type can be generally estimated using methods of moments (also known as variance analysis methods). The method proceeds by defining the sample variance-covariance matrix of the combined set of endogenous and exogenous variables, partitioned with the endogenous variables first:

$$S^g = \begin{bmatrix} S_{yy}^g & S_{yx}^g \\ S_{yx}^{g'} & S_{xx}^g \end{bmatrix}, \tag{8}$$

where S_{yy} denotes the variance-covariance matrix of the latent endogenous variables for group (segment) g (g = 1,2), S_{yx} denotes the covariance matrix between the latent endogenous and exogenous variables for this group, and S_{xx} denotes the variance-covariance matrix of the exogenous variables (which is taken as given). In this model, there are 6 endogenous variables and 9 exogenous variables, so S^g is a (15 by 15) symmetric matrix for each of the two segments.

Estimates of the correlations between each pair of latent endogenous variables are obtained using a maximum likelihood solution based on the cross-tabulations between the observed ordinal scales and the thresholds of the normal distributions determined in the first step of the model estimation. Each correlation between the two latent endogenous variables is the unobserved correlation of their bivariate normal distribution that would generate the cross-tabulations as a most likely outcome. They are known as polychoric correlation coefficients, and solution to the problem is described in Olsson (1979). Similarly, the unobserved correlation between each endogenous variable and

each continuous observed exogenous variable is known as polyserial correlation coefficient (Olsson, *et al.*, 1982).

The final stage of the estimation involves finding parameters such that the model-replicated variance-covariance matrix is as close as possible to the sample covariance matrix (3), according to some objective function. It can be easily shown using matrix algebra that the corresponding variance-covariance matrix replicated by an identified model system (1) with a given vector of structural parameters, θ, is

$$\sum(\theta) = \left[\begin{array}{c|c} (I-B)^{-1}(\Gamma\Phi\Gamma' + \Psi)\left[(I-B)^{-1}\right]' & \Phi\,\Gamma'(I-B)^{-1'} \\ \hline \Phi\,\Gamma'(I-B)^{-1} & \Phi \end{array} \right] \tag{9}$$

where $\Phi = S_{xx}$ is taken as given. An optimal vector of parameters is determined by finding vector $\hat{\theta}$ for which the model-implied covariance matrix (4) is as close as possible to the estimated matrix of polychoric and polyserial correlations (8) found in the previous step of the estimation. For continuous variables with observed product-moment correlations, it is appropriate to use normal-theory maximum likelihood (ML) estimation to define an objective function. However, ML assumptions do not hold for ordinal endogenous variables, and ML parameter estimates, while consistent, will have incorrect standard errors, and the method will yield incorrect goodness-of-fit (chi-square) statistics.

The method used to estimate parameters when a SEM has ordinal or otherwise censored observed endogenous variables is asymptotically distribution-free weighted least squares (ADF-WLS). The fitting function for ADF-WLS is

$$F_{\text{WLS}}^{g} = \left[s_g - \sigma(\theta_g)\right]' W^{-1}\left[s_g - \sigma(\theta_g)\right] \tag{10}$$

where s is a vector of polychoric and polyserial correlation coefficients for all pairs of latent endogenous and observed exogenous variables, $\sigma(\theta)$ is a vector of model-implicated correlations for the same variable pairs, and W is a positive-definite weight matrix, given by asymptotic estimates of the variances of the variances (fourth-order moments). Minimizing F_{WLS} implies that the parameter estimates are those that minimize the weighted sum of squared deviations of s from $\sigma(\theta)$. This is analogous to weighted least squares regression, but here the observed and predicted values are variances and covariances rather than raw observations. Browne (1982, 1984) has demonstrated that the ADF-WLS estimation based on objective function (10) will yield unbiased parameters estimates with asymptotically correct goodness-of-fit statistics. The method is also applicable to SEMs with measurement submodels (Golob and Hensher, 1998).

In multi-group SEMs, there is an observed and model-replicated variance-covariance matrix for each of the g = 1 to G groups, and the objective function becomes

$$F_{WLS} = \sum_{g=1}^{G} \left(\frac{N_g}{N} \right) F_{WLS}^g \qquad (11)$$

Here, we have G = 2 segments, for-hire carriers and private/contract-only carriers. Estimation was performed using the LISREL 8 and PRELIS 2 suite of programs (Jöreskog and Sörbom, 1993a,b). Other software is also available for ADF-WLS estimation of SEMs (e.g., EQS: Bentler, 1989).

Model Results

Model Fit

The chi-square value for the estimated model, derived from the fitting function (11), is 85.01 with 108 degrees of freedom. This corresponds to a probability value of $p = .950$. This means that the fitted model cannot be rejected at the $p = .05$ level. The model has 42 free parameters. In terms of the model specification of equation system (3), these parameters represent 6 direct effects between endogenous variables (B matrix elements), 26 exogenous effects (Γ matrix elements), 6 (Ψ matrix) error-term variances and 4 (Ψ) error-term covariances. The estimated direct effects of the twelve exogenous variables on the six endogenous latent variables are listed in Tables A.1 (for-hire carrier segment) and A.2 (private carrier segment) of the Appendix. These are the Γ matrices in equation system (3), simultaneously estimated for the two segments, shown transposed. The estimated variance-covariances of the error terms for the latent endogenous variables are listed in Table A.3. All estimated variances and covariances are identical for the two segments. These results are interpreted in the remainder of this Section.

Industry-sector Differences in Aspects of the Congestion Problem

For each of the five potential congestion problem areas, the direct effects of the exogenous variables tell us which types of trucking operations perceive that particular problem to be more or less serious than average. (These direct effects for the first five endogenous variables are equal to the total effects, given by equation (7), because there are no links between the first five endogenous variables.) Table 4 summarizes the coefficient estimates for the two segments given in Tables A.1 and A.2.

Slow Average Speeds

Carriers serving airports and those providing refrigerated services are more troubled than other carriers by slow average travel speeds caused by congestion. In addition, in the private and contract-only market segment, contract and bulk carriers are less troubled by slow average travel speeds than other carriers. The lesser effect of slow average speeds on contract-only carriers indicates that these carriers have compensated for speeds in their scheduling and costing out of services.

Unreliable Travel times

Unreliable travel times are more of a perceived problem for all types of carriers serving airports. This reflects the need for on-time delivery to meet flight schedules. Unreliable travel times are less of a perceived problem for all types of bulk carriers. They are also less of a problem for tank carriers in the private and contract-only segment. We

suspect that these carriers are more often driving well known routes on which drivers find ways to avoid recurring congestion wherever possible.

Table 4: Summary of the Exogenous Explanations of the Five Problem Areas

Problem caused by congestion	For-hire carrier segment		Private and contract-only segment	
	More Serious for	Less Serious for	More Serious for	Less Serious for
Slow average speeds	Intermodal air Refrigerated		Intermodal air Refrigerated	Contract carriers Bulk carriers
Unreliable travel times	Intermodal air	Bulk carriers	Intermodal air	Bulk carriers Tank carriers
Driver frustration and morale	Long Load Intermodal air Tank carrier	LTL carriers	Long Loads Refrigerated Tank carriers	LTL carriers
Fuel and maintenance costs	Long loads	Bulk carriers	Refrigerated	
Accidents and insurance	Tank carriers	LTL carriers	Refrigerated Contract carrier	

Driver Frustration and Morale

Driver frustration and morale is a aspect of the congestion problem particularly cited by all types of carriers with long loaded movements and tank carriers. It is also more of a problem for for-hire carriers serving airports. In the private and contract-only segment, driver frustration and morale is more of a problem for carriers specializing in refrigerated services. Carriers whose main service is less-than-truckload (LTL) deliveries, have less of a problem with driver frustration and morale caused by traffic congestion. We suspect this is because a higher proportion of LTL drivers work in local or regional operations than other drivers. Even if the operations of the company are national in scope many drivers are confided to areas they are familiar with. In addition, drivers working in local operations are much more likely than long distance drivers to be paid for hours worked rather than miles driven.

Fuel and maintenance Costs

For-hire carriers with long loaded movements are more likely to perceive increased fuel and maintenance costs as an important aspect the congestion problem. In the private and contract-only sector, carriers specializing in refrigerated services are likely to consider fuel and maintenance costs to be a more of a major problem. In opposition, this aspect of congestion is less of a problem for bulk carriers in the for-hire sector.

Accidents and insurance

The final problem area is increased accidents and insurance due to traffic congestion. Here, there are substantial differences between the for-hire and private/contract-only carrier segments. Among types of for-hire carriers, this aspect is more of a problem for companies specializing in tanker services.   It is less of a problem for for-hire LTL carriers.   Accidents, problematic for any carrier are especially disastrous for tank carriers, many of whom carry hazardous materials.   Among types of private and contract-only carriers, increased costs due to accidents and insurance is more of a problem for carriers specializing in refrigerated services and for contract-only carriers in general.

Industry-sector Differences in the Overall Seriousness of the Congestion Problem

The exogenous explanations of the final endogenous variable, the overall seriousness of the congestion problem for each respondent's business, must be calculated from the direct exogenous and endogenous effects using equation (7) for total (reduced form) effects, because of the multiple paths by which an exogenous variable can affect the overall seriousness variable through its effects on the problem components. These total effects are listed in Table 5. They are directly comparable, because the latent endogenous variable is standardized with unit variance for each segment.

Intermodal operations are the most important characteristics in terms of explaining the overall seriousness of the traffic congestion problem to trucking companies. If any type of carrier, either a for-hire and or a private or contract-only carrier, serves airports, traffic congestion is more likely to be viewed as a serious problem. In addition, private and contract-only carriers that serve either rail terminals or (to a lesser extent) seaports perceive traffic congestion to be a more serious problem than carriers who do not engage in intermodal operations.   Rail terminals and ports tend to be in urban areas, and congestion near the busiest ports and rail terminals is problematic. Rail schedules and port operating hours force intermodal carriers to work during peak hours.

Table 5: Total Effects of the Exogenous Variables on the Sixth Endogenous Variable:
Overall Seriousness of the Congestion Problem

Exogenous Variable	For-hire carrier segment		Private and contract-only segment	
	Effect	**z-statistic**	**Effect**	**z-statistic**
Conducts some contract operations	-.050	-3.24	-.070	-4.55
Carrier engages in LTL operations	-.028	-3.47	0.063	7.13
Primary service: tank transport	-.021	-1.79	-.039	-3.09
Primary service: refrigerated transport	0.012	3.03	0.070	8.09
Primary service: bulk transport	-.029	-3.77	-.032	-4.20
Averaged loaded movement > 500 mi.	-.027	-1.19	0.025	1.09
Delivers to or picks up at rail terminals	--	--	0.144	7.67
Delivers to or picks up at airports	0.102	5.84	0.086	4.91
Delivers to or picks up at seaports	--	--	0.041	1.97

Provision of refrigerated services also helps to explain the seriousness with which
carriers view the overall traffic congestion problem for all types of carriers. However,
there is a significant difference between the for-hire and private/contract-only segments
in terms of the relationship between LTL operations and the perceived overall
seriousness of the traffic congestion problem. For-hire LTL carriers perceive the traffic
congestion problem to be less serious, *ceteris paribus*, while private and contract-only
LTL carriers perceive the problem to be more serious, *ceteris paribus* (both effects
being statistically significant at the *p* < .01 level).

Contributions to the Overall Problem of Congestion

The estimated endogenous effects specified in the beta matrix (6) were found to be
equal across the two segments for all of the problem areas with one exception: higher
numbers of accidents and insurance costs, which contributes more to the overall
problem perceived by operators in the private and contract-only segment.   The
estimates of β_{61} through β_{65} for the two segments are given in Table 6.

For both for-hire and private carriers, scheduling problems due to unreliable travel times
is the most important component of the congestion problem. For for-hire carriers, the
least important component is higher accidents and insurance costs, but for private
carriers, accidents and insurance costs are more equivalent to the other components.
The cause of this difference is likely the fact that many of the managers in the for-hire

segment work with large numbers of owner-operators who share the burden of insurance costs.

Table 6: Estimated Contributions of the Five Congestion Problem Areas to the Overall Problem of Congestion

Component of overall problem	For-hire carrier segment		Private and contract-only segment	
	Coefficient	z-statistic	Coefficient	z-statistic
Slow average speeds	0.175	7.99	0.175	7.99
Unreliable travel times	0.202	10.00	0.202	10.00
Driver frustration	0.188	7.96	0.188	7.96
Fuel and maintenance costs	0.166	6.90	0.166	6.90
Accidents and insurance	0.090	2.78	0.159	5.47

Conclusions

More than 80% of the managers of 1,177 trucking companies operating in California consider traffic congestion on freeways and surface streets to be either a "somewhat serious" or "critically serious" problem for their business. The managers also rated five aspects of congestion -- slow average speeds, unreliable travel times, increased driver frustration and morale, higher fuel and maintenance costs, and higher costs of accidents and insurance – on the basis of how much of a problem that aspect was for their operations. A structural equation model specifically designed for ordinal-scale endogenous variables was used to identify significant relationships between operating characteristics and the severity of each of these five aspects of congestion, while simultaneously estimating the contributions of each aspects to the overall magnitude of the perceived congestion problem. Results show that the perceived problems of road congestion vary systematically across sectors of the trucking industry.

Overall, road congestion is perceived to be a more serious problem by managers of trucking companies engaged in intermodal operations, particularly private and for-hire trucking companies serving airports and private companies serving rail terminals. Companies specializing in refrigerated transport also perceive congestion to be a more serious overall problem, as do private companies engaged in LTL operations.

The most problematic aspect of congestion is unreliable travel times. This is followed by driver frustration and morale, then by slow average speeds. Unreliable travel times

are a significantly more serious problem for intermodal air operations in both the for-hire and private sectors. Unreliable travel times are less of a serious problem for bulk carriers and private carriers specializing in tanker services. Driver frustration and morale attributable to congestion is perceived to be more of a problem by managers of long-haul carriers and tanker operations, and by for-hire airport and private refrigerated operations. Slow average speeds are also more of a concern for airport and refrigerated operations, while being less of a concern for contract-only carriers and private bulk carriers.

Transportation planners concerned about improving the efficiency of freight operations through potential ITS and infrastructure investments can use these results to help identify sectors of the trucking industry that are most likely to benefit from and support different types of improvements.

Acknowledgments

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Appendix: Parameter Estimates

Table A.1: Estimated Direct Exogenous Effects: For-hire Carrier Segment
Coefficients Equal in Both Segments Shown Bold
(asymptotic z-statistics in parentheses)

Exogenous variable	Perceived problem caused by congestion					Overall serious-ness of the problem
	Slow average speeds	Unreliable travel times	Driver frustration	Fuel and maint. Costs	Accidents and insurance	
Conducts some contract operations						**-.050** **(-3.24)**
Carrier engages in LTL operations			**-.104** **(-4.05)**		-.097 (-2.54)	
Primary service: tank transport			**0.048** **(2.20)**		0.092 (3.50)	**-.038** **(-3.31)**
Primary service: refrigerated transport	**0.071** **(3.08)**					
Primary service: bulk transport		**-.086** **(-3.95)**		-.072 (-2.26)		
Averaged loaded movement > 500 mi.			**0.130** **(5.42)**	0.142 (4.28)		-.075 (-3.35)
Delivers to or picks up at rail terminals						
Delivers to or picks up at airports	**0.082** **(3.18)**	**0.079** **(3.22)**	0.083 (2.41)			**0.056** **(3.50)**
Delivers to or picks up at seaports						

Table A.2: Estimated Direct Exogenous Effects: Private and contract-only Carrier Segment. Coefficients Equal in Both Segments Shown Bold
(asymptotic z-statistics in parentheses)

Exogenous variable	Perceived problem caused by congestion					Overall serious-ness of the problem
	Slow average speeds	Unreliable travel times	Driver frustration	Fuel and maint. Costs	Accidents and insurance	
Conducts some contract operations	-.194 (-5.39)				0.084 (2.22)	**-.050** **(-3.24)**
Carrier engages in LTL operations			**-.104** **(-4.05)**			0.082 (3.68)
Primary service: tank transport		-.048 (-2.11)	**0.048** **(2.20)**			**-.038** **(-3.31)**
Primary service: refrigerated transport	**0.071** **(3.08)**		0.114 (3.34)	0.133 (4.22)	0.087 (2.27)	
Primary service: bulk transport	-.087 (-2.55)	**-.086** **(-3.95)**				
Averaged loaded movement > 500 mi.			**0.130** **(5.42)**			
Delivers to or picks up at rail terminals						0.144 (7.67)
Delivers to or picks up at airports	**0.082** **(3.18)**	**0.079** **(3.22)**				**0.056** **(3.50)**
Delivers to or picks up at seaports						0.041 (1.97)

Table A.3: Estimated Variance-covariances of the Errors in Equations
(asymptotic z-statistics in parentheses)

	Slow average speeds	Unreliable travel times	Driver frustration	Fuel and maint'nce Costs	Accidents and insurance	Overall serious-ness of problem
Slow average speeds	0.970 (23.04)					
Unreliable travel times	0.263[1] (7.23)	0.987 (23.69)				
Driver frustration and morale		0.247 (9.48)	0.952 (22.40)			
Fuel and maintenance costs				0.974 (23.21)		
Accidents and insurance	-.078 (-2.79)				0.980 (23.4)	
Overall seriousness of problem						0.792 (15.19)

[1] parameter is = 0.149 (7.29) for the private carrier segment