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Analysis of Pavement Damage Attributable to Overweight Trucks in New Jersey

RICARDO T. BARROS

ABSTRACT

A study was undertaken to quantify the magnitude of the pavement damage done by overweight trucks in New Jersey. This was accomplished using the AASHTO 18-kip equivalent axle load parameter, established engineering-economic procedures, and data obtained from the New Jersey State Police. Questions specifically addressed include (a) How much pavement damage is attributable to overweight trucks? (b) What are the costs associated with this damage? (c) Are these costs adequately covered by the revenues collected from the overweight violators? (d) Is mandatory off-loading (requiring violators to immediately lighten their loads at the ticketed location) justifiable? It was found that detected overweight trucks cause a relatively small shortening of pavement life and, had they been successfully off-loaded, a negligible savings would have resulted. However, there is serious concern that the number of overweight trucks actually detected represents only a small fraction of the total number of overweight violators. Attempts to estimate the total overweight truck population suggest that the total pavement damage attributable to all overweight trucks may approach $20 million per year. It was therefore concluded that a substantial increase in the revenue generated by overweight trucks may be appropriate.

The consequences of operating overweight trucks are a timely concern, particularly in light of the Surface Transportation Assistance Act (STAA) of 1982 that standardized truck size and weight restrictions across the nation. This analysis, requested by the Office of the Attorney General of New Jersey, specifically addresses the engineering and economic implications of excessive pavement loading in a state where maximum weight limits already comply with the federally mandated standards (1). Knowledge of these implications should provide guidance in making policy decisions pertinent to the mode and level of truck weight enforcement. This required that pavement damage be defined in terms of an established parameter and that the extent of this damage be quantified in a rational manner.

It is common knowledge to highway engineers that pavement damage increases dramatically with increasing vehicle weights. A legal, fully loaded tractor trailer combination may cause approximately 10,000 times the pavement damage caused by the heaviest of passenger cars. Intuitively, it might appear that illegally loaded trucks would cause substantially more damage than their legally loaded counterparts. However, this inference is only partly correct.

Analysis of the comparative pavement damage resulting from the myriad possible vehicle loadings is conveniently accomplished with the AASHTO 18-kip (18,000-lb) equivalent axle load (EAL) parameter (2, pp. 162-167). This parameter was developed to provide a common basis against which to assess the effect of repetitive loads on pavement serviceability. It permits information on vehicle configuration and weight on each axle grouping to be transformed into a single fundamental parameter, expressed as multiples of the pavement damage done by the standard 18-kip single axle load used in pavement design. A 28-kip load on a tandem axle on a 9-in. rigid pavement, for example, will ordinarily cause only 85 percent of the damage that would be done were an 18-kip load on a single axle applied to the same pavement. Thus the 28-kip tandem axle load may be described as doing 0.85 EAL damage. Given a specified pavement, either flexible or rigid, a measure of the pavement's strength, and a definition of the condition beyond which the pavement's serviceability is considered unsatisfactory, the EAL impact of any vehicle is simply summed from the EALs of each contributory axle group.

EAL analyses are straightforward and make it possible to quantify the relative damage sustained by a pavement for any specified combination of axle type, axle load, and pavement structure. Then, to predict the wear and tear actually sustained by a pavement, it is necessary to estimate the frequency with which each type of loading will be applied. Thus the distribution of vehicle types, as well as the frequency distribution for each vehicle type, must be considered in estimating the serviceability extracted from a pavement by the traffic loading.

If the applied traffic loading is known, and if a pavement's strength can be characterized, the EAL parameter can be used to estimate both the pavement damage and the economic loss resulting from overweight trucks. The following questions have been addressed in this analysis:

1. How much pavement damage is attributable to detected overweight trucks?
2. How much pavement damage is attributable to all overweight trucks?
3. What costs are associated with this damage?
4. Does the existing overweight fine structure adequately cover the losses suffered by the highway agency?
5. Is mandatory off-loading of excess weight (requiring overweight violators to immediately lighten their loads at the ticketed location) justifiable?
6. Finally, from a broader perspective, what toll would be exacted from the pavement system if

the enforcement program caused the same load to be carried by a larger number of legally loaded trucks?

SOME BASIC ASSUMPTIONS

Despite the narrow focus of the five questions posed, the scope of the analytical techniques used in their resolution was exceptionally broad. Statistical, engineering, and economic methods were used to transform raw overweight violation data into a meaningful indicator of marginal pavement damage in order to determine the efficacy of selected enforcement policies. This required that several assumptions be made. The most general of these were that

1. The AASHTO EAL parameter provides a rational means by which to apportion the consumption of pavement serviceability among the various vehicles using a roadway, and an increased rate of EAL application will proportionately reduce the life of a pavement.
2. Summonses issued by the state police for truck weight violations represent genuine excess loadings and culminate in the payment of legally prescribed fines. Also, the nature and total number of all overweight violators are approximately estimable from the summonses issued.
3. The characteristics of the overweight truck fleet observed in one year can be assumed to represent the characteristics of overweight truck fleets in future years.
4. The net cost associated with rescheduling planned overlays to earlier dates, plus the cost of truck weight enforcement, plus the (unquantified) cost in bridge damage, all expressed as their present worth, constitute the total economic loss exclusively attributable to overweight trucks.

OVERWEIGHT TRUCK DATA

The New Jersey State Police is the primary agency responsible for truck weight enforcement in New Jersey. Both portable and permanent weigh scales are used in this effort. Trucks found to exceed statutory weight limits are issued summonses for a violation of the Motor Vehicle Code and more than 9,000 summonses for overweight violations were issued in FY 1981. A sample of 2,265 violators taken from this population was used in this analysis, and the results were scaled upward to include the effect of unsampled citations. The sampled information included the distribution of actual and allowable weights as well as the class of road on which the violators were traveling. (Roads were classified as Interstate, state, or local and county.)

There is some doubt that detected overweight violators provide a representative sample of the entire overweight truck population because several potential biasing factors are readily apparent. First, permanent weigh stations have generally established hours of operation and known periods of inactivity. For example, they may not operate on weekends. It is reasonable to assume that an experienced driver who knew he was operating an overweight vehicle would choose an alternate route during those hours during which permanent weigh stations were open. For precisely this reason, portable weigh scales are strategically deployed. Certainly, the first trucks stopped at the permanent weigh stations may provide an unbiased glimpse of the overall overweight truck population, but the ubiquitous communication network made possible by citizens' band radios quickly alerts oncoming trucks to the weighing activity. It is suspected that some trucks that do not choose an alternate route may simply pull to the side to outwait the scale's operation (3,p.69). Also, roving enforcers selectively pull over individual trucks that display signs of a weight violation, such as slow speeds on inclines or an overly large tire imprint. Because of the overweight indications themselves, these enforcers are much more likely to detect a large weight violation than a small one. Finally, the correspondence between the number of detected violators and the total number of violators is difficult to establish. Summonses issued depend on several factors, including the size of the enforcement task force and the enforcement effort, so that any attempt to estimate the total number of violators as a multiple of the number of summonses issued is approximate at best.

Despite these numerous obstacles, an attempt is made to estimate the impact of all overweight trucks (both detected and undetected) in a later section. To take in this broader perspective, an admittedly lower degree of precision must be tolerated. Nevertheless, it is believed that this analytical methodology provides the best information currently available.

TRUCK WEIGHT VIOLATIONS AND FINES

In New Jersey there are several types of possible excess weight violations. A maximum load of 22.4 kips is allowed on any single axle, a maximum load of 34.0 kips is allowed on any tandem axle, and the maximum allowable gross weight is 80.0 kips for any truck. In addition, trucks may register at a lesser gross vehicle weight and pay a correspondingly reduced registration fee. This provision makes registered weight violations possible. That is, a truck registered to carry 10,000 lb may be cited when it transports an 11,000-lb load, even though this load is well below the 22,400 lb allowed on any one axle. Other violation types include triaxle violations and other vehicle-specific limits, such as a limit specifically applicable to a solid waste truck with a triaxle configuration. It should be noted that whenever a truck is found to be in violation of several limits simultaneously, the statute (before September 1983) permitted a court to assess only the single penalty associated with the largest fine. Thus only a tandem axle violation would be charged if a truck exceeded the tandem axle limit by a greater amount than it did the maximum gross weight limit.

A summary of one year's violation data is given in Table 1 and the frequency distributions for several of these violation types are shown in Figure 1. It can be seen that these distributions have a strong tendency to skew away from their respective limits and that only a small portion of the violations exceed their respective limits by more than 10,000 lb.

The overweight fine schedule used in New Jersey before September 1983 is given in Table 2. Applica-

TABLE 1 Frequency of Known Weight Violators by Cited Violation Type

Violation Type	Total Known Violations	Total Excess Weight (kips)	Average Excess Weight per Violation (lb)
Single axle	816	3,036.6	3,721
Tandem axle	4,752	22,858.1	4,810
Gross weight	1,392	9,493.9	6,820
Registered	1,500	7,473.9	4,982
Other	600	4,258.9	7,098
Total	9,060	47,120.5	

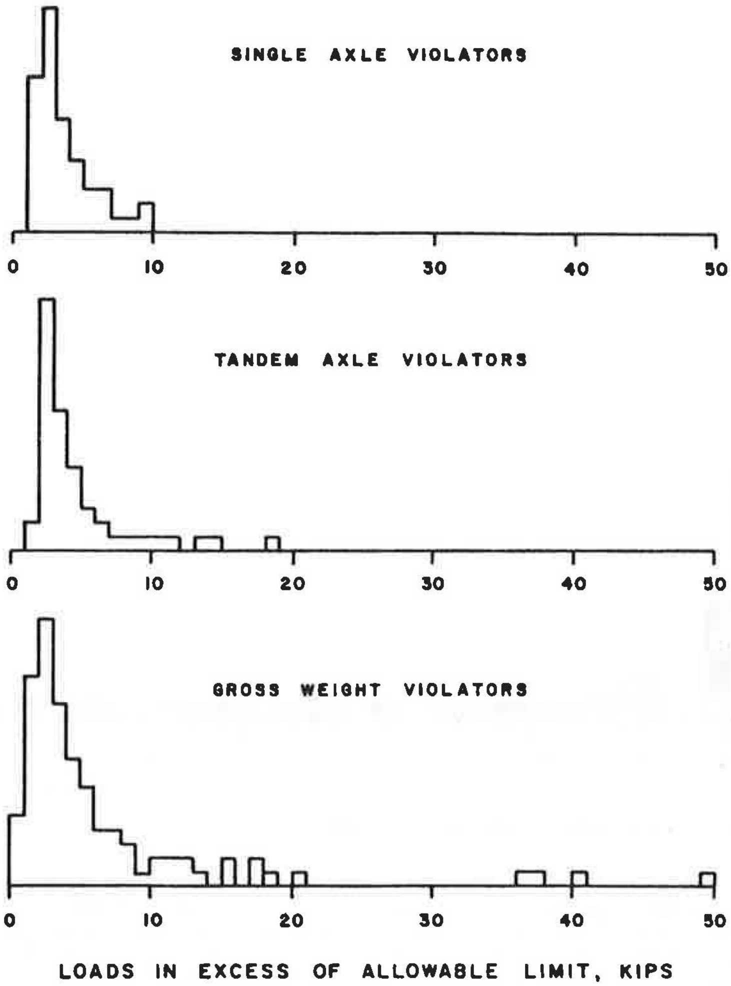

FIGURE 1 Relative frequencies of excessive weights for three violation types.

TABLE 2 New Jersey's Fine Schedule for Overweight Trucks Before September 1983

Excess Weight (lb)	Penalty ($)
0.0 to 2,500.0	50.00
2,500.1 to 10,000.0	0.02 per excess pound above legal limit
10,000.1 and more	0.03 per excess pound above legal limit

tion of this schedule to the truck fleet modeled in this analysis results in an annual revenue of $1.1 million, a figure consistent with actual data (source: Magistrates Fines Sections, New Jersey Department of Transportation).

The relative frequency distribution of assessed fines is shown in Figure 2. The distribution is discontinuous because of the abrupt increase in the penalty rate whenever excess weights exceed 10,000 lb. It is interesting to note that 91 percent of the violators would be charged less than $200 and that the other 9 percent, who are charged more, account for approximately 25 percent of the total revenue.

PAVEMENT DAMAGE MODEL

Pavements are designed and constructed with the knowledge that they will ultimately wear out. In practice, rehabilitation procedures are implemented before complete failure occurs and, consequently, a means by which to gauge the serviceability rendered must be established. Two of the possible approaches in modeling pavement serviceability would apply either mechanistic or empirical analyses. Mechanistic analyses are sophisticated, highly detailed investigations of the load distribution within a pavement structure and of the associated stresses and strains. They offer the advantage of isolating specific pavement failure modes, such as excessive rutting or cracking, but may be criticized for an overstated precision. Empirical analyses have an unabashedly straightforward derivation--materials, design elements, and construction techniques are correlated with service. Thus empirically based models provide a coarser level of information, but this information is more easily obtained and more easily digested. The following analysis will make use of the 18-kip equivalent axle load (EAL) parameter that represents an empirical-type model.

According to the AASHTO design procedure (4), pavements are designed to carry a specified number of loads during a predetermined period of time. Typically, for a rigid pavement, this may be 10 million EALs over a 20-year life. Assuming, for the sake of simplicity, a constant annual traffic flow, this corresponds to a design value of 500,000 EALs per year. If trucks operating over a pavement apply loads equivalent to 50,000 EALs annually, it can be stated that 10 percent of the pavement's service-

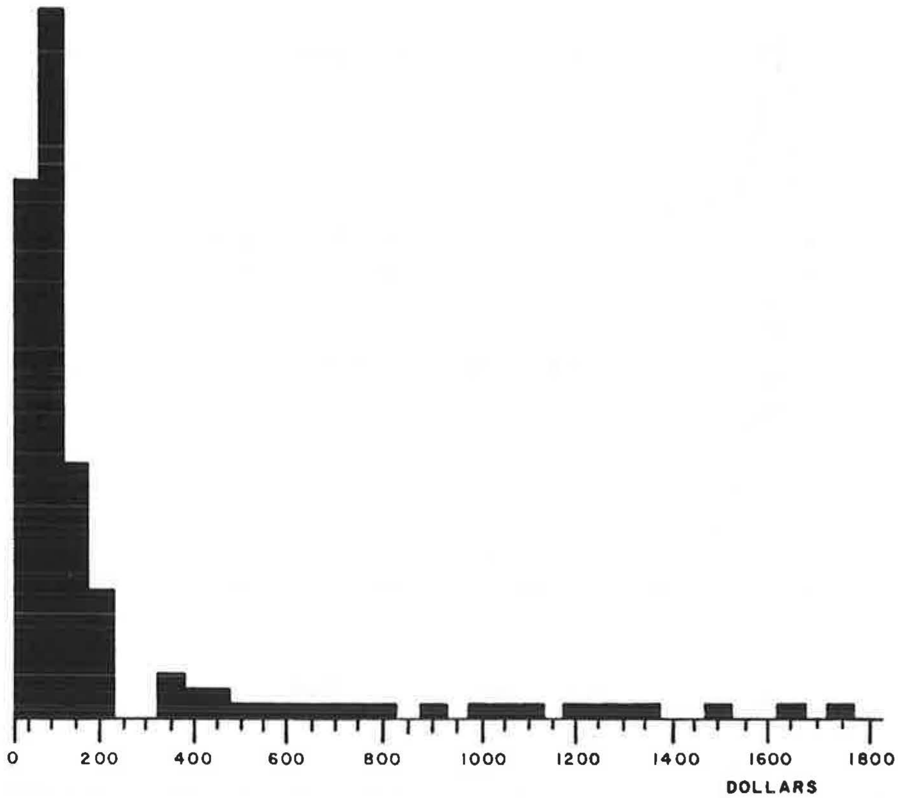

FIGURE 2 Relative frequency histogram of assessed fines.

ability is apportioned to this type of traffic. If the pavement damage attributable to trucks were to double, 20 percent of the design EALs would be exhausted by trucks, and it is assumed that the pavement would fail proportionately sooner.

The analytical model was based primarily on this relationship. Although highway engineers do allow for truck traffic in their pavement designs, usually planning on 10 to 30 percent trucks in the traffic mix, it is unlikely that they contemplate overweight trucks on a regular basis. Thus all overweight trucks are considered to be unplanned pavement loadings. These loadings reduce the predicted pavement life from its design value, resulting in an associated cost that can be reasonably quantified.

The development of a pavement utilization model required that several specific determinations be made, and these will be summarized briefly. The first of these was to develop a model truck fleet. This was necessary because actual violation data were not fully descriptive of the violating vehicle. In the case of single-axle and tandem-axle violations, raw violation data pertained exclusively to the violating axle group. In the cases of gross-weight and registered-weight violations, raw violation data pertained to the overall weight and not to axle-specific loadings. In all cases it was necessary to describe each violation in terms of an appropriate hypothetical truck for which all axle groups and axle loadings were known. Determination of the possible truck configurations was based on an auxiliary, detailed sample and resulted in a truck fleet partially shown in Figure 3. These truck configurations were used to estimate gross truck weights from single- and tandem-axle violation data, which include unreported axle groups, and to reduce gross- and registered-weight violations to axle-specific loadings.

The second preliminary determination involved the development of a typical New Jersey road over which the modeled trucks would travel. Approximately two-thirds of New Jersey's state roads are of flexible pavement, including composite pavement (rigid pavement overlaid with bituminous material), and about one-third is rigid pavement. It was assumed that all flexible pavements have a structural number of 5.0, reflecting a relatively strong section. New Jersey's rigid pavements are commonly 9.0 in. thick. Interstate pavements were reasoned to be at least as strong as state-owned pavements and, although local and county roads are generally less strong and predominantly bituminous, local and county pavements are also assigned a structural number of 5.0. (In the aggregate, assigning local and county roads a conservatively low structural number of 2.0 produced a negligible effect on the cumulative damage estimate.)

A typical mile of New Jersey pavement, therefore, was modeled in two sections: one-third rigid pavement, 9.0 in. thick, and two-thirds flexible pavement with a structural number of 5.0. On the basis of typical design considerations, 500,000 EALs are apportioned to each year of the pavement's design life. (This corresponds to roughly 10 million EALs over 20 years for rigid pavements and to 5 million EALs over 10 years for flexible pavements. Or, pooling these values for New Jersey pavements, maximum design values are 6.7 million EALs over a 13.3-year life. A terminal serviceability index of 2.5 was assumed.)

As the data given in Table 3 indicate, the 9,060 trucks ticketed annually for overweight violations were estimated by the model to cause 38,146 EALs of pavement damage. This corresponds to a 7.63 percent loss in pavement life. That is, of the 500,000 EALs designed to be exhausted in a 1-year period, 7.63 percent were illegally consumed by overweight trucks.

It may reasonably be argued that important bene-

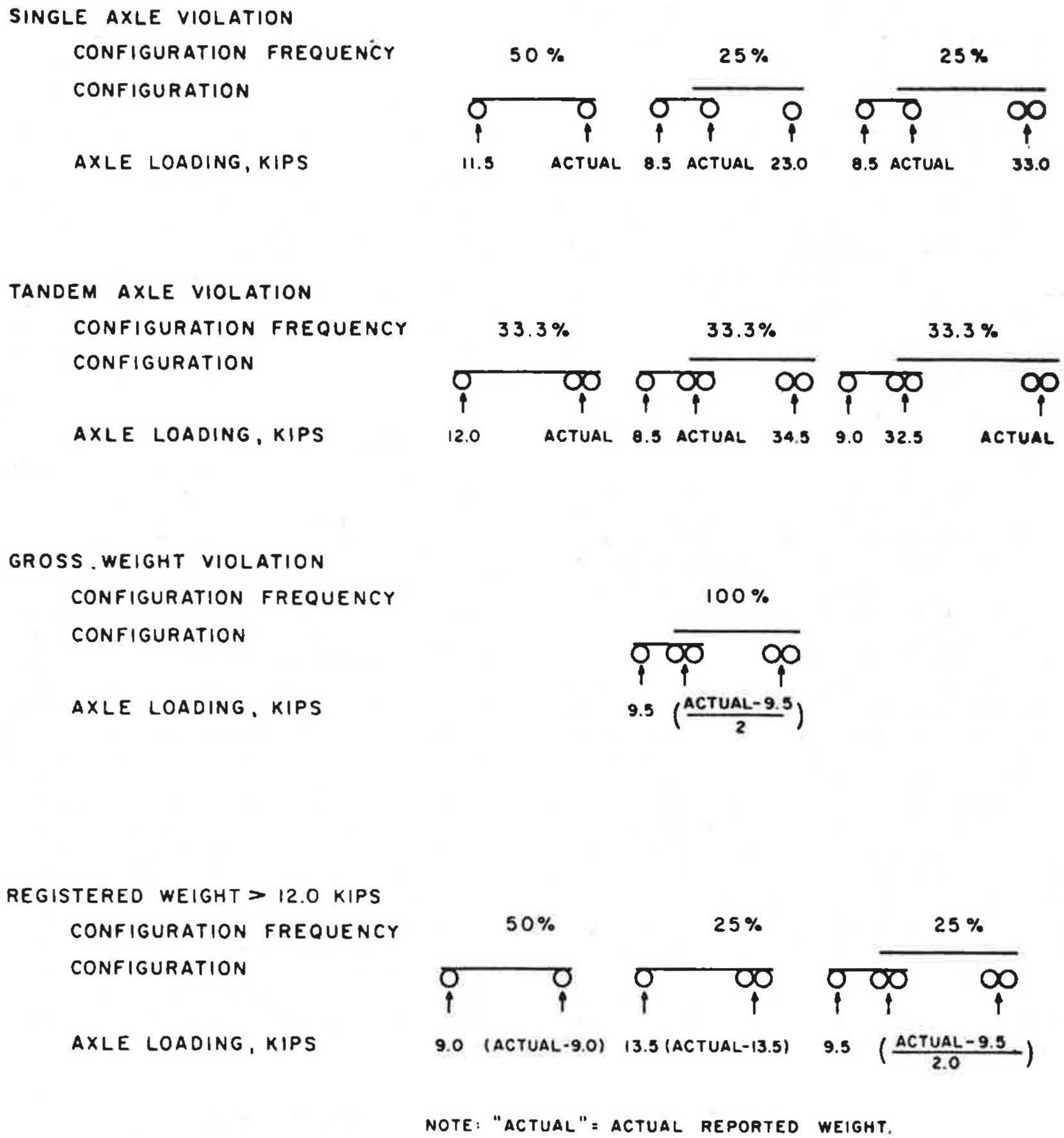

FIGURE 3 Selected truck configuration and axle loadings by violation type.

TABLE 3 Annual Pavement Serviceability Consumed by Known Overweight Trucks and by a Hypothetical Fleet of Legalized Trucks

Fleet	Trucks in Fleet	Gross Fleet Weight (kips)	Modeled 18-kip EAL	Modeled 18-kip EAL as a Percentage of Design
Actual	9,060	576,030	38,146	7.63
Legalized	10,190	607,560	30,869	6.17
Difference: (legalized minus actual)	+1,130	+31,530	-7,277	-1.46

Note: Additional trucks dispatched for all but registered-weight violations.

fits were derived from the transportation of the overweight cargos, although these cargos need not have been transported illegally. Therefore, to model the pavement damage that must be tolerated to maintain these same benefits, more trucks must be added to the traffic mix. These trucks would carry the excess loads of the overweight trucks so that all weights are reduced to the legal limits. The fleet of additional trucks was modeled as the required number of legal, fully loaded rigs the axle configurations of which were the same as the configurations of the trucks cited for being overweight.

The data in Table 3 indicate that an additional 1,130 trucks would be added to the traffic mix if the same loads were to be carried legally. Because each of these trucks would also introduce its tare weight, the pavement would be required to carry an additional 31,530 kips over a 1-year period. But, because each of the individual axle groupings would now carry less weight, the overall EAL loss would be only 6.17 percent per year of the intended design. In other words, assuming that the same amount of goods is hauled by either fleet, the net loss in service life attributable to detected overweight violations is 7.63 less 6.17 or approximately 1.5 percent.

ECONOMIC IMPACT MODEL

Although the quantified loss in pavement life is relatively small, capital and operating expenses associated with ownership of a pavement may be large enough to inflate the associated dollar loss beyond levels that should be reasonably tolerated. Therefore it is necessary to estimate the economic impact of this loss and determine whether the existing fine structure will generate sufficient revenue to cover it.

Two basically different methods have been proposed with which to estimate and apportion pavement-related costs. One computes the cost of the materials required to produce a pavement with the minimum structural number required to carry the designated loads. This approach would be suitable for analyses involving the capital expenditures associated with the construction of a new pavement but is considered inappropriate here. A second approach, which is more directly related to pavement maintenance, was used in this analysis. In this second approach, the cost of the several generations of overlays implicitly planned in a pavement's design is compared to the larger costs that will be incurred as the consequence of a premature loss of serviceability due to overweight trucks. That is, for the same time span, the overlay cost associated with the planned design loadings is compared to the total overlay cost associated with the unplanned, increased vehicle loadings. The present worth of the difference between these two costs is one measure of the economic damage done by overweight trucks. The basic concept underlying this approach is discussed in a recent paper (5) and is shown in Figure 4.

In New Jersey's overall roadway system, the population of existing pavements includes a broad range of ages. Some roads have been built recently, others are older, and some are 20 years old and older. A reasonable model of this roadway system must recognize that pavement failure and repair are a continuous process. If it is assumed that those pavements most needing attention receive it, it can be inferred that an approximately constant distribution of pavement ages exists and that the average of this distribution approaches a steady-state value representing the average remaining life of typical pavement. To simplify the model, all pavements are assumed to have the same value of remaining life. (Several numerical checks have shown that this produces essentially the same results as the more realistic but more complex model that uses a distribution of expected remaining life.)

Other factors that must be considered include interest and inflation rates, the average trip length of an overweight truck, and the total cost of a single overlay. At the time of this writing, interest and inflation rates are receding from their previous record levels and values of 8 and 5 percent, respectively, appear to be reasonable estimates. However, any attempt to project these levels into the future is risky at best so the analysis was run using both higher and lower values to determine the sensitivity of the outcome to these parameters.

Because New Jersey is about 50 mi wide and 150 mi long, trip lengths may range anywhere from short hauls of 10 mi or so to the length of the state. However, New Jersey has traditionally been regarded as a "corridor" state, which tends to suggest that longer trips are more common. Because the results are directly affected by the average trip length, values of 25, 50, and 100 mi have been used. And, because the analysis deals with the economic impact of rescheduling future overlays to an earlier date, all costs normally associated with a resurfacing contract must be accounted for.

These costs include engineering, traffic control, patching, resetting manholes, and so forth. A review of recent construction contracts in New Jersey indicates that a typical cost is about $10.00 per square yard. Also, in determining the number of square yards to be overlaid, it will be assumed that the typical pavement is two lanes (24 ft) wide.

The results of the analysis are given in Table 4. Given an average remaining pavement life of 10 years, an assumed typical trip length of 50 miles, and nominal interest and inflation rates of 8 percent and 5 percent, respectively, the economic impact of detected overweight violations is $46,549 per year. If additional trucks were dispatched to carry the excess loads, and none of these trucks were overweight, the annual cost in pavement serviceability would be $37,661. The net difference in this case is $8,888. Table 4 also gives the results of the sensitivity tests reflecting the uncertainty

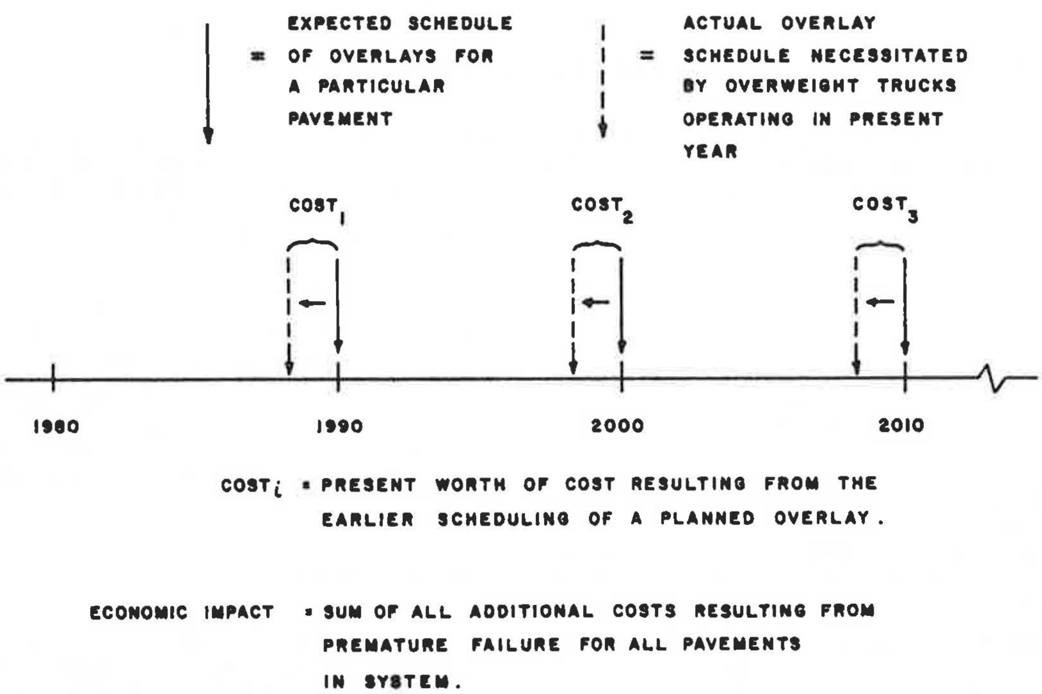

FIGURE 4 Concept on which economic impact is based.

TABLE 4 Annual Cost of Pavement Damage Attributable to Detected Overweight Trucks Under Steady-State Condition, 1983 Dollars

Average Remaining Life (yr)	Average Overweight Trip (mi)	Modeled Truck Fleet	Trucks Modeled	Interest and Inflation Rates (%)					
				5, 5	6, 5	7, 5	8,5	9,5	10, 5
5	25	Actual	9,060	26,855	26,855	26,834	26,795	26,737	26,662
		Legalized	10,190	21,732	21,730	21,712	21,679	21,630	21,568
	50	Actual	9,060	53,710	53,709	53,669	53,590	53,474	53,323
		Legalized	10,190	43,463	43,459	43,424	43,357	43,261	43,136
	100	Actual	9,060	107,420	107,418	107,338	107,180	106,949	106,646
		Legalized	10,190	86,926	86,919	86,848	86,715	86,522	86,271
10	25	Actual	9,060	26,855	25,612	24,419	23,275	22,178	21,128
		Legalized	10,190	21,732	20,724	19,757	18,830	17,942	17,092
	50	Actual	9,060	53,710	51,223	48,837	46,549	44,357	42,257
		Legalized	10,190	43,463	41,448	39,515	37,661	35,885	34,184
	100	Actual	9,060	107,420	102,446	97,674	93,099	88,714	84,514
		Legalized	10,190	86,926	82,896	79,029	75,322	71,769	68,367
15	25	Actual	9,060	26,855	24,426	22,220	20,217	18,397	16,744
		Legalized	10,190	21,732	19,765	17,979	16,356	14,883	13,545
	50	Actual	9,060	53,710	48,852	44,440	40,433	36,794	33,487
		Legalized	10,190	43,463	39,529	35,957	32,713	29,766	27,090
	100	Actual	9,060	107,420	97,704	88,881	80,867	73,588	66,975
		Legalized	10,190	86,926	79,059	71,914	65,426	59,532	54,179

of selected input variables. According to these tests, the previously calculated cost of $46,549 ranged from a low of $16,744 to a high of $107,420.

EXTRAPOLATION TO INCLUDE UNDETECTED VIOLATORS

If a considerable number of overweight violators remain undetected, it is of limited value to know the economic impact of only those that are detected. The quantified costs may be severely underestimated. Overweight trucks exact a toll in pavement life regardless of whether or not a citation is issued. But, as discussed in a previous section, it is difficult to obtain an unbiased glimpse of that particular segment of the overall truck population that has a decided incentive to remain undetected. Thus, if a glimpse of this segment is to be had, the price to be paid is reduced precision.

Two distinct approaches were attempted to estimate the magnitude of the factor used to multiply the costs presented in Table 4 so that the resultant product would also include the impact of undetected overweight violators. One approach is based on the ratios of summary statistics and the other on visual inspection of weight violation histograms. These two approaches produced similar results.

The estimation technique relying on ratios requires that the total number of truck trips be known. Recent loadometer studies in New Jersey suggest that 30 million annual truck trips may be a reasonable estimate. Three independent sources suggest that roughly 20 percent of these may be overweight. The first source is a bridge on Interstate 80 in Pennsylvania, just west of the New Jersey border, that was calibrated with strain gauges to monitor weights of five-axle trucks without driver awareness (6). This study concluded that approximately 20 percent of these trucks exceeded Pennsylvania's gross weight limits during the study period. An independent check of this 20 percent figure may be obtained by calculating the ratio of violators to trucks weighed in New Jersey using portable weigh scales. This ratio, for all violation types, is 0.174 or approximately 20 percent. And, finally, FHWA sources contacted personally indicate that 10 to 20 percent overweight trucks is a reasonable estimate on a national scale. Thus, to determine the approximate ratio of total weight violators to known weight violators, the estimated 30 million annual truck trips may be multiplied by 20 percent and divided by the roughly 10,000 known overweight trucks to obtain a factor of 600. If a 10 percent violation rate were assumed rather than 20 percent, the estimated factor would be 300.

A check on the reasonableness of this factor was performed by visually comparing the frequency histograms for weights on tandem axles as reported by the loadometer study and by the model based on state police data. In this comparison, the upper tails should (a) reasonably fit the body of the histogram and (b) be consistent with one another. Both of these criteria are met if the number of detected violators is multipled by a factor of approximately 400, as shown in Figure 5. Because the appropriate factor is estimated to be approximately the same by two independent criteria, the credibility of the estimate is enhanced. The appropriate multiplying factor was assumed to be 400 for the purposes of this study.

Returning to Table 4, a reasonable estimate of the total annual pavement damage done by all overweight violators is then 400 x $46,549 or approximately $19 million. This estimate could be as low as $7 million and as high as $43 million depending on the assumptions made regarding interest, inflation, the average remaining life of a pavement, and the average length of an overweight trip.

UNQUANTIFIED CONSIDERATIONS

One point estimate of the present worth of the pavement damage done by all overweight trucks in New Jersey is $19 million per year. The derivation leading to this estimate must be understood if a meaningful assessment of the implications arising from this figure is to be made. Pavement serviceability losses attributable to overweight trucks were quantified using the AASHTO EAL parameter and converted to a dollar value through economic formulas that calculate the cost of a premature maintenance expenditure at a future date. This procedure assumes that the only effect overweight trucks have on pavement's life is an increase in the utilization rate of the pavement's latent EALs. Bridge damage is not included in these costs. Unfortunately, at present there is no convenient way to estimate the damage done to bridges and there is concern that this might add significantly to the total costs.

It is possible that, in an extreme case, a single, excessively loaded truck may fracture a pavement and thereby drastically shorten its life.

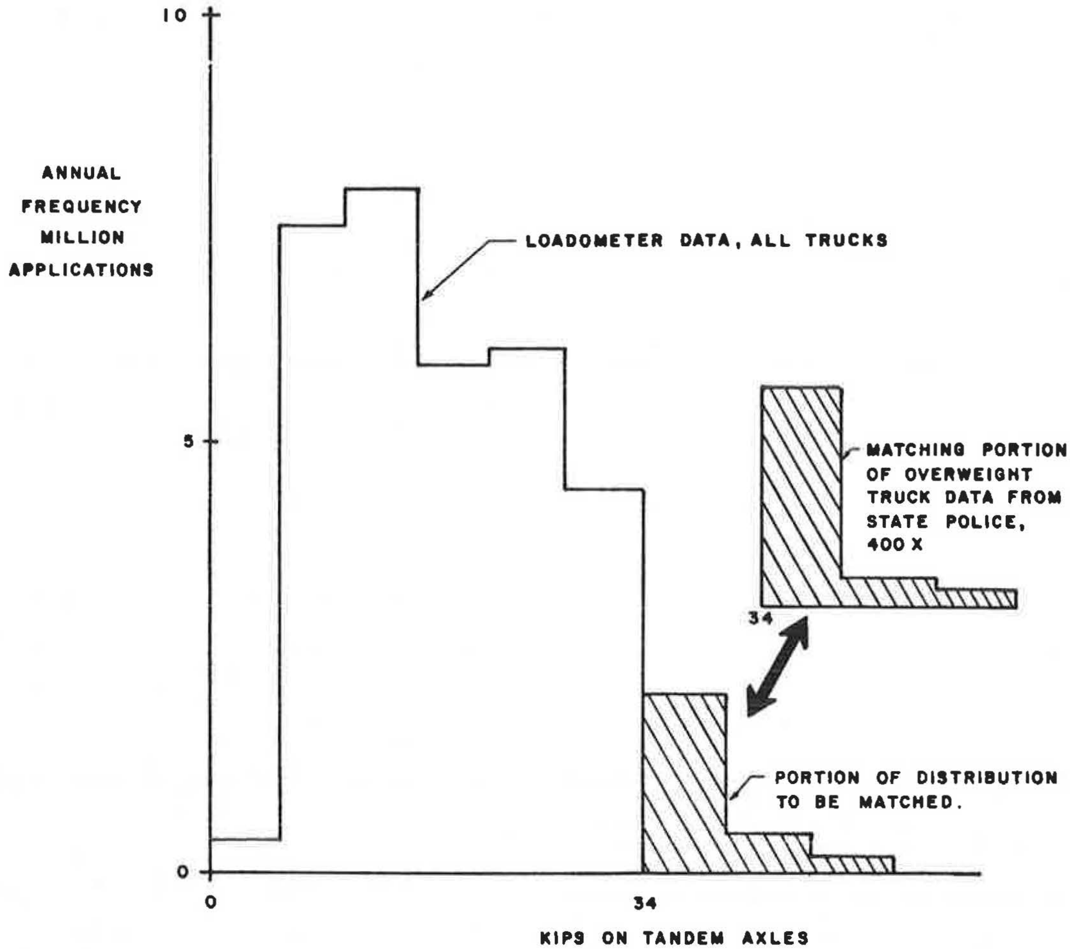

FIGURE 5 Frequency distribution of weights on tandem axles.

This would be more likely to occur on secondary roads where the pavement section is generally less strong. Although at least some of the overweight trucks must travel on secondary roads, it was judged unlikely that they would travel their entire (50-mi average length) trip on them. This would suggest that smaller portions of these roads may require excess weight-induced maintenance and that this maintenance may be less costly than assumed in the economic analysis. Nevertheless, this potential impact must be treated as an important unknown that could further increase the quantified costs.

The cost of enforcing the overweight statute cannot be overlooked. With the present level of enforcement, this cost was estimated to be $1.7 million per year (source: Division of State Police). It will undoubtedly increase if an improvement in the overweight detection rate is attempted.

This investigation focused on the primary economic considerations resulting from direct engineering analyses. Secondary economic effects were not investigated. Thus no adjustment were made to the revenue figures for the fuel taxes, toll road receipts, registration fees, and so forth that operators of overweight trucks pay. Similarly, overweight trucks were not charged for time lost due to increased traffic congestion, increased pollution, and other indirect considerations.

It was judged unnecessary to make an adjustment in the rate of pavement deterioration attributable to environmental considerations because, theoretically, this is a cost that is logically apportioned in full to all legitimate vehicles. Overweight charges were calculated as a differential from the established datum apportioned to all other vehicles. Thus, in large part, the interaction between overweight trucks and those environmental factors that affect cost considerations was screened from the analysis.

SUMMARY AND CONCLUSIONS

This study was undertaken to analyze the physical damage to pavements resulting from overweight trucks. To this end, two large samples were drawn from the population of known weight violators and, from these, specific truck characteristics (typical axle configurations, configuration frequencies, and typical axle loadings) were determined. This information was then coupled with characteristics of typical New Jersey pavements and, using the AASHTO EAL parameter, pavement serviceability was apportioned in a reasonable manner. Principles of engineering economics were then applied to quantify the magnitude of the associated monetary impact. These analyses led to the following conclusions:

1. Available data indicate that the pavement damage attributable to detected overweight trucks in New Jersey is relatively small, shortening the remaining pavement life by about 7.6 percent. If the same amount of goods was carried by an additional number of legally loaded trucks, the shortening of

life would be about 6.2 percent. The net shortening of life resulting from the trucks known to be operating in overweight is equal to the difference, or roughly 1.5 percent.

2. An analysis was done to assess the economic impact of these overweight violations. The shortening of average life results in an increased frequency of resurfacing that raises the overall costs of maintaining the pavement system at a serviceable level. However, as with the change in the average life expectancy, the increase in costs due to detected overweight trucks is relatively small and is overshadowed by the costs of the enforcement effort as a whole.

3. Therefore, with the present level of enforcement, mandatory off-loading may not be worthwhile because it affects only those violators who are caught. The most that would be gained were all of these violators off-loaded, even if this occurred at the trip origin, would be a savings in pavement life of about 1.5 percent, which corresponds to a cost savings of about $10,000 per year. In exchange, additional manpower would almost certainly be required and the highway agency would be exposed to a potentially increased liability for the welfare of the off-loaded goods. Thus the question is raised as to whether this enforcement practice is truly cost-effective. (An exception to this reasoning would be the case in which off-loading is done to avoid exceeding posted bridge load limits. Also unaddressed is the possible deterrent effect such a provision might have on undetected violators.)

4. Extrapolation of data to include undetected violators in New Jersey indicates that the total pavement damage attributable to all overweight trucks is considerable. One point estimate of the cost of this pavement damage is $19 million per year.

5. At the present level of enforcement, the fine structure that existed before September 1983 would generate about $1.1 million in revenue each year. This revenue, which is not sufficiently large to cover the costs of enforcement alone, is dwarfed by the extrapolated magnitude of total pavement damage. The discrepancy would be further accentuated if other, unquantified costs were also to be included.

6. On the basis of these findings, it is concluded that a substantial increase in the revenue generated by overweight trucks may be in order. This may be accomplished by increasing the present fine structure, the present level of enforcement, or both.

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Highway Cost Allocation Methodology for Pavement Rehabilitation and Capacity-Related Costs Occasioned by an Increment in Heavy Truck Traffic

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ABSTRACT

A methodology is outlined for estimating incremental pavement rehabilitation and capacity-related costs that would be occasioned by loading an increment of bulk commodity traffic on a highway link. The cost estimates are referred to as "build-sooner costs" because they represent the financial impact of the increment of traffic on the future timing of pavement rehabilitation and capacity improvement projects. The analysis encompasses eight bulk commodity truck movement scenarios in the Province of New Brunswick, Canada. The build-sooner costs are compared with incremental user fee revenues that would be generated by these movements if they were to be captured by the truck mode.

The methodology described in this paper was developed as part of a much larger research project on incremental costs and revenues occasioned by the trucking of bulk commodities on selected highway links in the Province of New Brunswick, Canada (1). That study examined five broad categories of incremental cost and three categories of incremental revenues, with the objective of assessing whether trucking firms enjoy an inherent advantage in competing for the movement of bulk commodities in the province. Such an advantage would exist if the incremental public costs of these truck movements were not fully recovered through highway user fees.

The focus of this paper is on describing the methodology developed to estimate one of the five categories of incremental cost. The cost component in question shall hereafter be referred to as "build-sooner costs."

Build-sooner costs related to the hypothesis that loading a large increment of heavy traffic on a link will cause two conditions to evolve. First, pavement life cycles are likely to become shorter, and, second, future capacity improvements will be needed sooner. Because both kinds of improvements require substantial expenditures, the cost of investing the capital "x" years sooner because of the increment of heavy traffic can legitimately be assigned to that traffic.

Before outlining the methodology used to estimate these costs, a review of other highway cost allocation studies from the perspective of their treatment of pavement and capacity costs is instructive.

LITERATURE REVIEW

Growing interest in highway finance has given rise in recent years to a significant research effort to resolve the question of the cost responsibility of various classes of highway users.

In Canada the recent work of Bunting (2) examined highway expenditures and revenues at three different levels--all of Canada, the Province of Ontario, and Highway 401. At the national and provincial levels, expenditures were allocated on the basis of highway usage patterns, with 40 percent of construction and maintenance costs and 30 percent of other costs assigned to heavy trucks (2,p.23).

In the Highway 401 analysis, 45 percent of pavement-related costs was assigned to trucks. This estimation of pavement costs was based on the assumption that 40 percent of highway construction expenditures were pavement-related (2,p.29). The remaining 55 percent of construction costs was allocated according to the trucks' share of capacity use, estimated at 50 percent.

Many of the cost estimation and cost allocation formulas used in Bunting's work were drawn from the most recent U.S. Highway Cost Allocation Study completed in 1982 (3). This study was concerned with the allocation of U.S. federal program expenditures to users of federal-aid roads. This research attempted to correct often-cited deficiencies of two previous U.S. investigations of highway costs, the Section 210 study on highway cost allocation, conducted between 1956 and 1965, and the AASHO Road Test, conducted between 1958 and 1960.

The major criticism of the Section 210 study is that it focused on capital expenditures for new pavement. Although this may have been appropriate for that period when the Interstate system was being constructed, it had become anachronistic with the current emphasis on rehabilitation of the system.

The AASHO Road Test, conducted in Illinois, attempted to measure the relationship between pavement deterioration and repetition of axle loadings. Although the results of this test have been widely used as a basis for pavement design, it has been strongly criticized as a method for assigning cost responsibility to classes of vehicles. One of the major criticisms is that it does not account for the effect of environmental conditions on pavement deterioration.

The 1982 highway cost allocation study uses a so-called "modified incremental cost allocation approach." First, a distinction is made between new pavement and pavement rehabilitation. In the case of the former, costs are allocated as follows (3,p.IV-43).

> New pavement costs are assigned based on current pavement design practice. Ve-

hicles from each class are hypothetically removed in equal proportions until further removal would not reduce pavement thickness requirements.

A major research effort was launched to develop relationships to assign pavement deterioration cost responsibilities. Pavement distress models were developed for both flexible and rigid pavements to measure distresses such as loss of serviceability, alligator cracking, rutting, transverse cracking, loss of skid resistance, faulting, pumping, joint deterioration, depression, and swell (3,Appendix D-24). Some of the distresses were found to be a function of traffic, some a function of traffic and other variables, and some independent of traffic. Costs are assigned on the basis of the relative importance of each type of distress in the decision to rehabilitate a pavement.

Capacity-related costs such as steepness of grades and roadway width again are assigned on an incremental basis by hypothetically removing successive classes of vehicles (e.g., vehicles in various weight-to-power ratios in the case of grade costs). Within-group costs (i.e., different vehicle types within a specific group) and residual costs (i.e., costs that cannot be attributed to a particular class of vehicle) were arbitrarily allocated on the basis of vehicle-miles traveled.

One of the criticisms of the most recent U.S. highway cost allocation approach is that it is based on expenditures, not costs. Any expenditures that are incurred in a particular year are allocated to the traffic of that year, even though the benefits arising from the investments are realized over a long period. Such an approach neglects the indivisibilities that are necessarily involved in the provision of highway infrastructure and the resultant excess of capacity.

The major consequence of the existence of this excess capacity is a residual of cost in the cost allocation process, a residual that can only be allocated among components of traffic by some arbitrary means. This is really an issue of cost allocation versus cost assignment. The difference between the two is well presented by Wohl and Hendrickson (4,p.223). They suggest that cost attribution involves "the identification of valid cause-and-effect relationships between highway cost and highway use."

The focus of this research is on cost assignment rather than on cost allocation. The difference between the two is explained by the existence of a residual of costs that can only be allocated according to some accounting rules.

In the remainder of this paper, the methodology for assigning pavement rehabilitation and capacity-related costs to bulk commodity truck traffic will be described and the results of the analysis summarized.

METHODOLOGY

Eight bulk commodity movement scenarios were analyzed in this study; none of the commodities are currently moved by truck. The objective was to estimate the incremental public costs that would result if these movements were to be captured by the truck mode. The commodity movements, projected annual tonnages, and length of haul associated with each movement are given in Table 1.

TABLE 1 Commodity Movement Scenarios

Commodity Movement	Projected Annual Tonnage	Length of Haul (mi)
Potash 1	700,000	50
Potash 2	1,400,000	35
Potash 3	2,100,000	–[a]
Woodchips 1	100,000	–[a]
Woodchips 2	75,000	115
Coal	360,000	210
Concentrates	500,000	75
Petroleum	150,000	105

[a]Consists of two separate movements.

Build-Sooner Period: Pavement Rehabilitation

The objective of this analysis is to determine the cycle time for pavement resurfacing with the commodity traffic moving on the highway compared with the pavement life cycle that would occur under existing traffic mix conditions and normal growth. In other words, how much faster will the pavement condition deteriorate to the threshold that triggers a resurfacing requirement? This concept is illustrated graphically in Figure 1. It should be noted that Figure 1 shows only pavement life cycle after the addition of the new commodity traffic.

Subsequent pavement cycles are important not only because each cycle is set ahead by the build-sooner period (BSP) but also because it is reasonable to expect that successive pavement life cycles will get shorter. If the rate of pavement deterioration is due to the cumulative effect of truck traffic, the slope of the deterioration function will increase with each successive pavement life cycle until the slope reaches some theoretical maximum. This is shown in Figure 2.

After a review of the literature on pavement deterioration, it was decided that the Ontario flexible pavement design method would be used to develop a pavement deterioration function for the various highway links and commodity movements under study (5).

The mathematical relationship between the parameters included in the Ontario method are

$$RCI_f = RCI_i - (P_t + P_e) \quad (1)$$

where

RCI_f = final road comfort index,
RCI_i = initial road comfort index,
P_t = loss of RCI due to traffic factors, and
P_e = loss of RCI due to environmental factors.

P is further defined as

$$P = 2.4455X + 8.805X^3 \quad (2)$$

where

X = 100 WN,
W = Odemark subgrade deflection,
N = number of ESALs per year, and
ESAL = equivalent single 18,000-lb axle loads.

Note that the Odemark subgrade deflection is derived from Dynaflect pavement deflection readings using the following relationship:

$$D = 0.9W + 40W^2 \quad (3)$$

where D is mean spring deflection and W is Odemark subgrade deflection.

P_e is further defined as

$$P_e = [RCI - (1 + BW)]\ (1 - e^{-0.06Y}) \quad (4)$$

where Y is number of years of loading and B is 60.

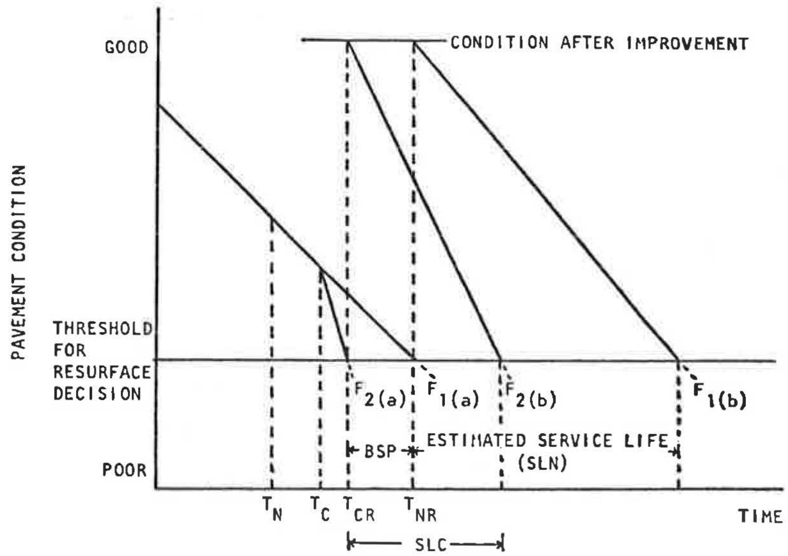

FIGURE 1 Build-sooner period for pavement rehabilitation. F_1 is a function that describes pavement deterioration under normal traffic conditions; F_2 is a function that describes pavement deterioration under the combined effect of normal plus commodity traffic; T_N is the present time; T_C is the time at which the commodity movement begins; T_{NR} is the time at which the pavement requires resurfacing under normal conditions; T_{CR} is the time at which the pavement requires resurfacing under the combined effect of normal plus commodity traffic; SLN is estimated pavement service life under normal conditions; SLC is estimated pavement service life with commodity traffic added; BSP is the build-sooner period (i.e., the life difference between SLN and SLC); (a) denotes the existing pavement cycle; and (b) denotes the second cycle. Note: function is shown as linear for simplicity of illustration.

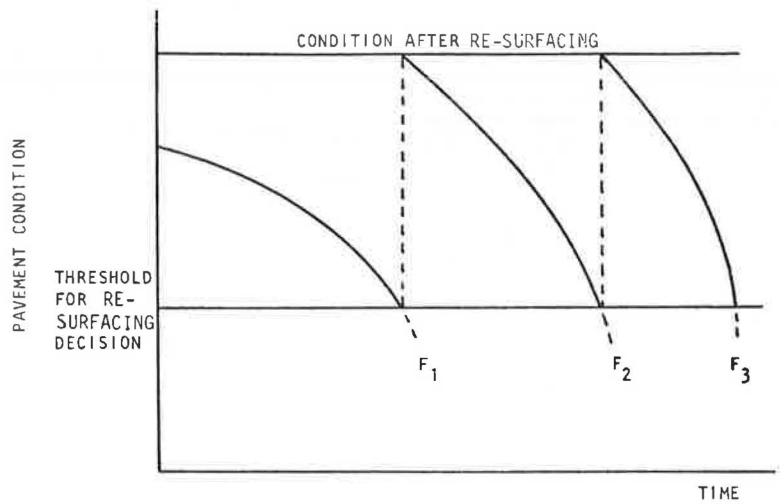

FIGURE 2 Pavement deterioration in successive life cycles. F_1, F_2, and F_3 are the pavement deterioration functions for successive cycles.

A key feature of these relationships is the road comfort index (RCI). The RCI is essentially a rating scale from 0 to 10 that describes on a subjective basis the comfort or rideability of a pavement surface. As the pavement surface deteriorates, so does the rideability. The mathematical relationship described is in essence an algorithm for forecasting future RCI values, which can be expected to decline because of both traffic and environmental factors. Before the relationship can be used, the values for each of the parameters must be either measured or calculated.

The initial RCI values were made available by the New Brunswick Department of Transportation (NBDOT). The NBDOT periodically conducts rideability assessments of its highways. Each rating section (a rating section is a section of highway that features relatively homogeneous physical characteristics) is assigned an RCI value following a field investigation.

The Odemark subgrade deflection factor is calculated using Dynaflect pavement deflection readings. NBDOT periodically collects this data for each rating section with a Dynaflect that uses a nondestructive testing method. The Dynaflect measurements are then converted to an equivalent Benkleman beam value using an appropriate regression equation.

A critical component of traffic impact on pavement deterioration is the repetition of axle loadings. In both the AASHO and the Ontario tests, the loading impact of a particular vehicle configuration is expressed in terms of an equivalent single 18,000-lb axle load (ESAL). The gross vehicle weight, the payload, the number of axles, and the axle spacing all affect the number of ESALs per vehicle. It is noteworthy that the ESAL conversion factors that have been developed assume that a passenger car is approximately equal to zero ESALs.

Because the purpose of this analysis was to determine the build-sooner period, it was necessary to first forecast future RCI values under normal traffic conditions. The analysis was then repeated with the commodity traffic added to the base load. The first step in the analysis was to convert the existing traffic stream into ESALs. This was done using average annual daily traffic (AADT) volumes and vehicle classification counts that permitted a disaggregation of the traffic stream as follows:

1. Automobiles,
2. Two-axle trucks,
3. Three-axle trucks,
4. Three-axle tractor-trailers,
5. Four-axle tractor-trailers,
6. Five-axle tractor-trailers, and
7. Tractor-trailers with more than 5 axles.

The AADT for each of these configurations was then converted into ESALs per day using the Asphalt Institute (6) conversion factors and axle weight data extracted from a 1981 truck vehicle weight, configuration, and dimension survey conducted by the NBDOT.

After the future RCI values were calculated under normal traffic conditions it was necessary to translate the commodity movement into ESALs. This required a forecast of the annual commodity tonnage and selection of an optimal truck configuration or handling the particular commodity. The ESALs produced by the commodity movement were then added to the existing base traffic load and a new set of future RCI values generated.

The next step in the analysis was to select a minimum desirable RCI value (i.e., a threshold that would theoretically trigger a decision to resurface the highway link being evaluated). The appropriate threshold for the New Brunswick situation was determined in consultation with NBDOT. For example, on arterial highways the minimum desirable RCI value was set at 5.5 whereas 4.5 was used on collector highways. With the threshold established, the build-sooner period would then be determined as shown in Figure 1 and Table 2.

It must be stressed that the methodology described presupposes that pavement resurfacing projects would be undertaken as soon as the minimum desirable RCI threshold is reached. In reality the actual timing of projects will depend on many factors other than pavement rideability, not the least of which is the economic justification of each project in comparison with other candidate projects competing for limited funds in a given year.

TABLE 2 Build-Sooner Period Hypothetical Results

Year	RCI Values with Normal Traffic	RCI Values with Commodity Traffic Added
1983	7.0	7.0
1984	6.7	6.7
1985	6.4	6.1
1986	6.0	5.4[a]
1987	5.7	4.4
1988	5.3[a]	3.1

[a]Threshold is RCI 5.5; therefore BSP = 2 years.

To summarize, the build-sooner period for pavement resurfacing was estimated using the Ontario flexible pavement design method. This method essentially produces a pavement deterioration function that is affected by both traffic and environmental factors. The procedure for converting build-sooner periods to build-sooner costs will be described later in this paper. The following section summarizes the methodology used to determine the build-sooner period for capacity improvements.

Build-Sooner Period: Capacity Improvements

The capacity analysis is similar in many respects to the build-sooner analysis for pavement resurfacing. In this case the build-sooner period is determined by a traffic growth function (under normal conditions and with the commodity traffic added). The threshold that triggers a decision for a capacity improvement is the capacity of the highway section under study at a given level of service. The capacity analysis methodology is shown graphically in Figure 3.

The capacity analysis was completed using techniques contained in the Highway Capacity Manual (HCM) developed by the U.S. Highway Research Board (1). The HCM techniques are widely accepted by traffic engineers in performing capacity analysis on elements of a highway system.

The HCM methodology is based on the following relationship:

$$C = CT \times (V/C) \times (W_L) \times (T_L)$$

where

C = practical capacity of a highway section at a given level of service;
LOS = level of service A, B, C, D, or E as described in the HCM;
CT = theoretical capacity;
V/C = volume-to-capacity ratio;
W_L = capacity adjustment factor for lane width and lateral obstructions; and
T_L = capacity adjustment factor for trucks.

The objective of this analysis is to determine the relative timing of capacity improvements under normal traffic conditions with the commodity traffic added to the existing traffic. The critical threshold that triggers the need for an improvement is the capacity of the section of highway under study. This capacity threshold varies with the selected minimum level of service desired. After consultations with NBDOT planners it was decided that the boundary between level of service C and D as defined in the Highway Capacity Manual would be used as the threshold for capacity improvements. The rationale for this choice is that when NBDOT plans and designs a highway capacity improvement, the decision is made that the highway should have sufficient capacity to operate at level of service C or better through its design life, given certain traffic growth assumptions. Again it must be recognized that no attempt was made to examine the justification for or priority of each of the capacity projects. A simplifying

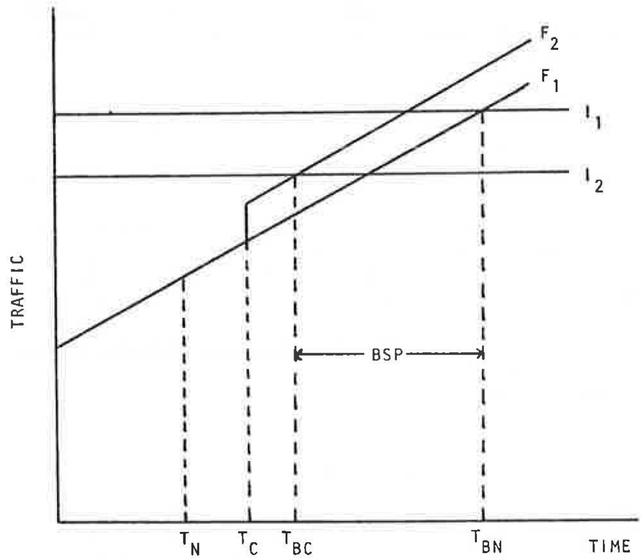

FIGURE 3 Build-sooner period: capacity improvements. F_1 is the traffic-versus-time function for normal growth (shown as linear for simplicity of illustration); F_2 is the traffic-versus-time function following an increment of commodity traffic; I_1 is the level of traffic at which a capacity improvement is required; I_2 is the level of traffic at which a capacity improvement is required following an increment of commodity traffic; T_N is the present time; T_C is the time when the commodity traffic is added; T_{BC} is the time when a capacity improvement would be required under normal traffic conditions; T_{BN} is the time when a capacity improvement would be required when commodity traffic is added; and BSP is the build-sooner period (i.e., the difference between T_{BN} and T_{BC}).

assumption was made that each of the capacity projects identified will be implemented when the critical capacity threshold is reached. In reality some of the projects will either not be undertaken or will perhaps be delayed at the expense of level of service. However, this approach was adopted because it appeared to be the most rational and consistent way to measure the impact of additional heavy truck traffic on the timing of improvements.

The practical capacity of a roadway section was calculated at the selected level of service using the previously outlined relationship. This was done by reducing the theoretical maximum capacity under ideal conditions (2,000 vehicles per hour) through the application of adjustment factors. These factors attempt to quantify the impact of certain conditions that tend to reduce the capacity of a roadway section. The factors are taken from the Highway Capacity Manual.

The T_L factor (truck adjustment factor) was a critical component of the capacity analysis in this study. The truck adjustment factors in the HCM are assumed to be valid for trucks within a certain operating performance range (i.e., power-to-mass ratio). A number of parameters affect the truck adjustment factor. Length of grade, magnitude of grade, type of terrain (level, rolling, mountainous), and percentage of trucks in the traffic flow all affect the number of passenger car equivalents (PCE) of trucks on any given section of highway. The PCE is simply the equivalent number of passenger cars of one truck under the existing physical and traffic flow conditions.

Clearly, as the length and magnitude of a grade increase, the number of PCEs per truck will also increase. It is also important to note that as the PCEs or percentage of trucks, or both, increase, the truck adjustment factor decreases. In other words, the increment of truck traffic due to the commodity movement not only increases the traffic, it also reduces the capacity due to a lower T_L factor. This is shown in Figure 3 in which the capacity threshold for F_1 is lower than the threshold F_2.

With the capacity of each section of highway established at a selected level of service, it was possible to project the number of years required to reach capacity under both traffic scenarios (normal traffic growth and with commodity traffic added). The growth rate assumptions applied to obtain forecasts of future traffic volumes were provided by NBDOT planners. In accordance with instructions from the client, the commodity tonnage projections assume zero year-to-year growth and a uniform distribution of truck traffic throughout each day.

When the build-sooner period had been estimated, it was necessary to identify the type of capacity improvement required. The range of alternatives include improvement of vertical and horizontal alignment, increased lane and shoulder width, provision of climbing lanes, and twinning of the highway. Again it must be recognized that, as in the case of the build-sooner analysis for pavement resurfacing, no attempt was made to examine the justification for each capacity project. The methodology is based on an assumption that each of the capacity projects identified will be implemented when the critical capacity threshold has been reached. It is conceivable that some of the projects identified would either not be undertaken or would perhaps be delayed at the expense of level of service.

To summarize, the build-sooner period for capacity improvements was determined using capacity analysis techniques documented in the Highway Capacity Manual. The effect of an increase in the presence of trucks due to the addition of an increment of commodity traffic is a lowering of the capacity of the highway at a given level of service. This in turn gives rise to the need for capacity improvements sooner than would be the case under normal traffic conditions. When the cost of these improvements is known, a build-sooner cost can be calculated. The methodology for estimating build-sooner cost is outlined in the next section.

Build-Sooner Cost

The purpose of the build-sooner cost analysis is to determine the financial impact of having to invest in highway resurfacing and highway capacity improvements sooner than would be the case if the commodity were not transported by truck on public highways. In other words, what is the cost of tying up the capital required for the improvement over the build-sooner period? Figure 4 shows a hypothetical example.

The example assumes that a hypothetical improvement costing \$1.0 million (1983 dollars) will be required in 1993 under normal traffic conditions. The same \$1.0 million improvements will be required in 1990 if the commodity traffic is added. The commodity traffic thus causes a build-sooner period of 3 years.

Because costs are in constant dollars, a real discount rate (in this case 4 percent) is used to determine the present value of each investment. Clearly for Case 2 the present value is higher because the investment is of the same magnitude but occurs 3 years sooner. The build-sooner cost in this example is \$84,353 representing the difference between the present values of the two investments.

This example calculated the build-sooner cost for only one improvement cycle (e.g., one pavement life

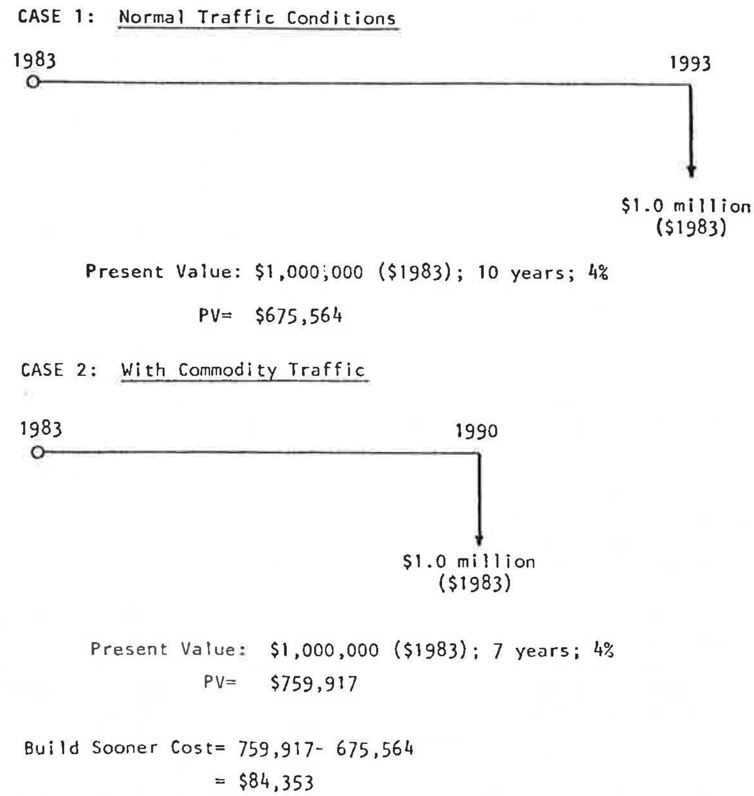

FIGURE 4 Build-sooner costs.

cycle). It is necessary to calculate build-sooner costs for each subsequent cycle within the study period or until the effects of discounting render the build-sooner cost insignificant.

The final step in the analysis involves converting the build-sooner cost into an equivalent annual cost over the life cycle of the improvements using the appropriate capital recovery factor. For each link, sensitivity analysis was done using real discount rates of 3, 4, and 5 percent. The assumption underlying the choice of real discount rates of this magnitude was that a spread of 3 to 5 percent between the yield on long-term government bonds and the inflation rate would be representative of the long-run cost of capital throughout the time horizon of this study.

TABLE 3 Annualized Build-Sooner Costs on Incremental Revenues (1983 dollars)

Commodity Movement	Build-Sooner Costs[a]		Incremental Revenues
	Pavement	Capacity	
Potash 1	110,000	39,000	201,250
Potash 2	195,000	7,000	307,800
Potash 3	292,000	42,000	509,100
Woodchips 1	24,000	91,000	55,000
Woodchips 2	40,000	5,000	92,100
Coal	225,000	46,000	494,500
Concentrates	81,000	6,000	247,100
Petroleum	6,000	74,000	90,400

[a]Discount rate is 4 percent.

Summary

Two categories of build-sooner costs were hypothesized in this study. A large increment of commodity traffic will theoretically cause pavement condition to deteriorate faster and will cause a section of highway to reach capacity earlier. To the extent that these phenomena occur, investments in pavement resurfacing and capacity improvements will also be required earlier. The cost of having to commit capital expenditures at an earlier date is the build-sooner cost.

SUMMARY OF RESULTS

Table 3 gives a summary of the results of the build-sooner cost analysis and compares annualized costs to estimated incremental annual user fee revenue that might be expected from each movement. The user fee revenue consists of fuel taxes, registration fees, and license fees, of which fuel taxes represent the largest contribution.

Table 4 gives build-sooner costs as a percentage of incremental revenue. It must be emphasized that Tables 3 and 4 present only the build-sooner costs that would result from the commodity movements. Other cost categories were addressed in the overall study but are not presented here.

Two major observations can be made from these data. First, build-sooner costs exceeded incremental revenues in only one case (Woodchips 1), (attributable primarily to capacity-related costs). This can be explained by the fact that the highway link in question has numerous steep grades, many in excess of 10 percent. Accordingly, the passenger car equivalent of each woodchip truck is high, with the result that capacity improvements that would not normally be required for many years on this relatively low-volume highway are advanced several years, creating a high build-sooner cost.

The other noteworthy feature of the data is that in all but two cases, pavement rehabilitation costs

TABLE 4 Build-Sooner Costs as Percentage of Incremental Revenues

Commodity Movement	Pavement Rehabilitation (%)	Capacity (%)	Total Build-Sooner Costs (%)
Potash 1	54.6	19.4	74.0
Potash 2	63.4	2.3	65.7
Potash 3	57.4	8.2	65.6
Woodchips 1	43.6	165.5	209.1
Woodchips 2	43.4	5.4	48.9
Coal	48.5	9.3	54.8
Concentrates	32.8	2.4	35.2
Petroleum	6.6	81.9	88.5

exceed capacity-related costs by a substantial margin. This appears somewhat surprising given the large expenditures normally associated with capacity enhancements. The explanation lies in the fact that the volume of commodity traffic (expressed in terms of passenger car equivalents) is generally low in comparison with existing passenger car and truck traffic. Hence the impact of the commodity trucks on capacity utilization is such that build-sooner periods were consistently shorter (0 to 3 years).

The sensitivity of results to changes in the discount rate was analyzed using real discount rates of 3, 4, and 5 percent. The higher discount rates do produce higher build-sooner costs. Although this may appear to be counterintuitive, it must be remembered that all build-sooner costs are estimates from the difference in present values of an investment made at two different points in future time. The difference increases even though the absolute magnitudes of the present values fall as the discount rate is increased. Furthermore, the capital recovery factor increases as does the discount rate resulting in higher costs.

The build-sooner costs analysis indicates that the bulk commodity movements studied would have a significant impact on future pavement rehabilitation and capacity-related costs, ranging from a low of 35.2 to a high of 209 percent of incremental revenues that would result from each movement. These costs arise from the need to advance the timing of these kinds of highway improvements because of the presence of the commodity traffic.

CONCLUSION

Previous highway cost allocation studies could, in general, be characterized as attempts to allocate highway expenditures to various classes of vehicles. The allocations are based in part on cause and effect relationships and in part on arbitrary accounting rules.

This study differs somewhat in that it assigns costs, not expenditures, attributable to a hypothetical increment of heavy truck traffic and then compares these costs to the incremental revenues that this same traffic would generate. The costs examined in this paper are those related to the impact of the incremental traffic on the timing of future pavement rehabilitation and capacity enhancement projects.

ACKNOWLEDGMENTS

The authors wish to acknowledge the financial assistance of Canadian National Railways and Transport Canada for the funding of this research. Appreciation is also extended to the several individuals in the New Brunswick Department of Transportation who cooperated in the provision of the data required for the analysis.

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Large Truck Accident Rates: Another Viewpoint

W. D. GLAUZ and D. W. HARWOOD

ABSTRACT

There have been many studies that have attempted to ascertain any difference in the safety of various large truck configurations. Special attention has been paid to double trailer combinations (doubles) compared to tractor-semitrailer combinations (singles). Most researchers have found little if any difference in their respective accident rates. The major exception is a large, widely quoted study conducted by BioTechnology, Inc., for the Federal Highway Administration. It concluded, among other things, that doubles have significantly higher accident rates than do singles. The research reported in this paper consisted of a thorough review of all aspects of that study, with particular emphasis on the structure and contents of the three major data bases used. These included data on 2,112 large truck accident involvements, vehicle classification count data taken at 78 sites, and driver and truck data (including size and weight) on more than 32,000 trucks. It was found that the conclusions drawn by BioTechnology, Inc., regarding doubles versus singles, as well as most of the other major conclusions, are not supported by the data bases. Although the accident data base may be useful to other researchers, if used with care, the two data bases needed to estimate exposure are totally inaccurate, and results derived therefrom are probably meaningless.

The passage of the 1982 Surface Transportation Assistance Act (1) (STAA) by the U.S. Congress accomplished many things. Among these was a mandate that the states not prohibit truck combinations involving two trailers from using the Interstate highways or other highways designated by the Secretary of the U.S. Department of Transportation.

Although such truck combinations, often called doubles or double bottoms, were already legal and regularly operating in many states--notably in the midwest and west--they were not legal in many of the southeastern and eastern states. Their legalization by the STAA raised many questions in the minds of concerned officials and citizens, especially questions about the safety of doubles compared with that of the more common tractor-semitrailers (singles).

The literature contains a number of original studies of this issue (2-10) as well as several reviews and summaries (11-13). Most of the studies found little difference in accident involvement rates of doubles and singles. The major exception to this trend is a study by Vallette et al. (10), often referred to as the BioTech study. It concluded that "twin trailer combinations have a significantly higher accident rate than single tractor-trailer combinations." (Vallette et al. use the word "twin" instead of "double"; however, "twin" is often taken to be the more limited configuration of a tractor plus twin van-type trailers. This distinction will be addressed further at a later point in this paper.) Their findings were met with much skepticism and criticism (14). Nevertheless, they were ultimately "accepted" and widely quoted (11-13).

Among those reviewing and criticizing the study were members of the trucking industry. Subsequently, Midwest Research Institute (MRI) was asked to conduct an in-depth, critical review of the work. This paper covers some of the major findings of that review.

THE BIOTECH STUDY

The work done by Vallette et al. (10) was a substantial and ambitious research effort funded by FHWA. It involved collection of massive amounts of data covering the 18-month period from July 1976 to December 1977, reduction and analysis of these data, and preparation of a final report that was ultimately published by FHWA in late 1981.

The concept was to determine the effect of a number of factors on accident rates of large trucks. The list of factors included highway type, truck weight, truck configuration, truck length, cargo type, and driver age and experience. To calculate an accident rate for a specified set of factors (e.g., doubles on urban freeways) requires knowledge of (a) the number of doubles involved in accidents on such facilities during a stated time period; and (b) the vehicle-miles of travel of doubles on those facilities during the same time period. Mathematically, the accident rate is calculated as

$$R = A/E \qquad (1)$$

where R is the accident rate (e.g., accident involvements per million vehicle-miles), A is the number of accident involvements for trucks with the specified characteristics, and E is the comparable "exposure," usually measured as vehicle-miles of travel. To make the representation more explicit, Vallette et al. (10) expressed Equation 1 as

$$R_{ij} = \sum_k (A_{ij})_k / \sum_k (E_{ij})_k \qquad (2)$$

In this expression i is the roadway class of interest (e.g., urban freeways), j is the variable or set of variables of interest (e.g., doubles or doubles weighing 50,000 to 60,000 lb), and k is a specific site or section of highway.

The research plan envisioned using a stratified random sample of sections of highway in a number of states. Three types of data were to be collected for each section to form data bases. The first type consisted of accident data for all truck accidents, and included information from the investigating officers' reports, plus more in-depth follow-up information. These data provide values for the terms $(A_{ij})_k$.

A second type of data was derived from vehicle classification counts (counts of the number of vehicles of specified configuration such as singles and doubles). The counts were to be made quarterly over the 18-month period, with each count covering a 7-day period, day and night. The primary method used to obtain these counts was a photographic sampling process described later. From these counts the vehicle-miles of travel could be calculated. The latter, in turn, can be used as $(E_{ij})_k$ in Equation 2 for questions involving only the truck configuration.

A third type of data base was required to apply Equation 2 to more detailed questions, such as the effect of truck weight or driver age. This data base, referred to as the size and weight data base, was to be obtained from weigh scales and truck stops. This information was intended to provide the appropriate values of $(E_{ij})_k$ needed to answer the more specific questions.

Altogether the study included 2,112 truck accident involvements at 78 highway sections in six states. A truck accident involvement is any truck involved in an accident (an accident involving two trucks yields two truck accident involvements). The second data base was planned to include 7 days x 6 quarters x 78 sites = 3,276 site-days of classification data. The third (size and weight) data base included information on 32,102 trucks observed during the study.

THE MRI REVIEW

The findings reported in this paper resulted from an unusually detailed review of all aspects of the BioTech study. Initially, the report (10) and its various drafts, along with the contractor's letter reports provided by FHWA, were reviewed. Internal FHWA memoranda and a report by the U.S. Department of Transportation Transportation Systems Center (TSC) presenting an independent review of the study (14) were also reviewed. Then, a number of the sites used in the study were visited by the lead author.

A critical activity was the acquisition and analysis of the data bases. The accident reports assembled by BioTech researchers were obtained and studied. Four data tapes containing the summarized data bases were used. More important, a fifth data tape, heretofore unexamined by others, was obtained from FHWA and decoded. It contained the "raw" vehicle classification count data base. From this data base it was possible to deduce the assumptions made by BioTech in deriving the summary classification count data tape that was later used by FHWA and TSC (14) in their review of the study. Unfortunately, the rawest form of the data (films and recording forms) no longer existed so they could not be examined.

Finally, comparative data (accident, exposure, and weight) were obtained from the California Department of Transportation (Caltrans). These data were then analyzed and compared, where feasible, with like data obtained in the BioTech study.

Although the BioTech study dealt with a multitude of truck-related issues, this review was directed mainly to the doubles versus singles issue. However, other issues that had a bearing on, or might help to explain, the authors' findings on doubles and singles were examined.

FINDINGS

The review process identified a number of research areas that were investigated individually. These ranged from the research design and its implementation to the in-depth study of each of the data bases and to the analytical and calculational procedures used. These individual areas and findings relative to them are described in this section. In general, the discussion of each area includes what the study intended, what the report states or implies was done, and the present authors' determinations.

Research Design--Site Selection

Vallette et al. clearly indicate at the outset that the research is not to be interpreted as nationally representative. Indeed, they purposely selected six states in which to collect data, each of which was in some sense unusual in regard to truck operations. The selected states tended to have unusual legal limits, high truck accident histories, or high truck volumes. One state allowed trucks up to 165,000 lb GVW; and other allowed 105-ft-long combinations. Thus, at best, the results obtained may only be applicable to the areas of the country from which the data were obtained.

Of the six states, only three allowed doubles, and the trucks in one of those three states (Michigan) are unique to that state. Thus all comparisons of doubles versus singles used data from just two states--California and Nevada. Indeed, 93 percent of the 189 accident involvements of "normal," five-axle doubles were from a single state--California. Thus the findings regarding doubles versus singles are perhaps valid only for that state. (As noted later, many of the doubles in California are of quite different configuration than are those observed elsewhere in the nation.)

A sophisticated, stratified random sampling scheme was planned. Six roadway types (later reduced to four) formed one level of stratification; truck accident frequency within roadway type formed a second level. However, final site selection procedures apparently did not follow the plan--high accident locations dominated. Further (as discussed subsequently), because the final analysis ignored the stratified design, the results largely reflect traffic safety at a very few sites. The data given in Table 1 illustrate this effect for the 31 sites in California and Nevada.

Classification Data

Site Uniformity

It was the stated intent of Vallette et al. that the sites would have "well-defined points of entrance and egress: to gain some assurance that vehicles (trucks and cars) entering one end of the site would be exiting the other end." It is evident, on examination of the sites, that this intent was not realized.

Examples are shown in Figures 1 and 2; many others could be cited. Figure 1 shows a 4-mi section of I-80 on the southern and eastern sides of Sacramento, California. The data quoted are from Caltrans vehicle classification counts obtained in 1976. Figure 2 shows a highway section in the agricultural Imperial Valley near Indio, where about half the truck traffic is generated within the section. Another example is Site 141, a section of the San Diego Freeway. The site is intersected by several small interchanges and by a major interchange with the Harbor Freeway, which experiences a heavy volume of turning movements. The cross section varies from three to five lanes northbound and from three to six lanes southbound. These examples, and many others,

TABLE 1 Dominant Sites

Stratum	No. of Sites[a]	Dominant Site	Dominance (%)[b]	Comments
Rural freeway	8	Site 114 I-5 (Grapevine)	56	Long, steep grade north of Los Angeles, eight-lanes, 26,500 AADT, 20 to 30 percent trucks, heavy fog common
Urban freeway	7	Site 145 I-80 (San Francisco-Oakland Bay Bridge)	47	Ten-lane toll bridge, 183,000 AADT, 9,500 trucks per day
Rural nonfreeway	11	Site 123 CA-152 (Pacheco Pass)	43	16-mi winding mountain road, partially two-lane, 12,000 AADT, 20 percent trucks, often cloud obscured, posted for high, gusty winds
Urban nonfreeway	5	Site 152 US-101 (just south of San Jose)	70	10-mi section of US-101 not yet up to Interstate standards, four lanes, uncontrolled access, 40,000 to 46,000 AADT, 8 to 9 percent trucks

[a]Sites in California and Nevada from which the doubles versus singles data were obtained.
[b]Percentage of all truck accident involvements for the stratum.

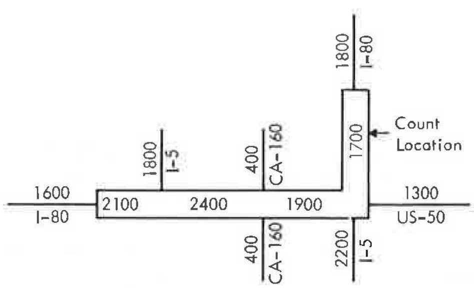

FIGURE 1 Site 143 (I-80) showing 5+ axle truck AADTs and major intersecting highways.

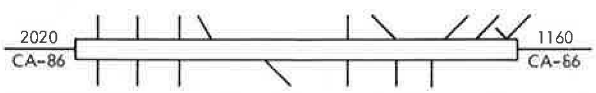

FIGURE 2 Site 121 (CA-86) showing total truck AADTs and intersecting roadways.

show that observations at one point in a site often were not representative of the whole site.

Directional Split

Classification data were obtained by observing traffic in only one direction. This would be acceptable if it could be demonstrated that the volumes, classifications, and accidents in both directions were about the same. However, such is not the case.

Table 2 gives, from the BioTech data, the difference in accident involvements, by direction, for those sites with a reasonable number of accidents during the study period (12 or more) and, for illustrative purposes, which did demonstrate a sizeable directional effect. Note that all four of the dominant sites of Table 1 demonstrate this difference.

Also shown in the table are the directions used for the classification and size and weight data. Note that these data were generally obtained from the direction having the smaller number of accidents.

Vehicle Sampling Adjustments

The classification and, subsequently, the $(E_{ij})_k$ data were derived by adjustments to counts obtained

TABLE 2 Sites with Directional Imbalance in Accident Numbers

	Accident Involvements		Direction Sampled	
Site	Directional Split	Dominant Direction	Classification Data	Size and Weight Data
112	14/8	South	North	Both
114	111/67	North	North	South
115	12/7	South	South	Unknown
123	36/20	West	East	East[a]
141	15/10	South	North	South
144	16/2	West	Both[b]	Both
145	64/39	East	West	West
152	17/13	North	South	South

[a]Both directions were eligible, but predominantly eastbound were interviewed.
[b]Switched directions part way through study.

through a photographic sampling process. A camera was positioned at each site, typically for a week or so at a time. The camera was triggered via an axle detector and counting circuitry designed to take a photograph after every N^{th} axle passage, where N was site specific. It was then intended to adjust these raw sample counts to arrive at estimates of annual vehicle-miles of travel by site and vehicle class.

State average annual daily traffic (AADT) data for the various sites were the basis of the adjustment. The state AADTs were first apportioned into trucks and nontrucks; then the truck values were further divided into numerous truck classes.

The researchers determined that their samples indicated a far higher percentage of trucks than state data showed. As a consequence, it was decided to use the state truck-nontruck split instead of what was directly observed on the films. This correction was made for only 18 of the 31 sites in the two states; inexplicably, no correction was made for the other 12, so their truck volumes remain greatly exaggerated. (At Site 145, the Oakland Bay Bridge, Vallette et al. used manual classification counts instead of the photographic process, so no adjustment of this type was needed.)

The reason for the discrepancy is that the sampling scheme was of axles, not vehicles. As stated by BioTech (10), "a five-axle truck would have five chances of having its picture taken while a three-axle truck would have only three chances of having its picture taken." The report further stated that the raw counts were adjusted to account for this sampling bias.

Although such an adjustment was clearly intended, it was not made. As stated earlier, the BioTech data tape, provided by FHWA and not previously reviewed, was thoroughly analyzed. It contained the raw counts of vehicles in 10 classification categories for each site, observation period (one of six calendar quarters), date, and time of day (day or night). It was possible to mathematically reproduce the published summaries from this tape without making any axle count adjustments. Thus, many-axle vehicles are over-represented, relative to passenger cars and other vehicles with fewer axles, in the BioTech classification data base.

Amount and Distribution of Data

The research plan called for classification data to be collected day and night at each site for one week during each of the six calendar quarters of the data collection period, and the report indicates this was done (10). However, the raw data tape does not contain 6 quarters x 31 sites = 186 data sets. There are only 74 sets of data from the films, plus one set from Site 145, where manual classification counts were made just once for a portion of one day. No data were obtained in the first quarter, and very little was obtained in the sixth. The bulk of the data (representing 25 of 31 sites) was obtained in the fifth quarter (July-September 1977). About half that amount was obtained in each of the second through fourth quarters. Because no seasonal adjustments were performed, the data base is biased toward the summer and early fall.

There was also a bias in the amount of data by site. Although some data were obtained at each site, no site had more than four data sets; most had just two. There were three sites for which only one data set was obtained, including Site 145.

The data base distinguishes between daytime and nighttime counts. All of the 74 photographic data sets include daytime data, but only 26 contain any nighttime data. Of these, three were of such questionable quality that BioTech discarded them. Review of the data suggested that, relative to the doubles versus singles issue, an additional 16 nighttime data sets could have been discarded either because of their extremely small sample sizes (fewer than five trucks in one of the two categories) or because of poor quality (discussed further subsequently). That would leave only seven sets of possibly useful nighttime photographic data, not the 186 the report implies were used.

When both day and night data existed in a given data set, BioTech combined them in a reasonable fashion to estimate the 24-hr distribution. Unfortunately, when night data did not exist, which was the case in 51 of the 74 data sets available, they simply used the daytime data as representative of the entire period.

This would be acceptable if, for example, the doubles-singles relationship could be shown to be the same both day and night. However, such is not the case. The data in Table 3 indicate this clearly. The data are from Caltrans classification counts collected routinely as part of an FHWA-mandated counting program and are for the six sites of the BioTech study at which the state made such counts. The doubles-to-singles ratio was greater at night than during the day in every instance except one--eastbound traffic at Site 122. Often the ratios differed by factors of three or more. By using only daytime data the exposure of doubles was greatly underestimated, relative to singles. Therefore, the doubles accident rate was greatly inflated relative to singles. Unfortunately, it is not possible to estimate how large an error was introduced overall because Caltrans counts are available for only six sites.

TABLE 3 Directional Differences in Truck Volumes

		Ratio of Doubles Volume to Singles Volume[a]	
Site	Direction	Day	Night
112	N	0.354	0.975
	S	0.301	0.951
114	N	0.495	0.945
	S	0.599	0.825
115	N	0.343	0.458
	S	0.371	0.412
122	E	0.364	0.333
	W	0.063	0.250
141	N	0.236	0.920
	S	0.211	0.537
144	E	0.839	1.728
	W	0.937	0.990

[a]From Caltrans classification counts, July-September 1977.

Quality of Data

The problems with the exposure data discussed so far can be evaluated fairly objectively. They deal, essentially, with how the data base was created and what data are included. It is more difficult to assess the quality of the data. For the most part the truck classification counts are based on the judgments of technicians who viewed the photographs of vehicles. Because the photographs apparently have since been destroyed or discarded, it is not possible to confirm the accuracy of the judgments. Nevertheless, it is possible to examine the data base in great detail and note discrepancies that are highly suggestive of reading errors.

The film readers attempted to classify each vehicle photographed into one of eight categories:

- Straight truck,
- Straight truck plus full trailer,
- Straight truck plus dolly,
- Single,
- Double,
- Triple,
- Bobtail (tractor only), and
- Nontruck.

Figures 3 and 4 suggest how difficult the classification process can be. These are photographs taken under essentially optimum conditions by MRI at a number of the sites in California.

The difficulty of distinguishing vehicle classifications from photographs, particularly when they are poorly exposed (as at night) was recognized by BioTech (BioTechnology, Inc., unpublished progress reports to FHWA, December 1975). To deal with this difficulty, they established two additional vehicle classifications, "unknown large truck" and "unknown vehicle." The first was to be used when the film reader could not make a clear distinction between truck classifications; the second was to be used when, obviously, a vehicle had triggered the camera to take a photograph but, for whatever reason, it was not possible to tell if the vehicle was a car or a large truck. This might happen, for example, if there were no illumination or if another vehicle or object was between the lens and the target vehicle.

These difficulties were sometimes pervasive. Table 4, for example, indicates that at a number of

FIGURE 3 Similar-appearing tank trucks.

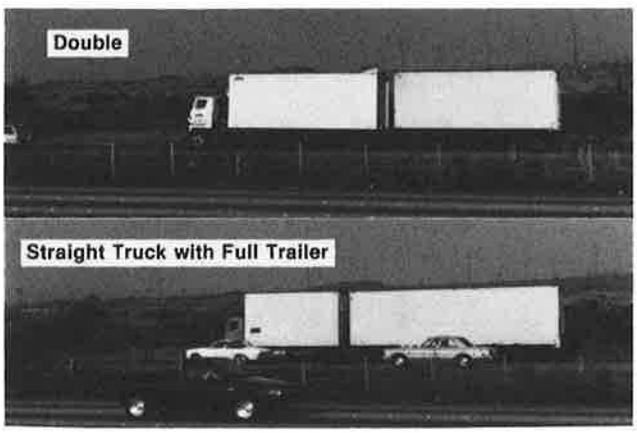

FIGURE 4 Similar-appearing van-type trucks.

TABLE 4 Sites with a High Percentage of Unknown Large Trucks

	Percentage of All Large Trucks			
Site	Singles	Straight plus Trailer	Doubles	Unknown Large Truck
111	33.3	12.5	11.2	26.3
113	58.0	14.7	15.7	6.9
114	52.2	17.2	19.0	7.2
115	40.9	17.1	12.8	22.4
121	29.1	25.2	26.8	10.1
131	29.8	19.0	4.8	2.6
133	30.1	6.5	34.2	12.6
142	29.8	21.7	14.9	8.1
144	33.1	21.4	25.0	13.8
152	40.4	20.0	13.2	15.9
162	3.9	7.9	3.9	3.9
413	65.4	8.6	15.3	4.0
421	54.1	4.4	5.1	26.1
442	44.0	12.3	6.2	10.9

sites the category "unknown large truck" contained the same magnitude of counts as the common truck classifications, and sometimes many more. For example, at Site 111 there were more unknown large trucks than there were doubles and straight trucks with trailers combined. After a review of much of the detailed count data, it appears that these unknowns were most likely either doubles or straight trucks with trailers. The net effect of this difficulty, then, is an underestimate of the exposure of doubles and, therefore, an overestimate of their accident rate.

Many specific, "unusual" data values were discovered on the data tape that were further evidence that data problems were encountered. A few brief examples follow:

1. Site 123, fifth quarter, night

Day	Nontrucks
Friday	23
Saturday	30
Sunday	57
Monday	3
Tuesday	28

2. Site 131, fourth quarter, day

Day	Straight Trucks
Tuesday	18
Wednesday	19
Thursday	3
Friday	4
Saturday	42
Sunday	27

3. Site 111, fourth quarter, night

Day	Unknown Large Trucks
Friday	5
Saturday	98
Sunday	0
Monday	1
Tuesday	4

4. Site 122, fourth quarter, day

Day	Straight with Trailer	Singles
Monday	1	43
Tuesday	5	20
Wednesday	34	0
Thursday	0	18

5. Various sites, day versus night

	Site 144		Site 421		Site 152	
Truck Type	Day	Night	Day	Night	Day	Night
Singles	137	24	602	50	151	8
Doubles	65	0	63	0	73	0
Straight	42	0	27	0	30	0
Unknown large trucks	29	87	4	253	6	36

The data in Table 5 suggest in a summary way the combined effects of the several difficulties inherent in the BioTech exposure data. The table covers all the sites for which comparable classification counts were available from Caltrans. Most of the latter were obtained in 1976 and 1977 and represent a complete count (100 percent sample) for a 24-hr weekday. (A few were obtained in 1975.) All Caltrans data are for both directions of travel except for Sites 131 (eastbound only) and 152 (southbound only). In every instance the BioTech data underestimate doubles exposure relative to singles exposure, compared with the Caltrans data. On the average, BioTech's data appear to underestimate doubles by 36 percent.

Size and Weight Data

The size and weight data base does not figure directly in the doubles versus singles issue. It does,

TABLE 5 Overall Underestimation of Doubles in Exposure Data Base

Site	Doubles-to-Singles Ratio BioTech	Doubles-to-Singles Ratio Caltrans	Caltrans-to-BioTech Ratio
111	0.336	0.428	1.27
112	0.316	0.476	1.51
114	0.364	0.694	1.91
115	0.316	0.391	1.24
122	0.054	0.133	2.46
123	0.487	0.840	1.72
131	0.161	0.176	1.09
141	0.250	0.298	1.19
144	0.756	0.861	1.14
152	0.327	0.438	1.34

however, affect peripheral conclusions asserted by BioTech, such as that empty or nearly empty vehicles (especially doubles) have substantially higher accident involvement rates than do loaded vehicles. It is therefore enlightening to briefly review the size and weight data base.

Data Collection Sites

The intent was to collect size and weight data at the same sites that were used for accident and classification data collection. However, this was accomplished at only eight of the 31 sites. At these eight locations, all in California, size and weight data were obtained at state scales.

Data were also obtained at state scales at five other California locations, but not necessarily on the same highway as a site. No scales were available in Nevada, but one was used in Utah near the state border. Additional data were obtained from interviews at truck stops. Altogether the data base contains data on more than 27,000 trucks from California and Nevada obtained at a total of 28 locations. That the locations did not always match the study sites (that is, they did not sample the same traffic stream) is perhaps moot, however, because no site-specific analyses were performed. All analyses performed, and conclusions drawn, were based on the entire, pooled, data set.

Data were generally obtained for only one direction of travel, with the implicit assumption that the two directions were equivalent. At many California sites, however, that is simply not true. Weight data obtained by Caltrans in both directions at six of the BioTech sites illustrated this. The Caltrans data were obtained routinely as part of an FHWA-mandated truck size and weight monitoring program. Table 6 gives the median weight of doubles for the summer of 1977 (Site 123 data were obtained in 1975). There are logical reasons for these differences. For example, most of the doubles at Site 123 were flatbed trucks that carried agricultural produce from the fields to the canneries and returned empty. Most of the doubles at Sites 114 and 141 were tankers hauling petroleum products away from refineries and returning empty.

TABLE 6 Direction of Travel Versus Truck Weight for Doubles

Site	Directions of Travel	Median Weight (thousand lb)
112	North/South	38/59
114	North/South	54/76
115	North/South	64/66
123	East/West	28/74
141	North/South	34/78
144	East/West	50/76

Empty Bypass Effect

The truck scales in California employ a "bypass" lane. Trucks that are empty are directed, by sign, to use this lane and bypass the scales. Because these trucks were not weighed, the BioTech data base greatly underestimates the low end of the truck weight distribution. This was recognized by the authors, and a second set of calculations was performed assuming 25 percent of all trucks (doubles and singles alike) were empty.

The Caltrans weight data were obtained in surveys in which the bypass lane was closed. The most common truck configurations (e.g., 3S2) were sampled on a 25 percent basis and all others on a 100 percent basis. Figures 5-7 show the comparative weight distributions based on data from the eight California sites where BioTech obtained scale weight data.

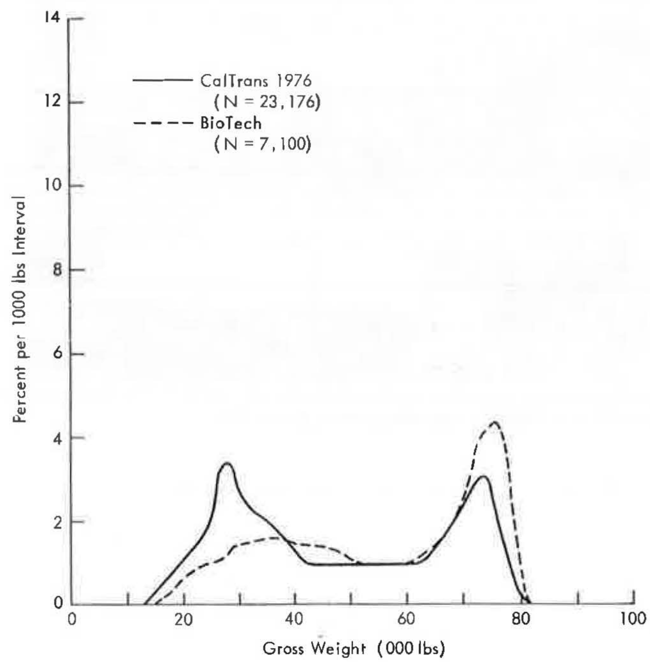

FIGURE 5 Weight distribution of singles.

Clearly, the discrepancies are sizable. The BioTech undercounting of empties results in an apparent overrepresentation of heavy trucks. Also, the discrepancies are not the same for the different truck classifications. Using 39,000 lb as an indicator of empty or not empty, the data in Table 7 are obtained. The data show that to correct the BioTech data base for undercounting empty trucks would require increasing their counts for empty singles by 68 percent, doubles by 395 percent, and straight plus trailer trucks by 614 percent. (Comparable results are obtained with other "indicator" values such as 33,000 lb.)

Missing Data

Of the entire California and Nevada size and weight data base, 93 percent of the data were obtained in

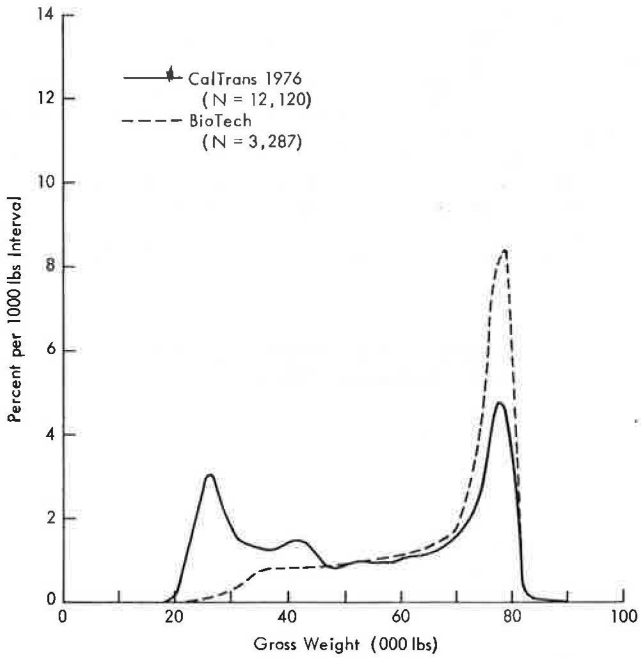

FIGURE 6 Weight distribution of doubles.

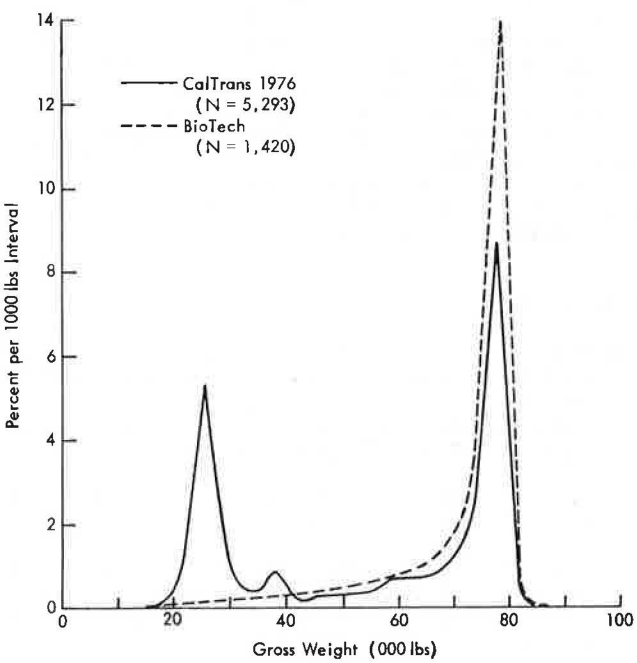

FIGURE 7 Weight distribution of straight trucks with trailers.

California. Nearly all (89 percent) were obtained during the day; it is not clear what biases this might have introduced. Presumably, for doubles, agricultural products would be less likely to be moved at night, and vans would be more likely then. Overall, according to Caltrans data, day and night truck volumes were comparable. However, doubles were relatively more dominant at night, as the data in Table 3 indicate.

In addition to truck weight, other data items were collected and analyzed, and conclusions were drawn. For example, one analysis compared accident rates of singles with 40- and 45-ft trailers. But this data element (length of first cargo unit) is

TABLE 7 Undercounting of Empty Trucks

	Percentage of Trucks Weighing 39,000 lb or Less	
Classification	BioTech	Caltrans
Singles	26.3	44.3
Doubles	7.3	35.4
Straight plus trailer	4.4	31.4

missing for 86 percent of the trucks. A number of analyses examined driver parameters such as age and experience. These data are missing for 92 percent of the trucks.

Accident Data

It was intended that all truck accident involvements occurring on the study sites in the year-and-a-half study period be investigated in depth. A total of 2,112 accident involvements are in the data base. A review of those from California, in comparison with the Caltrans computerized accident file, revealed a fairly good match, considering the difficulty of collecting such data. More than 90 percent of the truck accidents in the Caltrans files were covered by the BioTech data base. An independent review of the accident data in the file from another of the six states in the study, Michigan, and the state police data files, indicated about 45 percent of the accidents were missing (J. O'Day, University of Michigan, unpublished data). However, the Michigan data were not used in the analyses of doubles versus singles, so any problems with the Michigan data do not affect that aspect of the study.

The accident data base consists of data taken from the police accident reports plus data obtained by follow-up investigations by the researchers. The files are reasonably complete (∼ 95 percent) with respect to the police report data, but much of the expected follow-up information is missing. Missing data rates for these items range from about 30 percent (cargo area configuration), to 59 percent (truck weight), to 90 percent (truck weight distribution). The reasons for the missing data, such as difficulty in getting police reports in a timely fashion; difficulty in tracking down the involved drivers, trucks, or companies; and constraints of time and funds, are well understood by those versed in accident research.

The missing data of most importance, probably, are the truck weight data. These data were analyzed in comparison with other variables to determine if biases may have been introduced. Table 8 gives the differences in missing data rates as a function of cargo type. The cargo type "empty" had a known weight associated with it in more than 90 percent of the cases--that is, fewer than 10 percent were missing. Other cargo types had much more missing weight

TABLE 8 Likelihood of Knowing the Weight of an Accident-Involved Truck Versus Its Type of Cargo

Cargo Type	Percentage with Known Weight	N
Lumber products	50.0	18
Farm products	57.1	49
Solids in bulk	58.3	24
General freight	81.4	59
Liquids in bulk	83.9	31
Empty	90.2	143

information. More than 40 percent of the weights were unknown for trucks carrying farm products, a prevalent type of cargo in California. The effect of missing weight data for all truck classifications is evident in Table 9. The weight was more likely to be known if the truck was empty than if it was not empty (partly or completely loaded).

TABLE 9 Likelihood of Knowing the Weight of an Accident-Involved Truck Versus Its Empty/Not Empty Status

	Percentage with Known Weight	
Truck Type	Empty	Not Empty
All trucks	90.0	70.1
Single	95.6	81.5
Doubles	91.2	62.5
Straight	90.5	69.3
Straight plus trailer	84.6	69.6

The net effect of using the weight data with so much of it missing was to overstate the accident involvement rate of lighter trucks relative to heavy trucks, simply because the lighter (empty) ones were more likely to have a known weight than were the heavier (loaded) ones.

Data Analysis

The analyses presented in the BioTech report (10) were reviewed and many problems were found. The major problem, which affected all the computations, was the failure to account for missing data.

For example, the weights of about half the accident-involved trucks were not known. The computations of A_{ij} used only the trucks with known weights. Thus the calculated accident involvement role is apparently low by a factor of 2 because all of the vehicle-miles of travel were apportioned among only half the accident-involved trucks. In actuality, the situation is more complicated because the classification data (and the size and weight data) are also incomplete, and no corrections were made. Thus, for example, with 92 percent of the drivers' ages missing from the size and weight file (and assuming complete data on this item in the accident file), the computed rates would be high by a factor of 12.5. In summary, none of the computed accident involvement rates are numerically correct.

As indicated, a number of other problems were found in the analyses but need not be dwelled on. They could be corrected; the data bases cannot.

Representativeness of Truck Configurations

Even if there were no other problems with the BioTech study (10), a question would still need to be asked: "Are the results obtained likely to be observed elsewhere; that is, are they representative?" The authors clearly warn the reader not to extrapolate the data beyond the states in the study. However, many readers will be tempted to do so, and many have already (11-13).

The doubles versus singles issue, in most people's opinion, deals with the common van-type semitrailers and the increasingly common "twins," which are tractors plus two 27-ft van trailers. The latter, in particular, are becoming evermore popular in the "less-than-truck-load" (LTL) trucking industry--carriers involved in general commodity freight. Are these the types of trucks examined in the BioTech study?

Table 10 gives, for accident-involved doubles, the types of cargo configurations from the BioTech study. Of these 196 trucks, fewer than one-third (62) are of the common van or "twin" variety. There were more platform (flatbed) doubles than vans; such flatbed combinations are typically used to haul agricultural produce in California. Double tankers and bulk commodity carriers are also common in California.

TABLE 10 Cargo Area Configuration of Accident-Involved Doubles

Configuration	Number
Fully enclosed	62
Platform	74
Tank	30
Bulk commodity or dump	24
Other	6
Total	196

These nonvan doubles are frequently found in intrastate use in California but are not expected to become widely used elsewhere in the United States. Because of a quirk in California size and weight legislation before 1973, a double configuration could legally carry about 3,000 lb more than a single. This resulted from a kingpin-to-rear axle limitation coupled with bridge formula axle load limits. Thus, despite their greater capital investment requirements, there was an economic incentive to employ doubles in many industries in California. Although that particular economic incentive no longer exists, most of these industries continue to use such doubles within the state.

CONCLUSIONS

The MRI review of the BioTech study found that the major conclusions of that study are not supported by the project data base. The conclusion that doubles have substantially higher accident involvement rates than singles cannot be supported because

- Only one direction of traffic was sampled for classification data, but accidents in both directions were used. This is important because Caltrans data show that truck accidents and exposure differ greatly by direction at many sites.
- Most of the classification data were obtained during the daytime, even though about half of the accidents occurred at night. This is important because Caltrans data show that truck exposure, by type and configuration, differs greatly between day and night.
- Classification data were typically collected during only two quarters, not six as reported. This is important because both exposure and accidents differ greatly from season to season.
- The photographic classification data were based on a sample of axles, not vehicles, and no correction was made for this.
- The photographic classification data collected by BioTech differ greatly from manual classification data collected by Caltrans, even when comparisons are made between data collected at the same site in the same direction during the same quarter. These differences apparently arise from difficulties in interpreting the photographic data, which led to

a large undercounting of doubles and thus an inflated doubles accident rate.

The conclusion that empty or nearly empty trucks have high accident rates relative to loaded trucks cannot be supported because

- The truck weight data collected by BioTech differ greatly from those collected by Caltrans at the same scales, mainly because California routinely allows empty trucks to bypass the scales and these bypassed trucks were not sampled by BioTech. This problem resulted in a large undercounting of empty trucks, especially doubles and straight plus trailers, which led to inflated accident rates for empty trucks. No adequate correction for the bypassed trucks has been made.
- Most of the truck weight data were obtained during the daytime, even though one-half of the accidents occurred at night.
- Truck weights were missing from the accident data more often for loaded trucks than for empty trucks. This led to an inflated empty accident rate.

Many of the other conclusions of the study are not supported because of similar problems in the exposure and accident data bases.

Overall, the accident data base may be useful to future researchers, if care is taken to handle missing data properly. The exposure data bases, including both the classification data and the size and weight data, are totally inaccurate and analysis results derived from these data bases are probably meaningless.

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Axle Load Limits in Ontario: Long-Term Analysis

A. O. ABDEL HALIM and F. F. SACCOMANNO

ABSTRACT

Overloaded axles contribute significantly to the deterioration of road structures. Protection against severe pavement deterioration is provided in most jurisdictions by limiting permissible axle loads for commercial traffic. Within most provincial jurisdictions in Canada, axle load limits have been set arbitrarily with little reference to economic viability. In practice, axle load limits have been established from past experience based essentially on two conditions: (a) the need to maintain a reasonable level of serviceability on the road network and (b) available monies for annual rehabilitation and maintenance programs. The financing of rehabilitation and maintenance programs is supported from general revenues for each jurisdiction, and this allocation of funds may have little relevance to the incidence of costs and benefits to users of the road system or to the responsible transportation agency. In this study two actual axle load distributions are investigated to assess the effects of changing the axle load limits on transportation costs. These costs include pavement rehabilitation and maintenance and commercial and noncommercial vehicle operating expenditures. In Ontario the vehicle operating costs for commercial traffic are the dominant cost component that influences the economic viability of axle load limits. The increased operating costs of noncommercial traffic from reduced pavement serviceability appear to mitigate against increases in the maximum allowable axle load. Furthermore, long-term changes in truck fleet composition, resulting in a more efficient distribution of axle loads, may produce conditions under which higher axle load limits are economically justified.

Most jurisdictions provide protection against severe road surface deterioration by enacting legislation that limits permissible axle loads. These limits are established in most cases with little reference to general economic viability, and they remain both arbitrary and inconsistent across jurisdictional boundaries. A recent study by the Transportation Research board (1) suggests that failure to adopt consistent limits among states in the United Stated has imposed additional costs on both trucking operations and road administration. As noted by Connor (2) the situation is rendered difficult by divergent jurisdictional requirements that may affect the incidence of costs and benefits that result from different axle load limits in different environments. For example, in northern regions where subgrade strength may be reduced by severe freeze-thaw action, axle load limits are more critical in maintaining road serviceability than in a southern environment where seasonal variations are not as extreme. In Canada jurisdictional requirements and inconsistent economic guidelines have given rise to a wide range of provincial axle load limits.

In Ontario load restrictions were first applied in 1916 when single axle loads were limited to a maximum of 9 kips. Since then various attempts have been made by the Ontario Ministry of Transportation and Communication (MTC) to study the benefits and costs of various allowable load levels. In response to these studies, year-round limits have been systematically increased throughout this period. In 1961 the single axle load limit was set at 18 kips. A study conducted in 1966 by the Ontario Department of Economics and Development, quoted by Armstrong et al. (3), concluded that reduced vehicle operating costs for trucks amount to less than 4 percent of the cost of upgrading the road network to allow for maximum axle loads of 20 kips. Despite this finding, the maximum single axle load was again raised to kips in 1968. In this paper an attempt is made to assess the short-run and long-run economic consequences of this increase.

In this study economically viable axle load limits are established when the savings from reduced pavement deterioration and enhanced serviceability, which are realized by the road administration and by noncommercial traffic, are offset by additional costs to truck operators from reduced vehicle utilization. The basic objective of this paper is to assess the economic viability of increasing axle load limits from 18 kips (8.2 tons) to 20 kips (9.2 tons). Ontario axle load distributions for 1967 and 1981 are used to monitor the expected traffic responses to these changes.

The changes in axle loads before and after the introduction of new axle limits are assessed in terms of observed 1967 and 1981 load distributions. This approach is a significant departure from previous work in this area. In most studies to date, for example work by MacLeod et al. (4), observed axle load distributions are obtained for the base year conditions. Changes in these distributions for the horizon year are based on the application of exogenous elasticities to the base year profiles. The horizon year axle load distributions remain somewhat speculative because they depend on the accuracy of the unobserved arc elasticities.

The 1967 axle load distribution in this study is obtained from a random sample of 6,700 trucks weighed at various points along the 401 expressway in Ontario. Some of the results of this survey are documented in Armstrong et al. (3). The horizon year 1981 truck loadings are obtained from a sample of vehicles that were monitored at the MTC weigh-in-motion scale located on the eastbound approach of the 401 expressway near Whitby. Both surveys were conducted during the summer.

In general, the framework introduced in this paper should provide economically effective guidelines for establishing maximum single axle load restrictions in most jurisdictions where traffic composition and environmental factors are similar to those in Ontario.

PROCEDURE FOR ESTIMATING AXLE LOAD RESPONSES

In 1967 a survey of 6,700 trucks was conducted in Ontario to determine gross vehicle weights and axle load distributions by vehicle type. Some of the results of this survey are documented by Armstrong et al. (3). Figure 1 shows the distribution of axle weights from the 1967 truck sample for three types of axles: single, tandem, and tri-axle combinations. Given a single axle load limit of 18 kips, these distributions suggest a significant number of overload axles or violators in the traffic stream. As noted by Armstrong et al. (3):

> Though certain instances of pavement deterioration due to excess loads had occurred, undue and widespread damage was not being caused by the regime of vehicle axle and gross weights which was actually using the highways. This confirmed other studies indicating that pavements might tolerate greater axle loads.

Table 1 gives a summary of the truck axle weight distribution from Figure 1 for this 1967 sample. The daily gross vehicle weight was estimated as 251,417 kips. All single, tandem, and tri-axle combinations were assumed to carry empty vehicle weight components of 2.5, 5.0, and 7.5 kips per combination, respectively. This produced a daily empty loading for the sample truck fleet of 46,209 kips and a payload of 205,208 kips per day (or approximately 72 x 10^6 kips per year).

Load equivalency factors from Figure 2 were applied to the 1967 axle load distribution to yield the equivalent single axle damage units for each gross vehicle weight interval. These damage estimates are summarized in Table 2. The 1967 sample truck fleet produced 12,328 equivalent damage units (DUs) per day or 4.5 x 10^6 DUs for the entire year, neglecting seasonal load variations.

The DU is a standard unit that reflects the damage caused by the passage of a standard 18-kip single axle. One of the most common methods that relates pavement life to standard axle passes or DUs is provided by the AASHO Road Test (5) relationship. This is shown in Figure 3. The structural number

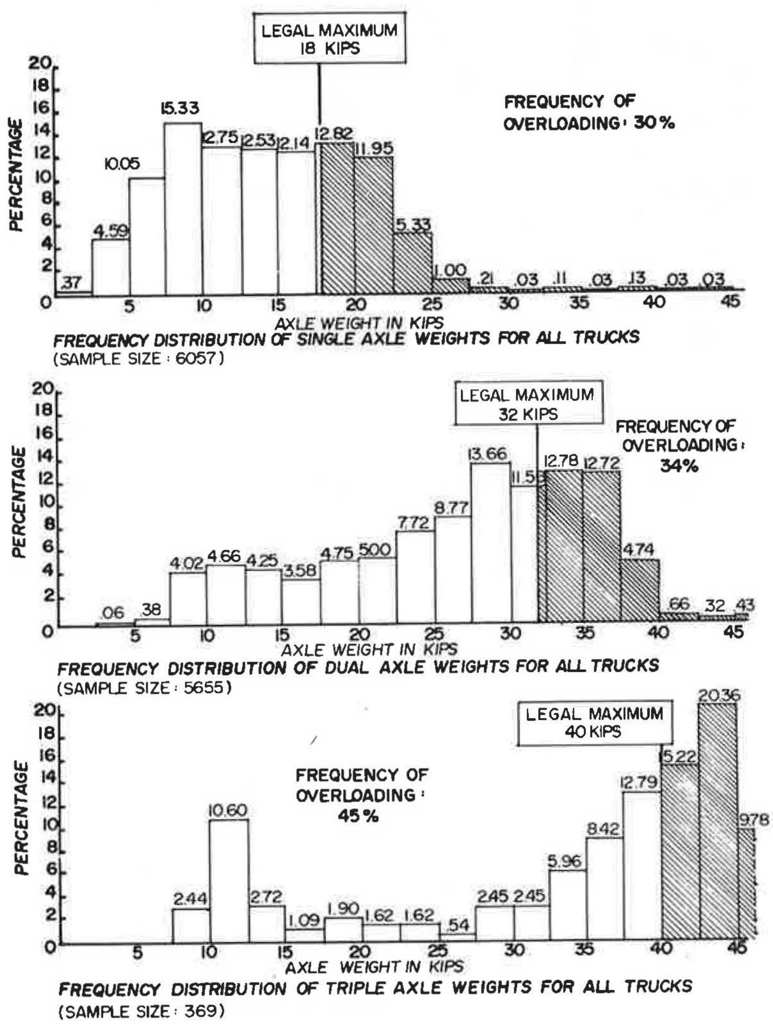

FIGURE 1 Selected data from 1967 truck survey.

TABLE 1 Truck Axle Weight Distribution, 1967

	Single Axles (50%)			Tandem Axles (47%)			Tridem Axles (3%)		
	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)
0-5	5.0	300	750.0	0.1	3	7.5	0.0	0	.0
5-10	25.5	1545	11587.5	4.4	250	1875.0	2.4	9	67.5
10-15	25.2	1527	19087.5	8.9	506	6325.0	13.3	48	600.0
15-20	24.9	1508	26390.0	8.3	472	8260.0	3.0	10	175.0
20-25	17.8	1077	24232.5	12.6	722	16245.0	3.3	12	270.0
25-30	1.2	73	2007.5	22.2	1270	34925.0	3.0	11	302.5
30-35	0.2	11	357.5	24.6	1410	45825.0	8.4	30	975.0
35-40	0.1	8	300.5	17.5	991	37162.5	21.2	77	2887.5
40-45	0.1	4	170.0	1.4	80	3400.0	35.6	129	5482.5
45+	0.0	0	0.0	0.0	0	0.0	9.8	35	1750.0
	100.0	6053	84882.5	100.0	5704	154024.5	100.0	361	12510.5

Note: Daily number of axles = 12,118 kips (payload plus vehicles); gross daily weight = 251,417 kips; vehicle weight (empty) = 46,209 kips (all truck types); daily payload = 205,208 kips; and annual payload = 72,000,000 kips.

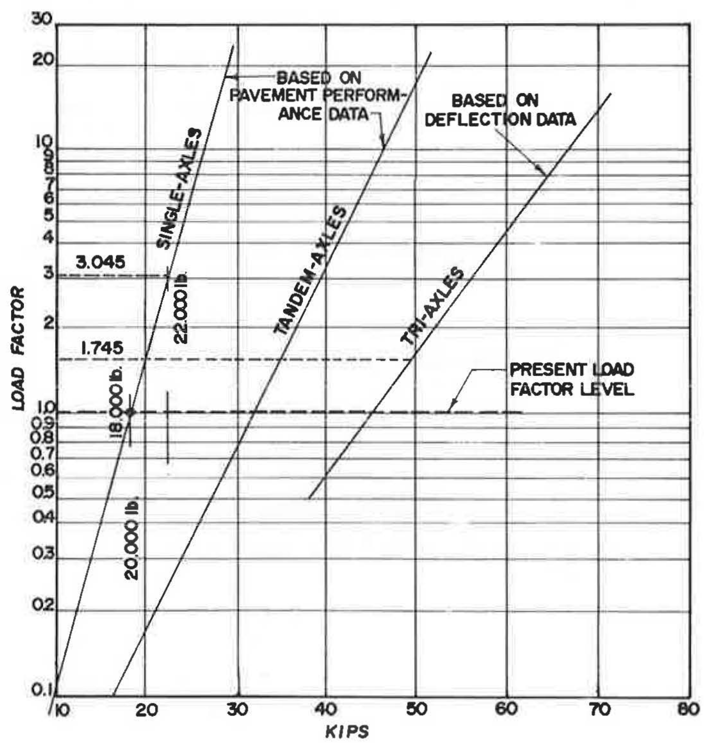

FIGURE 2 Load equivalency factors and axle load equivalents for flexible pavements, after Armstrong et al. *(3)*.

TABLE 2 Damage Units for 1967 Truck Axle Loads

	Single Axles			Tandem Axles			Tridem Axles		
Weight (kips)	Load Factor	No. Axles	Equivalent DU (18 kips)	Load Factor	No. Axles	Equivalent DU (32 kips)	Load Factor	No. Axles	Equivalent DU (44 kips)
0-5	0.05	300	15	0.05	3	0	0.05	0	0
5-10	0.10	1545	155	0.05	250	13	0.05	9	1
10-15	0.15	1527	229	0.10	506	51	0.05	48	2
15-20	1.00	1508	1500	0.15	472	71	0.05	10	1
20-25	3.05	1077	3285	0.20	722	144	0.15	12	2
25-30	10.00	73	730	0.40	1270	508	0.20	11	2
30-35	25.00	11	275	1.00	1410	1410	0.30	30	10
35-40	40.00	8	320	2.80	991	2775	0.50	77	39
40-45	50.00	4	200	5.32	80	426	0.80	129	103
45+	50.00	0	0	10.00	0	0	1.50	35	53
		6053	6717		5704	5398		361	213

Note: Daily equivalent damage units = 12,328 and annual DUs = 4,449,686.

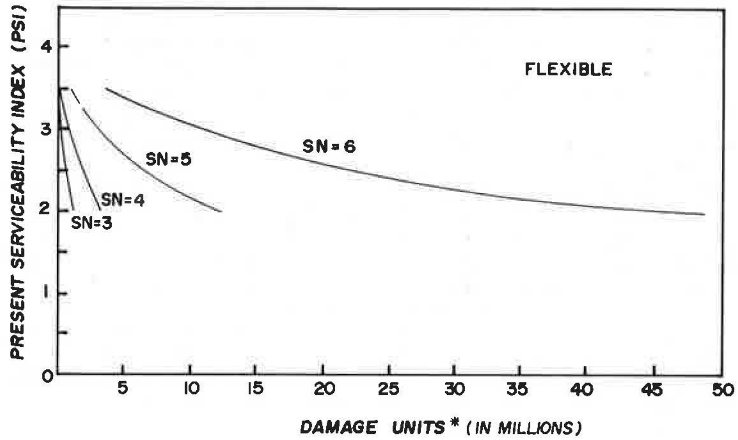

FIGURE 3 Present serviceability index versus damage units for flexible pavements.

(SN) in the Figure is an index that reflects the composition of the layered pavement structure:

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

where

D_1 = depth of pavement surface,
D_2 = depth of base course, and
D_3 = depth of subbase course.

Most common values for a_1, a_2, and a_3 are 0.44, 0.14, and 0.11, respectively. For the purpose of this analysis a structural number SN = 6 has been assumed. This is characteristic of a high-standard pavement structure capable of accepting significant load applications.

The present serviceability index (PSI) in Figure 3 is a rating, established by AASHO, that reflects the ability of the pavement to serve specific traffic requirements. When PSI drops below a critical value (e.g., PSI = 2.0), the pavement requires major rehabilitation of the entire layered structure so as to restore serviceability to its original level. This differs from routine maintenance and may be carried out before the PSI reaches the critical value for rehabilitation. In general, routine maintenance represents a minor component of rehabilitation expenditures and may be ignored for the purpose of this analysis (6).

The service life of the pavement, or the period between rehabilitation, can be determined for 1967 using the annual damage units estimated in Table 2 in conjunction with the AASHO serviceability relationship in Figure 3. Assuming a base year PSI value of 3.5 and a critical PSI value of 2.0, a total of 45 x 10^6 DUs can be tolerated between rehabilitation programs for an SN value of 6. This suggests that 10 years can be allowed between rehabilitation expenditures on the basis of the 1967 sample truck loadings.

The 1981 truck load profile was obtained for a sample of vehicles that were monitored at the MTC weigh-in-motion scale located on the eastbound approach of the 401 expressway near Whitby. These trucks were weighed between July 21 and August 3, 1981.

The axle load distribution for the 1981 truck sample is summarized in Table 3. The total weight carried within each weight interval and the number

TABLE 3 Truck Axle Weight Distribution, 1981

	Single Axles (62.6%)			Tandem Axles (36.9%)			Tridem Axles (0.5%)		
Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)
0-5	17.8	10627	26567	-	-	-	-	-	-
5-10	33.4	6647	49850	10.6	1243	9326	7.0	11	83
10-15	34.0	4060	50745	11.5	809	10117	7.0	7	83
15-20	7.5	640	11194	11.6	583	10205	5.0	3	60
20-25	5.0	332	7463	11.0	430	9677	1.0	1	12
25-30	2.3	125	3433	10.4	333	9150	1.0	1	12
30-35	-	-	-	16.6	449	14604	3.7	1	44
35-40	-	-	-	11.3	265	9941	4.0	1	48
40-45	-	-	-	8.6	178	7566	5.0	1	60
45-50	-	-	-	6.5	120	5719	18.6	5	222
50-55	-	-	-	1.4	23	1231	41.4	9	494
55-60	-	-	-	0.5	8	440	5.0	1	60
60+	-	-	-	-	-	-	1.3	0	15
	100.0	22431	149252	100.0	4441	87976	100.0	41	1193

Note: Daily number axles = 26,913; daily gross vehicle weight (adj.) = 238,420 kips (payload plus vehicles); vehicle weight (empty) = 38,420 kips; daily payload (constant) = 205,208 kips; and annual payload = 72,000,000 kips.

of axles in different combinations that carry this weight were modified to reflect the 1967 payload. The basic premise of this analysis is that the distribution of axle loads over the 1967-1981 period will adjust to new axle load limits. To ensure that axle load adjustments are not primarily a result of increased or reduced shipment levels over this period, the base year (1967) payload is applied to both 1967 and 1981 movements. In Ontario axle load limits were increased from 18 kips to 20 kips in 1968. The 1981 horizon year provides sufficient time for long-term changes to occur in response to the less restrictive load guidelines. A significant component of the change in the axle load distribution during the 13-year period, 1968-1981, may be technological in nature, reflecting changes in truck fleet composition. These changes require an extended period of time to occur. A horizon year that followed too soon after the axle load limit is adjusted would fail to capture these long-term effects. Because both the time of year and the general location of the two truck load samples for 1967 and 1981 are similar, changes in axle load distribution during the two time periods must occur in response to changes in the axle load limit. This is especially true given the adjustment for a constant payload during the 1967-1981 period.

The 1981 truck sample is subject to a single axle load limit of 20 kips. Although the payload has been assumed constant, the distribution of axle loads is expected to vary in response to less restrictive maximum allowable loadings. The empty weight component in Table 3 reflects the observed empty-to-gross vehicle weight ratio from the weigh-in-motion sample and an assumed constant daily payload of 205,208 kips.

The axle load distribution for 1981 from Table 3 suggests four trends for the period 1967-1981:

1. There is an increase in the proportion of single axles during this period. Single axles comprise 50.0 and 62.6 percent of the total axle passes in 1967 and 1981, respectively.
2. There is an increase in the proportion of heavy loadings that are allocated to tandem and tri-axle combinations, where the load transfer to the pavement is less pronounced. In general, despite a more generous load allowance, vehicle capacity in 1981 is being used more efficiently in relation to pavement deterioration.
3. Despite a constant assumed payload, the daily gross vehicle weight in 1967 is more than in 1981. In the latter year the empty vehicle component is a lesser proportion of the gross vehicle weight, which suggests a more efficient use of available truck fleet capacity. Clearly this is due to technological improvements rather than to the increase of the axle load limit.
4. The higher axle load limit in 1981 has not eliminated the incidence of overload axles in the sample. In general, overload single axles are reduced from the 30 percent level in 1967 to approximately 15 percent of the sample in 1981, although overloaded tandem axles in 1981 are similar in proportion to 1967 values at approximately 28 percent of the sample. The overload tri-axle proportion in 1981 has increased significantly from 1967, to approximately 60 percent of the sample from 45 percent in the earlier year.

It would be inappropriate to suggest from these results that reduced damage to pavement can follow an increase in allowable axle loads. Clearly technological developments during an extended 14-year period play a significant role in this observation. Nevertheless, axle load limits are not the central issue here. The truck fleet changeover between 1967 and 1981, which has allowed more efficient use of available vehicle capacity, has also produced reduced pavement deterioration for the same payload. In the long run, it can be argued that a truck fleet changeover to more efficient loading profiles should be a fundamental premise in any long-term guidelines that restrict axle loads.

Table 4 gives a summary of the damage unit results for 1981 based on the load factors designated in Figure 2. Interestingly, the reduction in single axle violators and the more efficient allocation of loads to tandem and tri-axle combinations have caused a reduction in damage units, despite an increase in axle load limit. In 1981 approximately 3.4 x 10^6 DUs per year were estimated. This suggests an increased rehabilitation cycle of 13 years. Despite an increase in the maximum allowable single axle load limits in the latter year, reduced pavement rehabilitation costs continue to be realized during the 1967-1981 period. This cost reduction is due essentially to truck fleet changeover and more efficient use of available vehicle capacity. Whether this development can be expected to take place indefinitely, or even in the short-run situation, is a concern that will be addressed later in this paper.

TABLE 4 Damage Units for 1981 Truck Axle Loads

	Single Axles			Tandem Axles			Tri-Axles		
Weight	Load Factor	No. Axles	Equivalent DU (18 kips)	Load Factor	No. Axles	Equivalent DU (32 kips)	Load Factor	No. Axles	Equivalent DU (44 kips)
0-5	0.05	10627	531	0.05	-	-	0.05	-	-
5-10	0.10	6647	665	0.05	1243	62	0.05	11	1
10-15	0.15	4060	609	0.10	809	81	0.05	7	0
15-20	1.00	640	640	0.15	583	87	0.05	3	0
20-25	3.05	332	1013	0.20	430	86	0.15	1	0
25-30	10.00	125	1250	0.40	430	133	0.20	1	0
30-35	25.00	-	-	1.00	333	449	0.30	1	1
35-40	40.00	-	-	2.80	449	742	0.50	1	1
40-45	50.00	-	-	5.32	265	947	0.80	1	1
45-50	50.00	-	-	10.00	178	1200	1.50	5	8
50-55	50.00	-	-	30.00	120	690	2.50	9	23
55-60	50.00	-	-	32.00	23	256	4.50	1	5
60+	50.00	-	-	50.00	8	-	15.00	0	0
		22431	4708		4441	4733		41	40

Note: Daily equivalent DU = 9,481 and annual damage = 3,413,160.

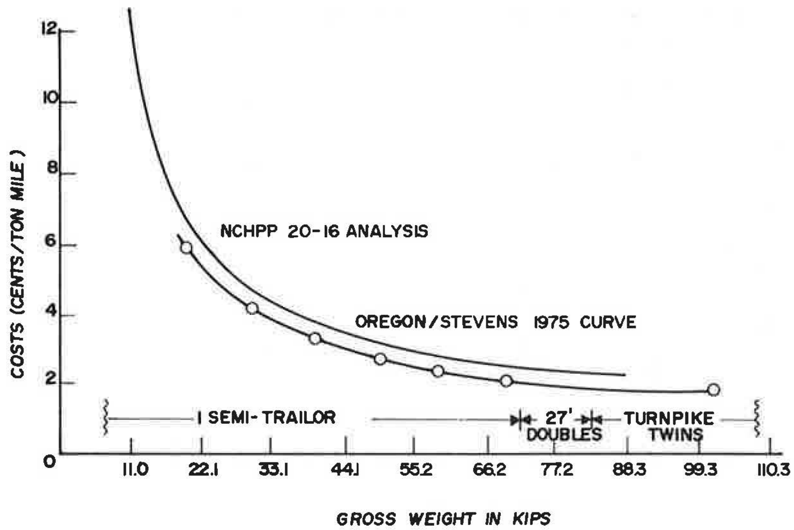

FIGURE 4 Costs per payload for fully loaded vehicles in 1974 U.S. dollars *(1)*.

INCIDENCE OF COST AND BENEFITS

For the purpose of benefit-cost analysis, the truck fleet in 1967 and 1981 is assumed to consist of three types of vehicles:

Type I	3-S2 and UD-5
Type II	3-S3 and UD-6
Type II	3-S2-3, UD-7, 3-S3-3, UD-8, and UD-9

Data on the distribution of gross vehicle weights for other truck types in 1967 were not available. In 1981 these categories represented 46.4 percent of all truck types monitored at the weigh scale or approximately 60 percent of the total equivalent 18-kip loadings.

Figure 4, taken from NCHRP Report 198 (1), shows the unit vehicle operating costs in cents per ton-mile against varying gross vehicle weights in kips. This relationship is consistent with different axle combinations and vehicle types. Figure 4 was applied to the axle load distribution for the 1967 and 1981 truck sample, for the three vehicle types noted, to give the unit vehicle operating costs summarized in Tables 5 and 6. The average unit vehicle operating costs for the 1967 and 1981 truck sample were remarkably similar in value, $2.73 per ton-mile for 1967 and $2.70 per ton-mile for 1981. Multiplying

TABLE 5 Vehicle Operating Cost by Gross Vehicle Weight and Truck Type (1974 U.S. dollars)

Gross Vehicle Weight (kips)	Unit Cost (c/T-M)	Type I Vehicles (%)	Type II Vehicles (%)	Type III Vehicles (%)
0-10	12.0	0.0	0.0	0.0
10-20	8.0	0.1	0.0	0.0
20-30	5.8	4.1	0.7	0.0
30-40	4.3	5.3	1.4	0.0
40-50	3.9	5.9	0.5	0.1
50-60	3.0	9.8	0.4	0.0
60-70	2.8	21.0	1.2	0.1
70-80	2.0	35.8	5.7	0.0
80-90	1.9	0.8	4.0	0.0
90-100	1.8	0.3	0.1	0.1
100+	1.8	0.1	0.0	2.5
		83.2	14.0	2.8

Note: Unit cost per variable: Type I = 2.32 c/T-M, Type II = 0.36, Type III = 0.05; total cost = 2.73 c/T-M; and total cost = $3063.33 per day.

through by the annual gross vehicle weight in each year yields the total truck vehicle operating cost associated with transporting a constant payload of 72×10^6 kips per year under the two single axle load limits of 18 kips and 20 kips. Annual truck vehicle operating costs in 1967 and 1981 were estimated at $\$1.103 \times 10^6$ and $\$1.034 \times 10^6$ (1974 U.S. dollars), respectively.

In an earlier study on axle load limits in less developed countries, Saccomanno and Abdel Halim (7) concluded that truck vehicle operating costs are the dominant cost component associated with axle load limit legislation when noncommercial vehicle operating costs are ignored. For the situation in Ontario, to ignore the automobile component of the traffic and its associated operating costs would be unacceptable because reduced pavement serviceability has its major cost impact on noncommercial traffic. This is shown in Figure 5 for different operating speeds.

The accelerated deterioration of the pavement in 1967 caused by increased equivalent 18-kip axle load applications is reflected in higher automobile operating costs at various PSI levels. The rehabilitation cycle is assumed to represent a reduction in PSI level from 3.5 to 2.0. This takes place over a 10-year period ending in 1967 and a 13-year period ending in 1981. Assuming a linear trend, the PSI versus pavement life relationship and the associated unit vehicle operating costs are shown in Figure 6. Because these costs are on a per vehicle basis, the annual totals depend on observed automobile traffic volume. For 1967 and 1981 annual automobile vehicle operating costs were estimated for two levels of automobile AADT:

	AADT 14,000	AADT 95,000
1967	$706,000	$4,788,000
1981	$202,000	$1,368,000

All costs are in 1974 U.S. dollars.

Again, because DUs in 1981 were lower than in 1967, the vehicle operating costs for noncommercial traffic are also lower. The important aspect to note here is the relative magnitude of these values in relation to truck vehicle operating costs. On roads where automobile traffic is light, truck costs dominate. However, on high automobile volume roads, vehicle operating costs are considerably more pronounced for automobiles than for trucks, especially in 1967 when pavement deterioration was more accelerated.

TABLE 6 Vehicle Operating Cost by Gross Vehicle Weight and Truck Type (1974 U.S. dollars)

Gross Vehicle Weight (kips)	Unit Cost $/T-Mi	Unit Cost $/Mi ÷2.2406	Type I Vehicles (% 3S2)	Type II Vehicles (% 3S3 UD6)	Type III Vehicles (% UD8 UD9)
0-10	12.0	0.60	0	0	0
10-20	8.0	1.20	0.1	0.0	0.0
20-30	5.8	1.45	5.4	0.7	0.6
30-40	4.3	1.51	11.0	2.8	3.2
40-50	3.9	1.76	13.4	1.9	2.9
50-60	3.0	1.65	21.4	2.7	0.9
60-70	2.8	1.82	11.4	2.8	0.6
70-80	2.0	1.50	12.4	3.5	1.0
80-90	1.9	1.62	10.8	5.4	2.4
90-100	1.8	1.71	10.7	12.0	3.9
100+	1.8	2.70	3.7	67.4	84.5
			100.0	100.0	100.0

Note: Unit cost per variable: Type I = 2.10 c/T-M, Type II = 0.45, Type III = 0.15; total cost = 2.70 c/T-M; and total cost = $2,873.04 per day.

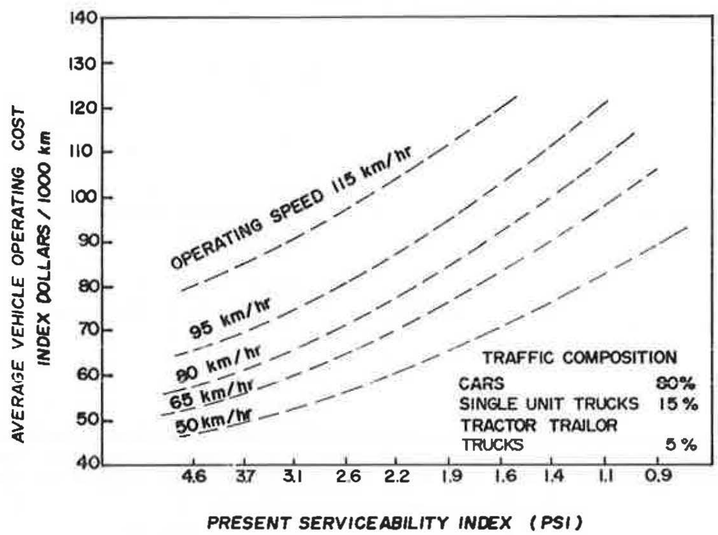

FIGURE 5 Vehicle operating cost index for rural, free-flowing conditions, after Haas and Hudson *(7)*.

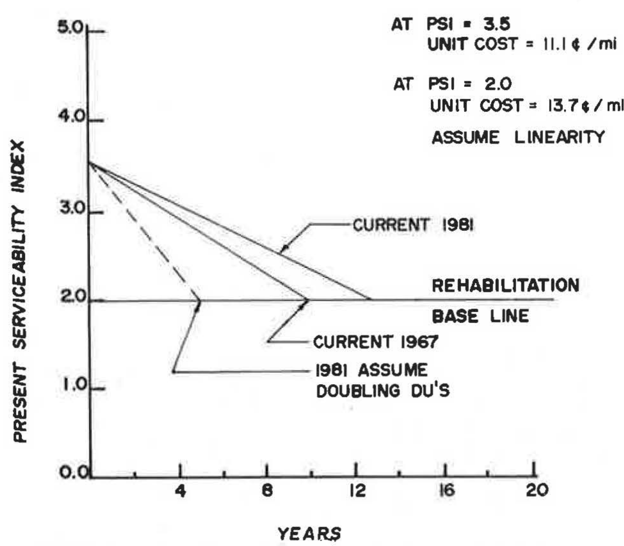

FIGURE 6 Automobile vehicle operating costs of various serviceability levels.

Annual pavement rehabilitation costs were estimated for 1967 and 1981 on the basis of a unit cost of $250,000 per lane-mile. For the 10-year rehabilitation cycle in 1967, the annual pavement deterioration cost was estimated at $14,000 per lane-mile. Clearly, pavement rehabilitation costs are a small component of truck and automobile operating costs and can be ignored in a benefit-cost analysis. From the point of view of economic viability, pavement deterioration costs are simply not an issue in setting effective axle load limits.

The results of these cost estimates are summarized in Table 7. As expected, depending on the assumed automobile volume, annual costs in 1981 are from $578,000 to $3,494,000 lower than in 1967. The shift in axle load limit from 18 to 20 kips per axle is clearly a cost-effective strategy. Because pavement deterioration is reduced in the latter year, everyone benefits from the higher limit.

As noted previously, it is unlikely that the truck fleet changeover that took place between 1967 and 1981 would also occur in the period immediately following a change in axle load limit. In the absence of technological advances, which give rise to a more

TABLE 7 Annual Costs and Benefits of Changing Axle Limit (thousands of 1974 U.S. dollars)

	At $250,000 per Lane-Mile	Automobiles AADT 14,000	AADT 95,000	Trucks	Annual Net Benefit
1967	14	706	4,788	1,103	
1981	9	202	1,368	1,034	
Difference	5	504	3,420	69	578 → 3,494
1967	14	706	4,788	1,103	
1981[a]	39	806	5,472	1,034	
Difference	-25	-100	-684	69	56 → 640

Note: Automobile vehicle operating costs tend to dominate cash flow when AADT is high.
[a]Assume doubling of damage units from 1967.

efficient use of vehicle capacity and reduced pavement damage, loss in pavement serviceability would obviously become more accelerated with a higher axle load limit. Table 7 gives a summary of the various annual cost components that would have occurred in 1981 if equivalent damage units had been doubled over their 1967 values. This is reflected in a rehabilitation cycle of 5 years (Figure 6). For this situation it would not be economically viable to increase axle load limits. Savings in truck operating costs are exceeded by losses from higher pavement rehabilitation costs and especially higher automobile operating costs. Depending on the number of automobiles in the traffic stream, this annual loss varies from $56,000 to $64,000 per lane-mile. Clearly the shift to higher axle loads under these circumstances would not be justified. Again the dominance of vehicle operating costs in this analysis is evident. This is especially true for automobile operating costs at high traffic volumes. Despite accelerated pavement deterioration under a 5-year rehabilitation cycle, annual rehabilitation costs remain a small component of the total costs and benefits to vehicle operators.

CONCLUSIONS

Several issues should influence the direction of future policies on axle load limits in Ontario:

1. Long-term changes in truck fleet composition to more efficient axle load distributions may produce conditions under which higher allowable axle loads are economically justified. This situation may not be realized in the short run. Thus it is important that axle load limits be continually monitored to reflect changing traffic conditions over time.
2. The relationship between axle load, tire pressure, contact stresses, and pavement deterioration has to be considered in more detail. This relationship would determine the actual causes of the observed damage to roads.
3. The availability of funds for extensive maintenance and rehabilitation programs has mitigated against the adoption of higher axle load limits, despite some obvious economic benefits of the strategy. This is clearly a cash flow problem that is likely to become more of a central concern as governments are subjected to more severe financial restrictions.

From the perspective of economic viability, the proportion of noncommercial traffic in joint use of the road system acts to curtail recommended increases in axle load limits. Where noncommercial traffic is appreciable, net increases in vehicle operating costs from reduced pavement serviceability offset benefits to the trucking industry from higher allowable axle loads. Again this appears to be true only in the short, run, where changes in truck fleet composition are not likely to be a factor.

ACKNOWLEDGMENT

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Vehicle-Miles for a Freight Carrier with Two Capacity Constraints

RANDOLPH W. HALL and CARLOS F. DAGANZO

ABSTRACT

The amount of freight that can be fit on a vehicle depends on the vehicle's weight capacity and volume capacity. In this paper mathematical equations are developed for evaluating the impact of weight capacity and volume capacity on total vehicle-miles. It is shown that the number of vehicle loads needed to carry a large amount of material is minimized when all vehicles are filled to the same capacity constraint. This is accomplished by mixing light items with heavy items in vehicle loads. Following this policy can reduce the number of vehicle loads and vehicle-miles. Under ideal circumstances, the reduction can be as large as 50 percent. Simple equations are provided for estimating the potential reduction in vehicle loads and vehicle-miles to be realized.

The cost of transporting a large quantity of items from one location to another depends on the number of vehicle loads required to carry the material and the distance traveled per vehicle load. Decreasing either the number of loads or the distance traveled per load reduces total vehicle-miles (the total distance traveled by all vehicles) and the cost of transporting the material.

The number of vehicle loads depends on the quantity of items that can be fit on a vehicle. Typically, this quantity is determined by dividing the "capacity" of the vehicle by the "size" of each item. However, vehicle capacity and item size can be measured in more than one way. Most vehicles have both a weight capacity and a volume capacity. The vehicle is full when either capacity is reached. Depending on the type of items carried, some vehicles might be filled to the weight capacity, and others might be filled to the volume capacity (Figure 1).

In this paper equations are developed that readily show how the number of vehicle loads depends on the weight capacity and the volume capacity. These equations are used to prove that the number of vehicle loads is minimized when all vehicles are filled to the same capacity constraint (that is, all loads are filled to the weight capacity, or all loads are filled to the volume capacity). To minimize the number of loads, items that have a low density (pounds per cubic foot) must be mixed with items that have a high density in vehicle loads (Figure 2). There are several ways to mix low-density with high-density items in a vehicle load. If a supplier produces both low-density and high-density items, the different items can be loaded in the same vehicle on the loading dock. Alternatively, if different suppliers located in the same area produce low-density and high-density items, the different items can be mixed by routing vehicles by both types of suppliers. Low-density items can also be mixed with high-density items at a transportation terminal.

It is also demonstrated that standard vehicle routing methods do not minimize total vehicle-miles when some locations produce (or receive) items that have a low density and other locations produce (or receive) items that have a high density. Equations are provided to show when it is important to design modified vehicle routes that result in all vehicles being filled to the same capacity constraint.

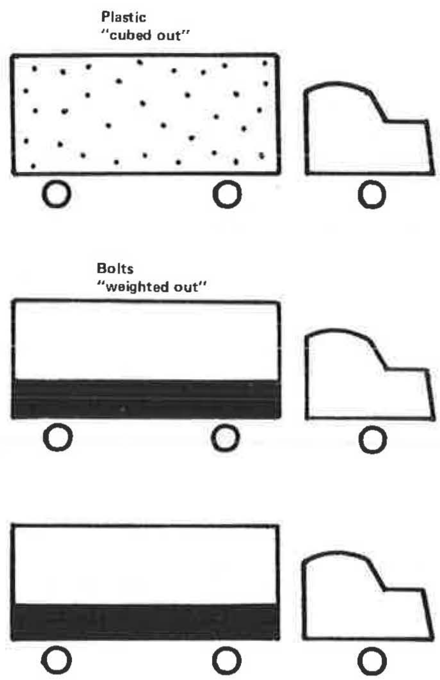

FIGURE 1 Light and heavy items shipped in separate vehicles.

Vehicle routing has been studied extensively during the last 25 years (1-3). For example, the vehicle routing problem (4) concerns routing a fleet of vehicles from a single terminal to a number of destinations so that travel distance is minimized and vehicle capacity constraints are not violated.

Although the vehicle routing problem is neper complete (5-7) and difficult to optimize, many heuristics identify close to optimal solutions. For example, simple heuristics for solving the closely related traveling salesman problem, such as the Clarke-Wright method (8) locate solutions within about 7 percent of the optimal cost (9).

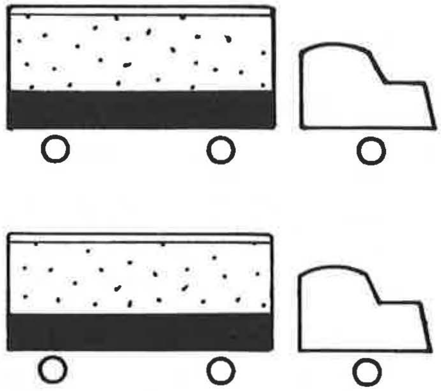

FIGURE 2 Light and heavy items mixed in vehicles.

Despite the many applications of this problem, and the research invested in developing efficient routing algorithms, many industries continue to route vehicles manually. There are many reasons for this including lack of data and inability of available algorithms to account for all the important factors that influence the cost of operating vehicles.

The existence of two vehicle capacities (weight and volume) is one factor that routing heuristics do not normally consider (although computationally impractical, a second capacity can be used in some of the optimization algorithms). Most vehicle routing heuristics group stops into routes according to geographic proximity (Figure 3). Although this approach may minimize the vehicle-miles traveled per load, it does not minimize the total number of loads and total vehicle-miles. Vehicles may have to travel "out of their way" to ensure that each load carries a mixture of low-density and high-density items (Figure 4).

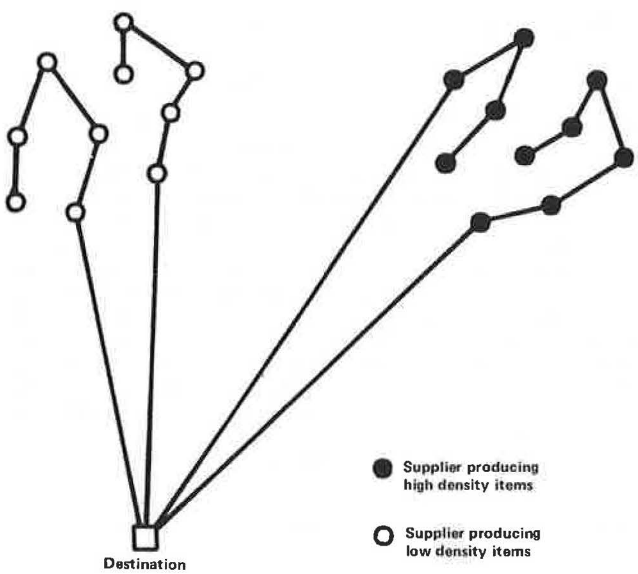

FIGURE 3 Possible vehicle routes when accounting for one capacity constraint.

Although this paper is written in the context of vehicles picking up items from many different origins, the results also apply to delivering items to many destinations. The equations developed in the first section can also be used to analyze transporting different types of items from a supplier or transportation terminal.

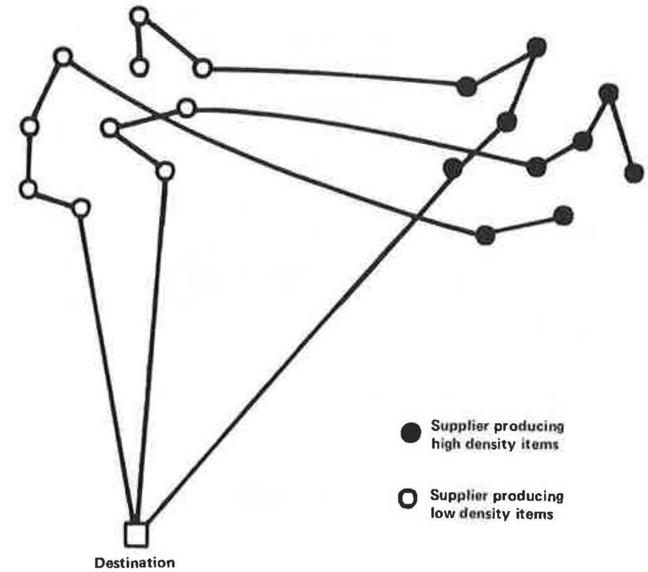

FIGURE 4 Possible vehicle routes when accounting for two capacity constraints.

NUMBER OF VEHICLE LOADS

Consider a region in which vehicles pick up different items from many different locations. Items differ in weight, volume, and production rate, where

W_i = weight of item i (pounds),
V_i = volume of item i (cubic feet),
F_i = total production rate of item i in the region (items per week), and
d_i = material density of item i (W_i/V_i, pounds per cubic foot).

The quantity of material that can be loaded onto a vehicle depends on the vehicle's weight capacity and volume capacity, where

C_w = vehicle's weight capacity (pounds) and
C_v = vehicle's volume capacity (cubic feet).

The weight and volume capacity are dictated by vehicle design, risk of damage to cargo or to other vehicles, and ability of the guideway (road or tracks) to sustain the load. A weight capacity of 80,000 lb and volume capacity of 4,200 ft^3 are common for large trucks operating on U.S. highways.

Suppose initially that each vehicle carries only one type of item. Then T, the minimum number of vehicle loads per week required to transport a large amount of material, is

$$T = \sum F_i \max [(V_i/C_v), (W_i/C_w)] \quad (1)$$

Equation 1 is simplified by introducing the symbol d* to represent the material density that simultaneously fills the vehicle to both the weight capacity and the volume capacity. That is,

$$d^* = C_w/C_v \quad (2)$$

Also substituting W_i/d_i for V_i, Equation 1 can be rewritten as

$$T = \sum (F_i W_i/C_w) \max [(d^*/d_i), 1] \quad (3)$$

If the density of an item is less than d^*, the load reaches the volume capacity before the weight capacity. Otherwise, the load reaches the weight capacity first. The ratio d^*/d_i is an adjustment factor to account for the actual weight of material that can be fit onto the vehicle, taking into account both the weight and volume capacities.

Equation 3 can be expressed as a function of a few parameters that represent average item weights and densities. First, let F be the total number of items produced per week (the summation of F_i). Let a "light" item be an item with a density less than d^* and a "heavy" item be an item with a density greater than d^*. Also let L be the set of light items, H be the set of heavy items, and

p = proportion of items that are light $= \sum_{i\varepsilon L} F_i/F$

W_l = average weight of the light items $= \sum_{i\varepsilon L} F_iW_i/\sum_{i\varepsilon L} F_i$

d_l = average density of the light items $= \sum_{i\varepsilon L} (F_iW_i)/\sum_{i\varepsilon L} (F_iV_i)$

W_h = average weight of the heavy items $= \sum_{i\varepsilon H} F_iW_i/\sum_{i\varepsilon H} F_i$

Equation 3 can now be written as

$$T = (F/C_w)\ [(W_lpd^*/d_l) + W_h(1-p)] \quad (4)$$

Letting W be the average weight of all items [$W = W_lp + W_h(1-p)$], Equation 4 becomes

$$T = (FW/C_w)\ \{1 + [W_lp(d^*-d_l)/Wd_l]\} \quad (5)$$

Equation 5 can be reduced further by introducing two new composite variables. Let

P = proportion of weight produced per week that is composed of light items $= W_lp/W$ and
r = ratio of the average material density of the light items to $d^* = d_l/d^*$.

The minimum number of vehicle loads required per week can now be expressed as a function of just five parameters:

$$T = (FW/C_w)\ [1 + P(1-r)/r] \quad (6)$$

P and r must both be less than one and greater than zero. They must also satisfy the following inequality:

$$d = \{W/[V_lp + V_h(1-p)]\} < W/V_lp = (W_l/V_l)\ (W/W_lp)$$

for $d < d_l/P$. When $d > d^*$, $d^* < d < d_l/P$. In terms of r and P,

$$P < r \quad \text{if } d > d^* \quad (7)$$

If $d < d^*$, P and r are only constrained to be between zero and one.

Returning to Equation 6, the first term gives the number of vehicle loads when accounting for the weight capacity alone. The second term is an adjustment factor that specifies the additional number of loads when accounting for both weight capacity and volume capacity. Notice that the adjustment factor must always be greater than one, and that it increases as the proportion of weight composed of light items (P) increases, and increases as the average density of light items (rd^*) decreases.

LOADS CONTAINING DIFFERENT ITEMS

Suppose now that vehicles carry different types of items with different weights and densities. Then the number of vehicle loads (T) is minimized when all loads are filled to the same capacity constraint. That is, all loads are filled to the weight capacity, or all loads are filled to the volume capacity.

This statement can be proved by contradiction. Suppose that one load contains light items and is filled to the volume capacity and another load contains heavy items and is filled to the weight capacity. Then any arbitrary proportion of material can be exchanged between the two loads without violating a capacity constraint.

Let w_1, w_2, v_1, and v_2 be the respective weights and volumes of the light and heavy loads, where $w_1 < C_w$, $v_1 = C_v$, $w_2 = C_w$, and $v_2 < C_v$. Let the circumflex ($\hat{}$) denote the weight or volume of a load after a proportion (q) of material is exchanged between loads. Then

$$\hat{w}_1 = w_1(1-q) + w_2q \qquad \hat{v}_1 = v_1(1-q) + v_2q$$
$$\hat{w}_2 = w_2(1-q) + w_1q \qquad \hat{v}_2 = v_2(1-q) + v_1q \quad (8)$$

which can also be written as

$$\hat{w}_1 = w_2 - (w_2 - w_1)(1-q) < C_w$$
$$\hat{v}_1 = v_1 - (v_1 - v_2)q < C_v$$
$$\hat{w}_2 = w_2 - (w_2 - w_1)q < C_w$$
$$\hat{v}_2 = v_1 - (v_1 - v_2)(1-q) < C_v \quad (9)$$

Notice that exchanging any proportion (q) of material between the two loads reduces the weight and volume of both loads below the respective capacities. Therefore, a necessary condition for minimizing T is that all loads be filled to the same capacity constraint.

To minimize T it is not necessary that all loads carry exactly the same mix of different items or carry exactly the same weight and volume of material. For example, if all loads are filled to the volume capacity, it does not matter how much weight of material is loaded onto each vehicle. Thus the statement that all loads are filled to the same capacity constraint is both a necessary and a sufficient condition for minimizing T.

SAVINGS FROM COMBINING DIFFERENT ITEMS IN VEHICLE LOADS

Whenever light items ($d_i < d^*$) are shipped in separate vehicles than heavy items ($d_l > d^*$), as is the case when vehicles contain only one type of item, the number of loads is given by Equation 6. Combining light with heavy items in vehicle loads always results in decreased loads. Let T^* denote the number of loads when all vehicles are filled to the same capacity constraint (that is, when T is minimized). Then

$$T^* = F\{\max\ [(V/C_v),\ (W/C_w)]\}$$
$$= (FW/C_w)\ \{\max\ [(d^*/d),\ 1]\} \quad (10)$$

where V is average volume of all items and d is average density of all items (W/V).

The first term of Equation 10 gives the number of loads when accounting for weight capacity alone, and the second term is an adjustment factor that specifies the additional number of loads when accounting for both capacities. If d*/d is greater than one, all vehicles are filled to the volume capacity and the adjustment factor equals d*/d. Otherwise, all vehicles are filled to the weight capacity and the adjustment factor equals one. Therefore the adjustment factor is greater than or equal to one.

T/T* is the ratio of the number of loads when light items are not mixed with heavy items to the number of loads when light and heavy items are mixed, and equals the ratio of Equation 10 to Equation 6:

$$T/T^* = \begin{cases} 1 + P(1-r)/r & \text{for } d > d^* \quad (11a) \\ (d/d^*)[1 + P(1-r)/r] & \text{otherwise} \quad (11b) \end{cases}$$

Equation 11 can be used to estimate quickly the maximum reduction in vehicle loads from filling all vehicles to the same capacity constraint.

Recall that P must be less than r when d/d* is greater than one. Equation 11a is maximized when P equals r. Therefore substituting P for r in Equation 11a,

$$T/T^* < 2 - P \quad \text{for } d > d^* \quad (12)$$

As a function of P, T/T* approaches two as P approaches zero, and approaches one as P approaches one. Figure 5 plots Equation 12 as a function of P and plots Equation 11a as a function of P and r. Notice that T/T* increases both when P increases and when r decreases. Therefore, when d > d*, it is most important to combine light and heavy items in vehicle loads when a large proportion of the weight produced per week is composed of light items, and the average density of light items is much less than d*.

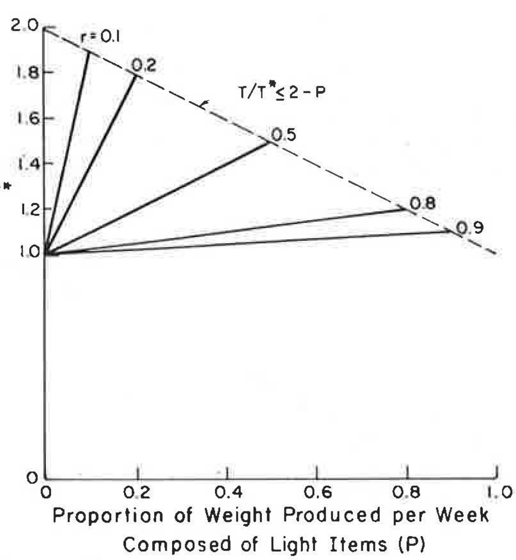

FIGURE 5 Ratio of loads per week without mixed loads to loads per week with mixed loads.

Similar results occur when d < d*. T/T* also ranges between one and two, depending on P, r, and d. Tables 1 and 2 give sample data for Equation 11a. Five suppliers located in the same city produce 11 different parts. Parts are transported in 3,800-ft³, 70,000-lb capacity trucks. Hence, d* equals 70,000/3,800 = 18.42 lb/ft³. The parts produced by Sup-

TABLE 1 Example Part Data

	Weight (lb)	Volume (ft^3)	Production Rate (parts/week)
Supplier 1			
Part A	1.0	1.0	1,000
Part B	0.5	0.4	2,000
Part C	0.8	0.2	1,000
Supplier 2			
Part D	10.0	0.2	5,000
Supplier 3			
Part E	0.1	0.01	50,000
Part F	0.2	0.005	50,000
Part G	5.0	0.1	50,000
Part H	0.4	0.01	50,000
Supplier 4			
Part I	5.0	10.0	1,500
Part J	5.0	10.0	500
Supplier 5			
Part K	2.0	0.1	10,000

TABLE 2 Summary Data

Supplier	Production Rate lb/week	Production Rate ft^3/week	Average Density (lb/ft^3)	Trucks per Day
1	2,800	2,000	2.8	0.53
2	50,000	1,000	50.0	0.71
3	285,000	6,250	45.6	4.07
4	10,000	20,000	0.5	5.26
5	20,000	1,000	20.0	0.29
Total	367,800	30,250	12.2 < d*	

Note: P = (2,800 + 10,000)/367,800 = .0348; d_1 = (2,800 + 10,000)/(2,000 + 20,000) = 0.582; r = d_1/d^* = 0.0316; and T/T* = 1.36. Vehicle load comparison: one route per supplier, 10.86 trucks per week; one route for all suppliers, 7.96 trucks per week; saving, 2.90 trucks per week (27 percent).

pliers 1 and 3 have small densities and fill the vehicle to volume capacity. The parts produced by the other three suppliers have large densities and fill the vehicle to weight capacity.

If each supplier shipped independently of the others, 10.86 truckloads, on average, would be needed per week. However, if the different parts were combined in the same vehicles, so that all vehicles were filled to the volume capacity, the number of truckloads would drop to only 7.96 per week (a reduction of 27 percent). Equation 11a predicts that the ratio of T to T* should equal 1.36 for this example, which exactly matches the ratio of 10.86 to 7.96.

MODIFYING ROUTES TO REDUCE NUMBER OF LOADS

Most vehicle routing heuristics group stops into routes according to geographic proximity and do not necessarily minimize total vehicle-miles (8,10,11). It is not unusual for geographic regions to contain many different companies engaged in the same industry. For instance, one region may contain a large concentration of plastic companies, and another may contain a large concentration of fastener (nuts and bolts) manufacturers. If vehicles are routed on the basis of geographic proximity alone, all the vehicles in the plastics region would be filled to volume capacity, and all the vehicles in the fastener region would be filled to weight capacity, resulting in as many as twice as many loads as necessary.

Figure 6 shows a situation in which manufacturers in one city produce light items and manufacturers in another city produce heavy items. A fleet of vehicles picks up items at these two cities and delivers them to a common destination. If routed on proximity alone, each vehicle would visit only one of the two cities. However, to minimize the total number of loads (and

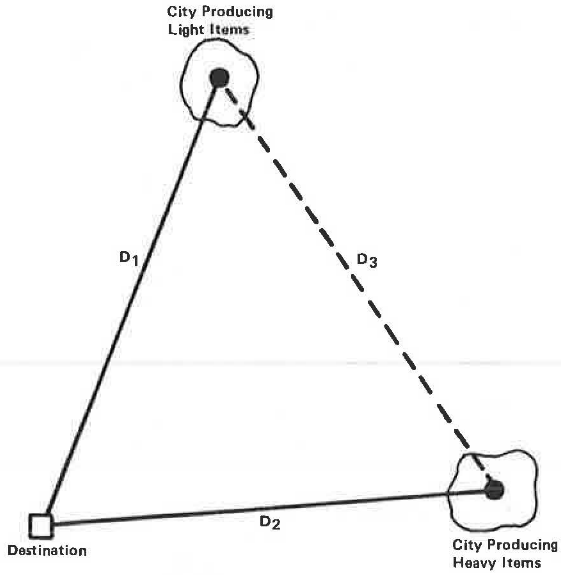

FIGURE 6 Locations of cities and destination.

ensure that all vehicles are filled to the same capacity constraint) vehicles must be routed through both cities.

The total distance traveled on a vehicle route includes the local distance traveled to pick up items within the two cities and the line-haul distance between the cities and the destination. The local distance depends on the total number of stops and the stop density [e.g., stops per square mile (12,13)]. Assuming that the two cities do not overlap, the local distance is nearly independent of whether all vehicles visit both cities or just one. Therefore only the line-haul distance is considered in the following analysis.

The following equations apply to the situation in which $d > d^*$. Following the same approach, it is not difficult to derive similar equations for the case where $d < d^*$. Let

D_1 = distance from city producing light items to the destination (miles),
D_2 = distance from city producing heavy items to the destination (miles), and
D_3 = distance between the two cities (miles).

Assume initially that all vehicles return empty from the destination. Then, if all vehicles visit only one city, the number of vehicle-miles traveled per week (L_1) is

$$L_1 = (FW/C_w)\ 2\ \{[D_1(P/r)] + [D_2(1-P)]\} \qquad (13)$$

Alternatively, if all vehicles visit both cities, the number of vehicle-miles is

$$L_2 = (FW/C_w)\ (D_1 + D_2 + D_3) \qquad \text{if } d > d^* \qquad (14)$$

It is not necessary for all vehicles to visit both cities to minimize T. However, if $d > d^*$, all vehicles visiting the "light" city must also visit the "heavy" city, and, if $d < d^*$, all vehicles visiting the "heavy" city must also visit the "light" city. Equation 14 is an upper bound on total vehicle-miles with this type of coordination. Exact calculation of total vehicle-miles is not complicated, but it does require detailed information on the densities of all items. Therefore this calculation will not be performed.

The ratio of L_1 to L_2 is

$$L_1/L_2 = \{2[D_1(P/r) + D_2(1-P)]\} \div (D_1 + D_2 + D_3) \qquad \text{if } d > d^* \qquad (15)$$

If L_1/L_2 is greater than one, it is better to route all vehicles through both cities than through just one. This ratio ranges from zero (e.g., when $D_2 = 0$ and $P = 0$) to two (when $D_3 = 0$, $P = r$, and $r = 0$). Therefore routing all vehicles through both cities can reduce total vehicle-miles by as much as 50 percent.

SPECIAL CASE: $D_2 = D_1 + D_3$

To facilitate interpreting Equation 15, two special cases will be examined. This section examines the case in which $D_2 = D_1 + D_3$ (that is, the destination and the two cities fall on a line and the "heavy" city is farther from the destination than the "light" city). For this special case, the number of vehicle loads is minimized when all vehicles visit the "heavy" city, and Equation 15 is exact. In the following section the case in which $D_1 = D_2$ (that is, the two cities are the same distance from the destination) will be examined. All of the following equations assume that $d > d^*$.

When $D_2 = D_1 + D_3$, Equation 15 can be reduced by substituting $D_2 - D_1$ for D_3:

$$L_1/L_2 = [2D_1(P/r) + 2D_2(1-P)] \div 2D_2 \qquad \text{if } D_2 = D_1 + D_3 \qquad (16)$$

Because the 2s cancel out in Equation 16, L_1/L_2 is the same whether or not vehicles must return empty from the destination.

Let K equal the ratio of D_1 to D_2 ($K = D_1/D_2$). K must be between zero and one. Then

$$L_1/L_2 = K(P/r) + (1-P) \qquad \text{if } D_2 = D_1 + D_3 \qquad (17)$$

Because P must be smaller than r, and K must be less than one, L_1/L_2 must be less than or equal to two. Figure 7 shows plots of L_1/L_2 as a function of P and r, for a value of r = 0.5. Notice that this ratio increases as K increases. When K is greater than r,

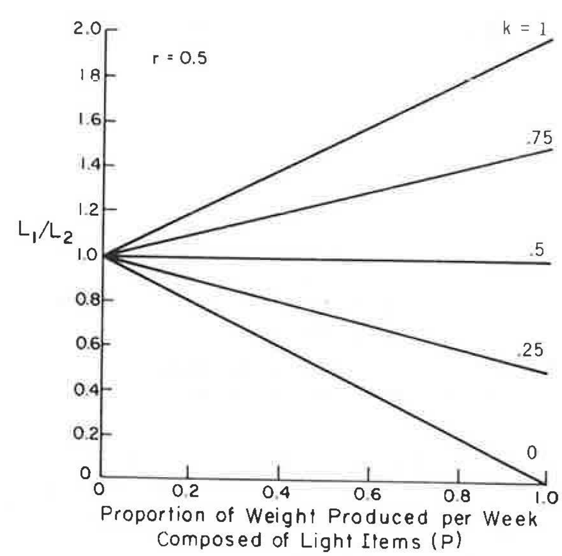

FIGURE 7 Ratio of vehicle-miles when visiting both cities to vehicle-miles when visiting one city.

L_1/L_2 also increases as P increases, but when K is less than r, L_1/L_2 decreases as P increases. Therefore it is most important to route vehicles through both cities when K is large and a large portion of weight produced per week is composed of light items (provided that $K > r$). The ratio also increases as r decreases. Therefore it is more important to route vehicles through both cities when the average density of light items is small than when it is large.

The breakeven point between routing vehicles through both cities and routing through just one occurs when $L_1/L_2 = 1$.

$$1 = K(P/r) + (1-P) \quad \text{if } D_2 = D_1 + D_3$$

or, more simply, when

$$K = r \quad \text{if } D_2 = D_1 + D_3. \tag{18}$$

When r is less than K, it is better to route all vehicles through both cities than through just one. For example, if the average density of items produced in the "light" city is one-half d* ($r = 0.5$), vehicles should be routed through both cities when K is greater than 0.5; that is, the "heavy" city is less than twice as far from the destination as the "light" city. Because K approaches zero when r approaches zero, it can still be worthwhile to route all vehicles through both cities when the two cities are far apart.

SPECIAL CASE: $D_1 = D_2$

For the special case in which $D_1 = D_2$, the two cities are the same distance from the destination. For this special case, it may not be necessary to route all vehicles through both cities to minimize the number of vehicle loads. Therefore L_2 gives an upper bound on total vehicle-miles when the number of loads is minimized. Let $D = D_1 = D_2$. Then Equation 15 becomes

$$L_1/L_2 = 2D[P/r + (1-P)]/(2D + D_3) \tag{19}$$

The breakeven point between routing all vehicles through both cities and routing all vehicles through just one city occurs when Equation 19 equals one. That is, when

$$(2D + D_3)/2D = 1 + P(1-r)/r \tag{20}$$

Notice that the left side of Equation 20 is the ratio of vehicle-miles per route when vehicles visit both cities, to vehicle-miles per route when vehicle visit just one city. The right side of Equation 20 is the ratio of the number of vehicle loads when vehicles visit both cities, to the number of vehicle loads when vehicles visit just one city (T/T^*). Let D_b be the vehicle-miles per route when vehicles visit both cities and D_o be the vehicle-miles per route when vehicles visit just one city. Then Equation 20 can be rewritten as

$$D_b/D_o = 1 + P(1-r)/r \tag{21}$$

When D_b/D_o is less than the right side of Equation 21, fewer total vehicle-miles are required when vehicles visit both cities than when they visit just one. Otherwise, total vehicle-miles are minimized when vehicles visit just one city.

Notice that the right side of Equation 21 is identical to the right side of Equation 11a, which is plotted in Figure 3. Therefore the breakeven point between routing vehicles through both cities and routing vehicles through just one increases as P increases and r decreases.

Equation 21 also applies when vehicles do not return empty from the destination. D_b would then be $D + D_3$ (the length of two legs of the route) and D_o would then be D. For any given D and D_3, this ratio is larger when vehicles do not return empty than when vehicles do return empty. Therefore it is less advantageous to route vehicles through both cities when they do not have to return empty from the destination than when they do have to return empty from the destination.

Equation 19, which gives the ratio L_1 to L_2, can also be expressed as a function of D_b/D_o:

$$L_1/L_2 = (D_o/D_b)\,[1 + P(1-r)/r] \tag{22}$$

Equation 22 is identical to the right side of Equation 11a (plotted in Figure 3), except that Equation 22 is multiplied by the factor D_o/D_b. If the two cities are in opposite directions from the destination, D_o/D_b can be as small as 0.5, and L_1/L_2 would range between 0.5 and one (i.e., it would always be better to route vehicles through one city than two). D_o/D_b can be as large as one if the two cities are located at the same place, in which case L_1/L_2 would range from one to two (i.e., it would always be better to route vehicles through both cities than through just one).

SUMMARY

The impact of weight capacity and volume capacity on total vehicle-miles has been discussed. It has been shown that the number of vehicle loads is minimized when all vehicles are filled to the same capacity constraint (that is, all vehicles are filled to the weight capacity or all vehicles are filled to the volume capacity). This may be accomplished by mixing heavy items and light items in vehicle loads.

Combining light items with heavy items in vehicle loads was shown to reduce the number of loads and vehicle-miles by as much as 50 percent. The exact reduction depends on two parameters. When the number of loads is minimized by filling all vehicles to the weight capacity, these parameters are (a) the ratio of d_1, the density of light items, to d*, the density of material that simultaneously fills vehicles to both the weight and volume capacities and (b) the proportion of weight produced per week that is composed of light items (P). A similar equation results when the number of loads is minimized by filling all vehicles to the volume capacity.

It has also been shown that commonly used heuristics for routing vehicles can obtain solutions that are far from optimal when light items and heavy items are produced in geographically separated regions. Most heuristics group stops into routes according to geographic proximity. Although this may minimize vehicle-miles traveled per route, it does not minimize total vehicle-miles. If vehicle routes are designed to ensure that all vehicles are filled to the same capacity constraint, the number of vehicle loads (and vehicle-miles) can be reduced by as much as 50 percent.

Considerable effort has been expended in the last 25 years to improve the efficiency and effectiveness of algorithms designed to solve the vehicle routing problem. However, even straightforward heuristic (such as the Clarke-Wright method), can generally obtain solutions within 7 percent of the optimum of the vehicle routing problem. The evidence provided in this paper indicates that the savings from accounting for two capacity constraints can well exceed 7 percent.

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Urban Freight Practice—An Evaluation of Selected Examples

PHILIP A. HABIB

ABSTRACT

A diverse group of urban goods movement projects and actions taken by municipalities are documented and the principal lesson or lessons derived from each project are highlighted. The research used the literature, field visits, interviews, and independent research to formulate the presentation of the selected examples. The paper contains eight examples of municipalities that have implemented projects in curb space management, off-street facility planning, and zoning. Six examples are drawn from U.S. cities and two from Canada. An evaluation follows each example to highlight the positive and negative results of each as they might affect application elsewhere. This paper is drawn from research sponsored by the UMTA University Research Program and was conducted by the author while at the Polytechnic Institute of New York.

This paper provides a detailed review of a selected number of actions taken by various municipalities to address urban freight transportation. The documentation for several of these actions included field trips and interviews. The literature, plus the author's personal knowledge or involvement, provided the documentation on the other actions.

The urban transportation planner's or the engineer's justifiable preoccupation with the need to optimize the transportation infrastructure to move people has, to date, left a wide gap in professional skills necessary to foster successful urban freight project development and evaluation. The ability to draw on the work and experiences of similar projects has not only markedly facilitated people-transportation project development but has also provided knowledge of feasible actions to the nonspecialist. The objective of this paper is to begin the construction of a practices-sharing effort in freight, focused primarily on the more typical needs of municipalities.

Difficulties in freight transportation in the vast majority of cities first arise from high densities of pickup and delivery activities concentrated to form a few problem locations, usually in the central business district. Some of these problems can be addressed using "quick-fix" actions; others may require intermediate-term project development; and still others may only be addressed in long-term master planning.

The research effort (1) from which this paper is drawn focused on the vehicle movement of urban freight and discounted the urban movements by rail, pipeline, or helicopter. This paper consists of sections dealing with existing projects and practices in curb space management, off-street freight facilities, and zoning for off-street requirements. These practices are derived from U.S. and Canadian cities. The first part of each section deals with project descriptions and the remainder of each section evaluates each project and addresses the conditions most suited for application.

CURB SPACE MANAGEMENT

Curb space is the primary facility for loading and unloading freight in central areas. This curb space is also the primary facility for bus stops, taxi stands, metered parking, passenger loading and unloading, bus lanes, and other traffic and transportation uses. In the central business district the multidimensional demand characteristics for curb space often exceed the supply during the work day period resulting in a deterioration of the curb space regulatory structure and a reversion to a first-come first-served structure (e.g., trucks parking in bus stops, automobiles double parking, trucks double parking).

The rationing of curb space among its competing users can be organized into three regimes: time, space, and time and space. The most commonly stated objective of a rationalized system for a curb space when the overall demand is greater than the overall supply is to "equitably" allocate space to satisfy the peaks of the various demand patterns (traffic or bus lane in the rush hour, freight pickup and delivery in midmorning, shopper parking in late morning and early afternoon, and the like). Two examples of freight planning and curb space management are described in this section. The cities from which the examples are drawn are San Francisco and Dallas.

San Francisco Reserved Zone

The principal arterials in the San Francisco central business district (CBD) experience heavy surges of peak-hour traffic after which arterial demand for vehicle movement is quite low and the curb space can revert to nontraffic uses. San Francisco has a strong commercial core that attracts a high shopper demand for short-term parking. To service these commercial establishments, large and small, freight pickup and delivery activity is also intense at most locations in the CBD.

On several of the one-way arterials in the CBD, the curb space is controlled by parking meters and parking signs. Except for bus stops, driveways, hydrant zones, and other restricted areas, parking meters are installed along the curb face. Curbside standing is not permitted in the morning peak period on inbound arterials nor in the evening peak period on outbound arterials, and signing on the sidewalk and on the meter heads so indicates. However, when parking is permitted, portions of the curb space are reserved for pickup and delivery vehicles for selected time periods. These reserved metered spaces, which when combined form a loading zone, have special striped marking and a plaque on the post supporting the meter that identifies the space as a truck loading space (the local name is a zebra zone). Typically, these spaces are only allocated to truck loading and unloading until 11 a.m. when the demand peaks for delivery to small retail establishments. These freight vehicles do not have to deposit coins in the meters (Figure 1).

All spaces become available for short-term metered parking on a first-come first-served basis after the reserved period has expired. Freight vehicles rarely will find available metered curb space under this first-come first-served management scheme and typically stop in a hydrant zone or a bus stop or double park.

Commentary

A combination of events maximizes the effectiveness of this management scheme. First, the reserved spaces are positioned to be attractive to most freight vehicles; second, the delivery demand is already decreasing by 11 a.m.; third, although many delivery vehicles do double park after the reserved period has expired, the arterial traffic flow is sufficiently low that any adverse effect is usually negligible; and fourth, the businesses are served as their freight and patronage needs are both accommodated.

During several days of observations by the author

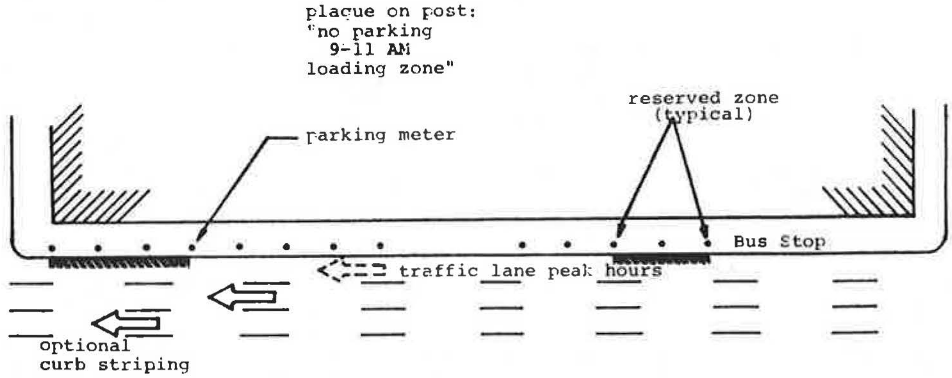

FIGURE 1 Typical reserved zone layout.

in San Francisco, the approach just described was found to work well without explicit enforcement. The use of curb paint to further reinforce the temporary loading zone is also beneficial. The minimum length of a zone was two parking stalls, or about 40 ft. (Almost every freight vehicle was a straight truck or smaller.) An installation should not be considered where, from the demand viewpoint, it is unwarranted. The freight demand necessary to justify the reserved-zone concept should typically exceed four pickup and delivery (PUD) vehicles per hour for each 30 ft of curb space already available for loading and unloading on the block face. This available space can include hydrant zones and inactive driveways. The placement of the reserved zone should be based on field observations and distribution of demand and located, if possible, adjacent to hydrant zones, driveways, and bus stops to facilitate access and egress. According to research (2) on truck and traffic impacts, the highest benefit to traffic is derived from placing such zones near the ends of the block face because interference with traffic flow at these critical points causes maximum delays on arterials.

FIGURE 2 Truck meter installation.

Dallas Metered Loading Zone Project

In the fall of 1981, the city of Dallas instituted what is believed to be the first metered truck loading zones in the United States. Two such zones were placed on arterials in the Dallas CBD, one on Commerce Street and the other on Main Street. The purpose of the installations was to increase the curb space capacity of existing truck loading zones. Both installations were of a pilot nature, with a subsequent evaluation to determine their effectiveness.

Each truck meter is set for 20 min and then must be reset. The meters on Commerce Street were free meters and the meters on Main Street cost 5¢. The objective was to determine whether timing of the PUD activity would increase turnover and reduce the number of non-PUD users in the loading zones. Using the meter system as a mechanism for enforcement of the city's loading zone time limit (also 20 min) was also considered a positive element of the installations. The Commerce Street zone typically services office PUD trips whereas the Main Street zone is on a block dominated by small retail establishments.

Figure 2 shows a typical installation. The meters were set approximately 30 ft apart, one meter per pole. Except for the periods between 7 and 9 a.m. and 4 and 6 p.m. when the curb lane becomes a traffic lane, the metered loading zones are exclusively for vehicles loading and unloading freight.

Commentary

A before-and-after study was conducted at each of the two installations to determine their effectiveness in achieving the project objectives. Two full weekdays of data were collected at each location. Table 1 gives the resultant vehicle type distributions.

In general, the after data show a slight reduction in total vehicles compared to the before. It cannot be concluded that this is an effect of the meter program both because of statistical confidence considerations and because the before data were collected in late October and the after data were collected in December and January, slower goods movement periods, especially on Main Street. Therefore the vehicle populations served by the meters were essentially unaffected by the installations. Because the number of passenger cars (typically non-PUD vehicles) using the loading zones did not decrease, one of the main objectives of the meters was not accomplished.

Table 2 gives the effect of the 20-min meter on average dwell time.

The installation on Commerce Street (typically office PUD activity) showed a reduction in the relatively long average dwell times as might have been expected. However, totally unexpected is the increase in dwell time shown for the Main Street (typically retail PUD activity) installation. Most of the after data were collected between December 16 and 22, a principal shopping period in the retail areas. This may have had an impact on the characteristics of the Main Street installation. Fortunately this hypothesis can be checked because, in addition to the before-and-after data collection at the installation sites, before-and-after data were also collected on a nonmetered loading zone on Ervay Street (also in the retail district). Table 3 gives the average dwell times at this "control" loading zone during the periods when before-and-after data were being collected for the installation sites.

It appears that, during the after analysis in the retail section of the Dallas CBD, increases in dwell time compared to the before period was a base characteristic, which probably overshadowed the impact of placing the meters in the Main Street loading zone. Therefore no conclusion can be drawn about the effectiveness of the Main Street installation.

Observations indicate that at the Commerce Street installation (office-related PUD activity) the meter spacing of 30 ft 0 in. was larger than necessary and, as a result, irregular parking patterns (not organized about the meters) ensued (Figure 3). This irregular pattern was no different than what might have been expected had no meters been installed in that loading zone. Observations at the Main Street installation showed a more regular parking pattern; however, the demand for that loading zone was substantially less than at Commerce Street and the zone was greatly underused in the afternoon.

To address the difficulty of accommodating various sized PUD vehicles in a regular pattern, it is suggested that, for any new installations of this type, the single-headed meter spacing of 30 ft 0 in. should be replaced with double-headed meters spaced 45 ft 0 in. on center in an office PUD environment and 50 ft 0 in. on center in a retail PUD environment (Figure 4). "Doubling up" provides a more efficient accommodation of the various sized vehicles and keeps them organized about the meters.

TABLE 1 Distribution of Vehicle Types

	Commerce St.				Main St.			
	Before		After		Before		After	
	No.	Percentage	No.	Percentage	No.	Percentage	No.	Percentage
Passenger cars	95	49	98	53	39	59	32	64
Light trucks[a]	88	45	70	38	16	24	12	24
Straight trucks	11	6	17	9	11	17	6	12
Tractor trailers	0	0	0	0	0	0	0	0
Total	194	100	185	100	66	100	50	100

[a]Vans and panel and pickup trucks generally 20 ft 0 in. or less in length.

TABLE 2 Average Dwell Times at Installation Sites (min)

	Commerce St.		Main St.	
	Before	After	Before	After
Passenger cars	17.9	14.5	14.31	22.5
Light trucks	25.0	16.7	16.3	27.7
Straight trucks	28.9	25.3	26.4	44.2
Tractor trailers				

TABLE 3 Average Dwell Times (min) at Control Site

	Evray Street	
	Before	After
Passenger cars	16.8	32.2
Light trucks	20.5	26.3
Straight trucks	16.2	39.6
Tractor trailers	80[a]	200[a]

[a]Small number of samples.

FIGURE 3 Typical irregular parking pattern.

Overall, as a pilot program, the installations in Dallas have provided partial evidence of the behavior of PUD vehicles under metering in the loading zone. What made the Commerce Street installation successful in terms of reduced dwell times was that almost all PUD drivers in the zone were servicing office buildings and out of close contact with their vehicles. On Main Street, however, with the storefront retail activity and the relatively low PUD demand at the installation, little or no efficiency would be expected. At neither installation did PUD drivers avoid using the zones because of the metered installations. Also, the meters did not appear to prevent unauthorized use of the loading zones by non-PUD vehicles.

Summary

The management of curb space requires recognition of the patterns (primarily temporal) of the competing users. The shared-zone concept in San Francisco is an excellent example of accommodating the traffic, freight, and shopper activity of a typical downtown arterial (Figure 5). The concept of the traditional all-day loading zone within retail sections of the CBD is difficult to justify, especially because the PUD demand falls off rapidly after 12 noon. In Dallas, where one loading zone was quite active, the installation of meters proved an effective management tool. However, where a loading zone is used actively only during a portion of the day, the most effective management tool would be to free the space to all users on a demand-response basis. Therefore installing truck meters in such a loading zone is not recommended.

CENTRAL AREA FREIGHT FACILITIES

The most practical long-term planning approach to minimize freight loading conflicts with traffic on the arterial system is to physically separate these operations where possible. Because most central area generators tend to be quite small, an aggressive planning approach to provide off-street loading docks in new buildings will only partly address the issue. Three examples of physical separation for loading and unloading of freight, which have been implemented and which may have wider applications, are presented. These are in Dallas; Rochester; and New York and Brooklyn, New York.

Thanksgiving Square Truck Terminal--Dallas, Texas

Dallas' 1969 Master Plan calls for, among other things, underground truck traffic connected to strategically located terminal facilities that, in turn, are connected to various buildings. One of the components of the plan is the Thanksgiving Square Truck Terminal (also known as the Bullington Truck Terminal) that was constructed and opened for operation in May 1977 (Figure 6). The land for the facility was donated by a private foundation and the surface level has a park, a chapel, and elaborate pedestrian facilities. The underground truck terminal serves a projected 5 million square feet of office buildings surrounding it with "finger" passageways leading

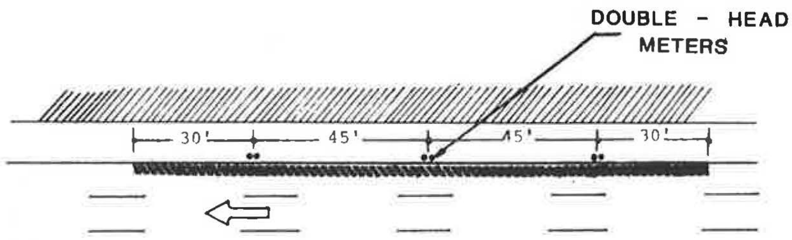

FIGURE 4 Recommended layout for loading zone metering.

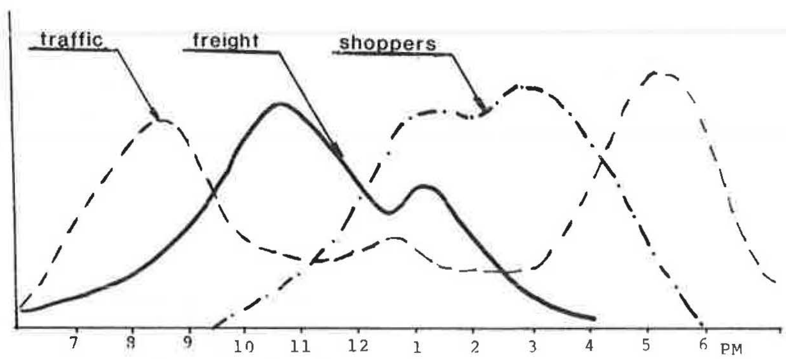

FIGURE 5 Typical peaking of curb space use.

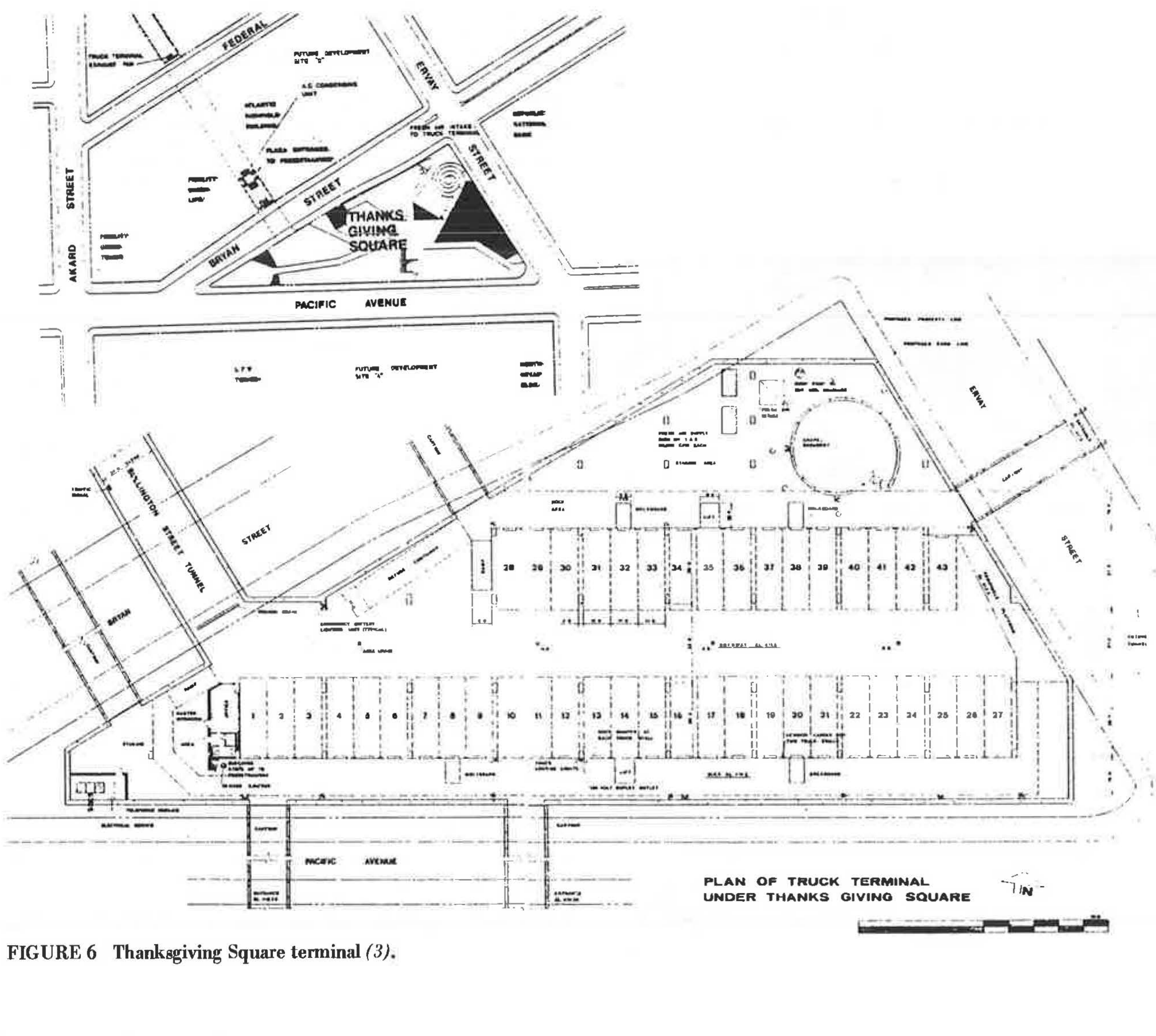

FIGURE 6 Thanksgiving Square terminal *(3)*.

from the facility. Selected characteristics of the facility are

- Forty-three truck bays;
- Operates 6 a.m. to 6 p.m., weekdays;
- Capacity of 800 deliveries per day;
- Annual operating cost in 1980 of $96,000; and
- Street access via a two-way, 24-ft ramp.

Each arriving vehicle is assigned to a position number by a dispatcher as the vehicle enters. The dispatcher keeps track (via a display board) of position occupancy and typically assigns a truck to a position as close to the destination building as possible.

Commentary

There is little doubt that the truck demand (700 to 800 truck trips per day) associated with 5 million square feet in different buildings would cause significant disruption to surface traffic and pedestrians in this concentrated area of downtown Dallas. For an estimated average service time of 30 min per delivery, the facility accommodates 350 to 400 truck space hours per day. The absolute benefit of the project for surface traffic operations is difficult to measure because there is no "before" condition. If it is assumed that, with a capacity of 800 operations per day for 250 days annually, the facility has an operating cost of approximately 50 cents per operation, which is borne entirely by the buildings being served. Furthermore, the buildings connected to the facility now have an area at least the size of the truck terminal (47,000 ft^2) available for rental because they are not required to have their own off-street facility, which translates conservatively into a minimum of $1.0 million of additional annual rental revenues for these buildings, or ten times the operating cost of the facility. As such, the road-user benefits accrued by the project--and they are substantial--are being achieved at no incremental cost, a remarkable achievement.

The principal lesson of the facility is that a shared off-street facility for large office buildings is feasible. The facility has physical connections to each existing and future building site and all connections run under the adjacent street system. The facility could just as well have been in the basement of a new building (instead of the "basement" of a park) and would have operated in a similar manner (except for the structural configuration and size of the internal columns). The point here is that new large buildings, many of them public, are routinely constructed in the central area and the opportunity to provide much needed off-street truck spaces is not seized.

New shared facilities do not have to be of the scale of Thanksgiving Square. However, many buildings adjacent to a redevelopment site that do not have adequate off-street parking facilities and adjacent buildings on principal arteries are the essential signals that should trigger consideration of opportunities for shared off-street loading facilities.

Underground Truck Road in Rochester

The Underground Truck Road is a subgrade truck tunnel serving the central core of downtown Rochester, New York. It consists of five segments built at different times (4). Excavation for the Underground Truck Road began in 1959 and the midtown section was opened in 1961. The tunnel was constructed originally to serve Midtown Plaza, America's first and largest downtown shopping center and office-hotel building development under one roof (a 7 1/2 acre site, more than a million square feet of retail space).

The total length of the existing truck tunnel is approximately 1,440 ft. The width of the tunnel varies from 24 to 30 ft. Two T-intersections at the subgrade Cortland Street limit the use of the truck tunnel for the largest semitrailers. There are two signals controlling traffic in the tunnel. There is only one street level access to the tunnel, with divided up and down ramps.

There are more than 30 truck loading docks of different types and heights in the different sections along the road and there are only three designated parking places for service vehicles. Many of the loading areas are behind closed overhead garage doors that enclose either the entire area or just the end of the dock.

The downtown truck tunnel serves two major functions: freight pickup and delivery and vehicular access to underground parking facilities. The tunnel provides freight service to more than 40 businesses including two major department stores, a hotel, and a restaurant. More than 700 vehicles were counted entering and leaving the tunnel between 6:30 a.m. and 8:45 p.m. one day in July 1981. Of that number, 375 were automobiles. The following table gives the breakdown:

Vehicle Type	Vehicles in/ out of Tunnel
Automobiles	375
Light trucks	194
Medium trucks	128
Tractor trailers	19

Commentary

The Underground Truck Road is a valuable asset to downtown Rochester and a vital link in its pickup and delivery transportation system of alleys, ground-level off-street loading docks, and underground loading docks. With approximately 400 PUD vehicles (trucks and automobiles) using the facility in the typically slow goods movement month of July, this is one of the most heavily used central area facilities in the United States. Unlike Dallas, Rochester does not appear to have an official master plan that supports the underground truck distribution concept. However, at each opportunity, the tunnel is extended. With its current length of just over 1/4 mi, significant reductions in surface traffic vehicle-miles of travel are accruing to the arterial system, thereby benefiting traffic flow as well as pedestrians.

The security benefits of this system are also identified as a principal attribute. A major bank as well as consumer freight movements are involved in this PUD process. Several receivers use shutters to close themselves off from the tunnel, sometime with a truck at the dock. Rochester also has harsh winter months and a major underground PUD component provides measurable benefits in time and convenience of goods transfer.

Livingston-Bond Garage and Remote Dock

Whereas the previously discussed facilities are for shared use, the facility discussed in this section is for a single user. A large department store in downtown Brooklyn needed to expand its off-street facilities significantly and to free large numbers of vehicles queued on-street at the present off-street docks (5). Simultaneously, a new municipal parking garage was being constructed on the other side of the street (Livingston Street, an arterial). The New York City Department of City Planning and representatives of the department store concluded an arrangement whereby the city of New York would build a remote off-street loading facility in a portion of the garage and then lease that portion to the user on a long-term basis. Figure 7 shows the facility.

The freight component of the garage has seven berths of varied dimensions. Delivered freight is unloaded at the dock and transferred to a tow-line dolly system (continuous cable in the floor) that moves down a ramp (about 10 percent grade) under the garage (Figure 7), under Livingston Street, and into the basement of the receiving facility where it is loaded into a freight elevator. The empty dolly then returns on the tow-line directly to the dock of the remote facility.

COMMENTARY

The remote facility is unique in character and operationally sound. The facility has expanded the receiving capacity of the department store to a desirable (actually excessive) level. The tow-line has the capacity to move more than 100,000 lb of freight per hour, or about that generated by continuous unloading operation at a 12-berth facility. Because the tow-line is on ramps for a portion of its length, the dollies cannot handle extremely heavy items. One option might have been to use a freight elevator at dockside to transfer the loaded dolly to the basement level and then to use the tow-line to transfer the dollies to the destination.

The implementation and successful use of a remote loading facility open applications for future consideration. The concept is to provide off-street loading space in a new facility in order to reduce or eliminate curbside freight activity on the ar-

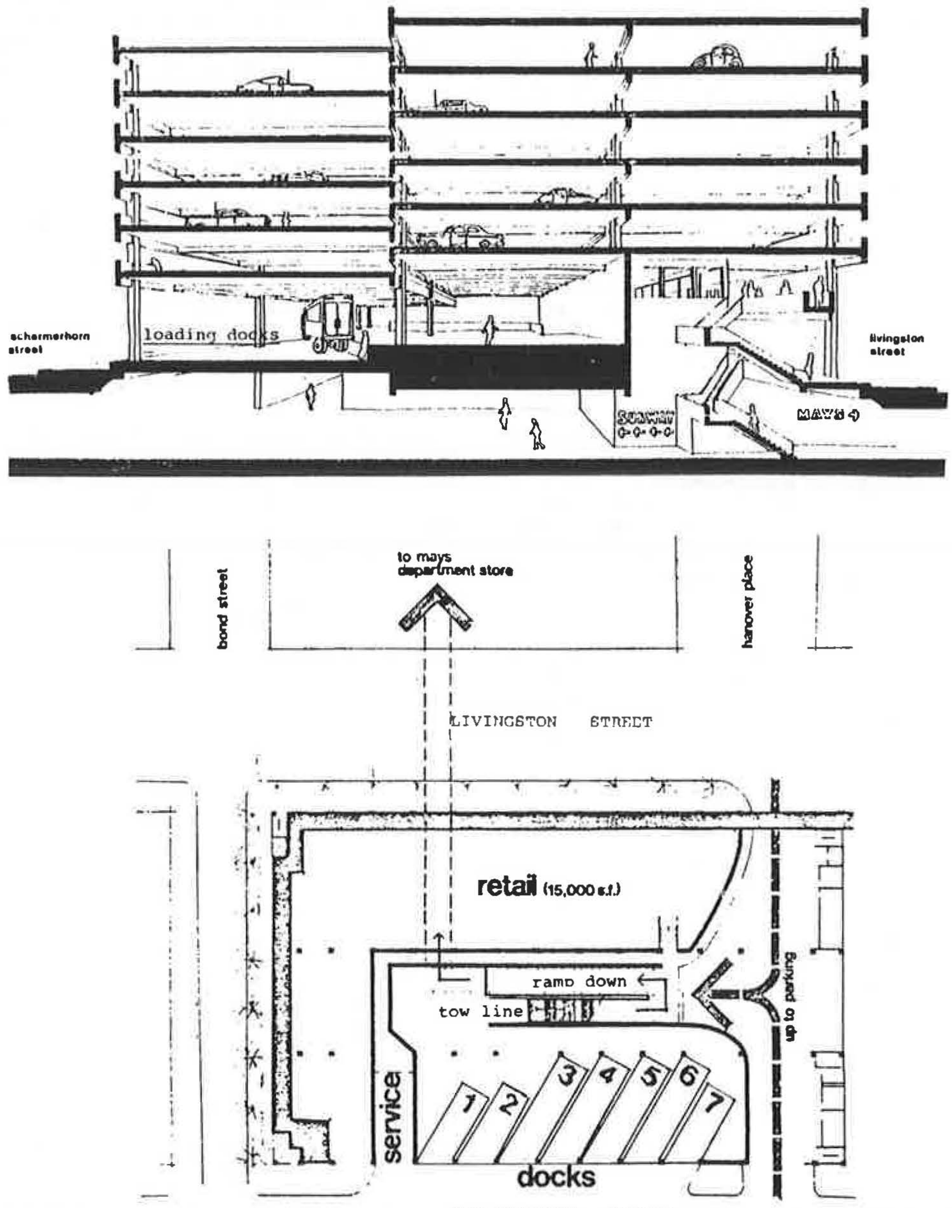

FIGURE 7 Livingston-Bond garage.

terial system at a problem location. The application of the concept to a central area department store appears to be the most reasonable one. Central area department stores are strong traffic generators, are generally fairly old, have antiquated handling facilities and therefore use curbside loading for much of their freight, and are usually located on the arterial system.

Parking garages are constructed to supplement automobile parking at the curbside. Spatial separation of trucks from the curbside appears to be a logical extension of this principle. The reuse of a portion of an existing parking facility for freight distribution is one of a battery of measures available to transportation engineers as this example exhibits.

OFF-STREET ZONING AND LOADING REQUIREMENTS

The implementation of off-street loading facilities in new buildings typically follows the requirements set forth in a municipality's zoning ordinance. The zoning stipulates how many berths are required in a new building as a function of building size and use. Zoning will usually also stipulate the required dimensions of the off-street area; however, it will not stipulate how the area should be managed after construction. Most ordinances do not require that the spaces be at a dock, but only that they be off-street (in the building's parking lot or garage) and on the building's premises.

Zoning requirements for off-street loading facilities are not new. Most cities have such requirements. However, findings from previous research efforts show that these requirements have evolved from secondary source material not from independent investigations by the municipalities. The examples in this section focus on office buildings and the cases presented come from Dallas, Calgary, and Ottawa. The Dallas example presents new concepts in ordinance development; the Calgary example treats different components of PUD operations in a unique manner. The Ottawa example, although not directly related to zoning, was a case study of implementing central receiving and shipping in an existing office building.

Dallas Zoning Ordinance

Off-street zoning revisions began in 1974 with a review (6) of off-street ordinances from other cities in the United States that showed, as suspected, that Dallas had one of the lowest off-street loading requirements in its central area (7). The acknowledged problems with the ordinance were somewhat reduced because most developers exceeded the ordinance requirements in providing off-street facilities. The unacceptable likelihood of trucks loading and unloading in front of their buildings, it is understood, motivated developers to increase facilities.

Several years passed before additional work was conducted to actually revise the ordinance. In 1979 loading and unloading counts at critical locations were taken to verify demand estimates for various land uses and to quantify the deficiencies in existing buildings. Table 4 gives these deficiencies between the maximum number of PUD operations in the critical hour and the capacity of the existing off-street loading facilities. The deficiencies varied considerably among large buildings.

The concept of the new ordinance is the provision of loading space necessary to fully accommodate peak-hour demand at a site. The draft ordinance was reviewed by a city council-appointed advisory committee, as well as by the major downtown developers. Several severe objections were recorded by the developers because of the increases in the new ordinance. Face-to-face meetings and discussions followed in which both sides adjusted their positions. As an example, the demand estimate used for office buildings was found to be about 15 percent too high, and the requirement for accommodating 100 percent of peak-hour demand in off-street facilities was modified to include a provision that curbside loading zones, where available, could substitute for a portion of the off-street requirement.

Figure 8 graphically shows the new ordinance requirements in terms of number of off-street loading spaces and Tables 5 and 6 give the size distribution and location of these spaces. It is to be noted that, in Table 5, emphasis is placed on maximizing space available to developers by tailoring the size of the spaces to the inventoried vehicle-type characteristics loading at each land use. The data in Table 6 indicate that where curb space is available for a conveniently placed loading zone, up to 40 percent of the ordinance requirements can be placed on-street for the largest generators.

TABLE 4 Loading Deficiencies in Peak Hour (7)

Block No.		Description	Peak Hour Stops Supply	Demand	Deficiency
63E	(1)	Federal building	21	47	30
75	(2)	LTV-Dresser building	26	32	6
76 & 76½	(3)	Kirby building	67	72	5
223½	(4)	Dallas Times Herald garage	11	12	1
232	(5)	Sanger-Harris	46	67	23
107	(6)	Joske's block	46	71	25
243	(7)	Crow building	44	49	5
247	(8)	2001 Bryan	40	47	7
257/258	(9)	Plaza of the Americas	18	73	55
478	(10)	Dallas Centre	15	26	11

Commentary

The ordinance developed in Dallas addresses the concept of accommodating peak PUD operations (over a 60-min period) at the generator. For the vast majority of these generators, this accommodation is off-street. The use of the on-street complement (if available) for the largest generators to satisfy the ordinance is unique among U.S. cities. The combined off-street and on-street loading requirements address the differences between buildings in the center of the core (presumably there would be little or no side-street curb space available) versus buildings at the fringes (or outside) of the core where curb space is more readily available for loading zone use.

The ordinance significantly downgrades the importance of the tractor trailer (55 ft 0 in. vehicle) in off-street loading. Most studies typically show 2 to 3 percent tractor trailers in downtown PUD operations, with department stores having the highest percentages (5 to 6 percent). The ability to eliminate off-street loading facilities for vehicles longer than 35 ft 0 in. makes it possible to justify (to developers) the increase in the total number of off-street spaces with little or no change in square footage allocation to the loading and unloading function. It would appear, however, that the explicit write-off of tractor trailer facilities in the commercial and industrial land use category would be inappropriate for non-CBD facilities and potential users of the Dallas model should adjust the requirements to accommodate some large vehicles.

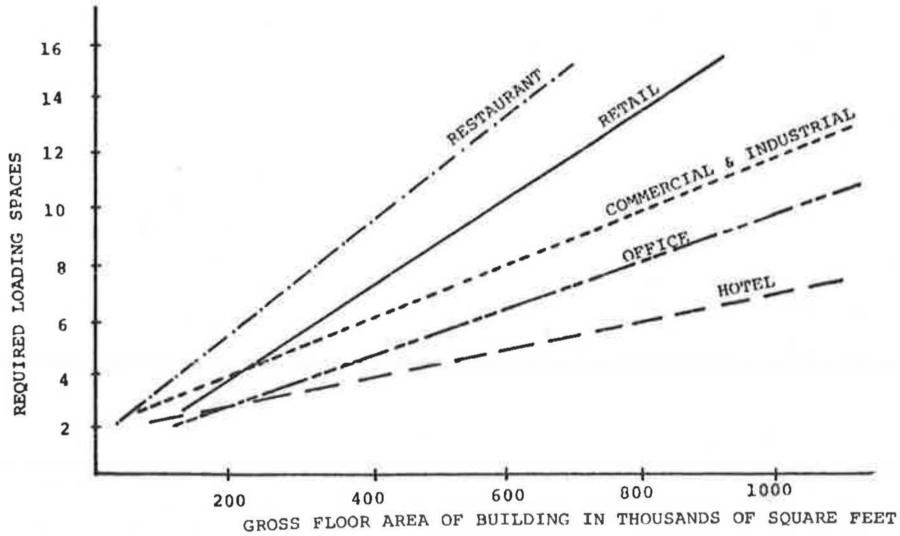

FIGURE 8 Dallas ordinance requirements.

TABLE 5 Loading Space Size Distribution for Various Land Uses

	Percentage of Space Sizes		
Land Use Category	55 ft	35 ft	20 to 25 ft
Office	–	40	Balance
Retail and personal services	–		Balance
Retail, if over 60,000 ft^2	25	25	Balance
Commercial industrial	–	40	Balance
Hotel or motel	1 space	75	Balance
Food and beverage services	–	40	Balance

TABLE 6 Options to Satisfy Off-Street Loading Space Requirements

No. of Required Spaces	Minimum Off-Street	Maximum On-Street
6	6	0
7	6	1
8	6	2
9	6	3
10 or more	60 percent	40 percent

Calgary CBD Office Building Requirements

This project developed a detailed statistical background on PUD operations at office buildings, with a special focus on the emergence of courier services in the CBD. The output of this project was the development of loading requirements for Calgary office buildings and the incorporation of these requirements into the city's by-laws (H. Ho and J. Morrall, Freight Facilities for Central Business District Office Buildings, internal paper provided by Transport Canada, 1981).

As in Dallas, a detailed inventory of PUD operations was undertaken at selected CBD office buildings in 1978 and 1979. The inventory included vehicle arrivals, type, service times, a survey of building managers, and a building loading facilities inventory. A major difference in this Calgary project was that the then by-law requirements were perceived to be too severe by developers, and few if any office buildings met the requirements (Figure 9). For example, 1-million-square-feet office buildings would require about 23 loading spaces (compared to 10 in the new Dallas ordinance).

The project calibrated detailed arrival time and service time statistical distributions for office buildings for the 9 a.m. to 12 noon period. This represented the period when PUD operations were highest and during which the developed by-law revision would be applicable.

The calibrated exponential service-time distributions are unique for each type of operation:

Trucks and Delivery Vehicles

$P(g \geq s) = e^{-0.03635}$, $n = 1.207$, $\mu = 27.6$ min

Courier Vehicles

$P(g \geq s) = e^{-0.10205}$, $n = 3,065$, $\mu = 9.8$ min

Service Vehicles

$P(g \geq s) = e^{-0.02075}$, $n = 118$, $\mu = 48.31$ min

where $P(g \geq s)$ is probability of a service time greater than or equal to s, n is number of observations, and μ is the mean service time.

The loading standards derived from the analytical representation of demand (9 a.m. to 12 noon) and service are based on full accommodation (zero queue) for the average 180-min demand of each vehicle type. The demand from 9 a.m. to 12 noon is somewhat less than the peak-hour demand and, as such, the standards, as implemented, imply some queues in the peak hour. Table 7 gives these off-street standards. It is noted in Table 7 that the recommendation is to also accommodate courier and service vehicles with off-street parking spaces.

Commentary

Under the new guidelines, a new 800,000-ft^2 office building in Calgary would be required to have 10 PUD loading spaces versus 8 in Dallas. It would appear that there are some discrepancies because the Dallas standard is designed for full accommodation in the peak hour and the Calgary standard for accommodating an average arrival rate over a 3-hr period. An independent study by the author that determined off-street loading requirements on the basis of minimal

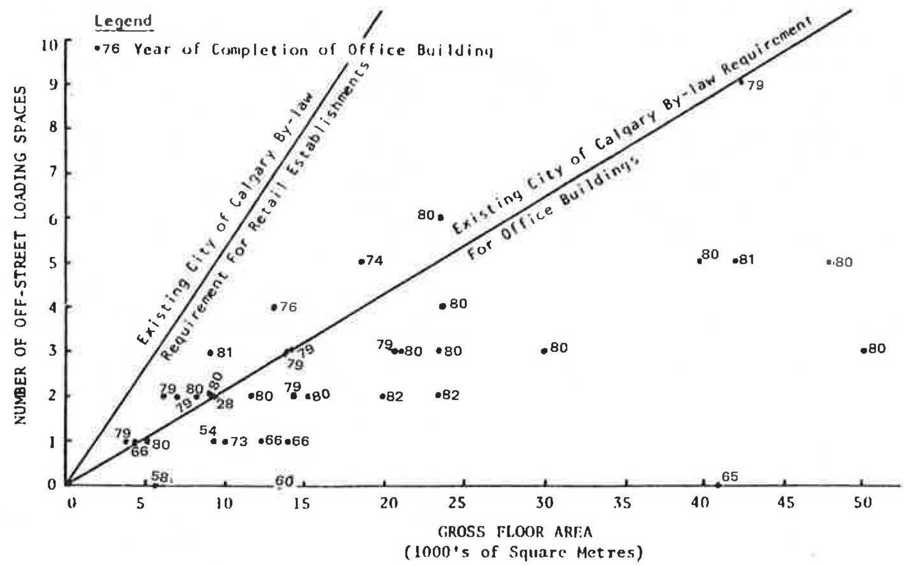

FIGURE 9 Existing loading spaces in Calgary CBD major office buildings.

TABLE 7 Recommended Freight Requirements for CBD Office Buildings in Calgary

Range of Total Gross Floor Area (m^2)	Minimum No. of Loading Spaces Required for Trucks and Delivery Vehicles	Minimum No. of Parking Spaces Required for: Courier Vehicles	Service Vehicles
10 000 - 14 999	4	2	1
15 000 - 19 999	5	3	2
20 000 - 27 999	6	4	3
28 000 - 39 999	7	5	4
40 000 - 49 999	8	6	4
50 000 - 64 999	9	7	5
65 000 - 79 999	10	7	5
80 000 - 94 999	11	8	5
95 000 - 109 999	12	9	6
110 000 or more	Additional one for every 15 000 m^2 or fraction thereof	Additional one for every 17 000 m^2 or fraction thereof	Additional one for every 47 000 m^2 or fraction thereof

Note: 1 m^2 = approximately 10.8 $ft.^2$

peak-period queuing found that seven berths would be appropriate. It therefore appears that the Calgary requirements may still be somewhat excessive. It is noted here that the previous by-laws in Calgary would require about 16 PUD spaces and thus the recommended changes do more accurately represent facility needs.

The concept of accommodating couriers and service vehicles is novel; this appears to be the first instance in which inclusion of nonloading vehicles is recommended for by-law revision. The provision of separate courier space must be considered on a city-by-city basis. As an example, in San Francisco a substantial portion of courier traffic at office buildings moves by bicycle. In New York bicycles, transit, and walking account for much of the courier traffic.

The provision of separate space for service vehicles has been supported by most researchers involved in freight and services transportation. It is difficult for service vehicles to find parking in the CBD. Most loading time restrictions are shorter than the average dwell time of a service vehicle and most vans and light trucks, commonly used for service, cannot be accommodated in garages due to headroom restrictions and insurance limitations. However, as in the case of courier vehicles, individual cities have different needs for service vehicle accommodation. In the densest cities, such as New York, Chicago, San Francisco, Philadelphia, and Dallas, many service trips can be provided by walking between destinations where electrical, telephone, or light maintenance functions are being performed. In cities with spread-out central areas, such as Phoenix, Los Angeles, and to some degree Seattle and Washington, D.C., transportation by vehicle between destinations is essential. In reviewing the criteria developed for service vehicle accommodation in Calgary, potential users should consider these ideal needs and tailor the necessary accommodating facilities on the basis of city characteristics, current and future use of curb space, expected developer cost, and other location and project characteristics.

Ottawa Receiver Consolidation Demonstration

This third example, from Ottawa, Canada, in 1977-1978, was designed as a demonstration project to evaluate the effectiveness of implementing central receiving in a multitenant office building (8). The objective was to reduce the temporal aspects of the pickup or delivery thereby improving curb space use, reducing carrier costs, reducing local traffic congestion, and improving air quality.

The demonstration project was conducted during a period of 6 months and involved having a desk and space in the lobby, two persons working 10 hr per day each, two telephone lines, and a secure storage room to hold freight overnight. The selected office building had multitenant occupancy and was just over 100,000 ft^2 in size. The project involved substantial amounts of data collection needed for before-and-after analysis of PUD dwell time, curb space use, traffic flow speed, and engine idling. In addition, attitudinal surveys of tenants and carriers were conducted after the experiment. It should be noted that the use of consolidated receiving in the demonstration building was completely voluntary on the part of the tenants and several chose not to participate.

In general, the experiment proved its point by reducing somewhat dwell times for shipments going through central receiving. The number of samples collected was limited in the after data and therefore statistical significance cannot be proven at the 95 percent confidence level. Table 8 gives a summary of the dwell time analysis. Of particular note here is the uncharacteristically short "before" dwell times for PUD operation at this building. This is partly explained by the small size of the building, which may prove to have been too small a building for which to achieve appreciable benefits. Another contribution to short dwell time may be an inordinate number of courier vehicles (typical of office buildings).

TABLE 8 Dwell Time Effects of Receiver Consolidation

	Front of Building			Upstreet/Downstreet		
	Before	After Using	After Not Using	Before	After Using	After Not Using
Passenger cars						
Observations	79	8	63	18	5	18
Mean	6.4	5.3	5.9	4.4	4.8	6.4
Standard deviation	5.3	4.9	3.6	2.0	4.7	3.6
Light trucks, vans						
Observations	72	13	38	25	7	47
Mean	8.4	7.3	7.6	7.6	7.7	8.2
Standard deviation	7.0	3.9	5.5	3.7	4.0	6.4
Heavy trucks						
Observations	37	10	21	12	2	14
Mean	8.1	8.9	7.6	8.8	5.5	8.5
Standard deviation	6.5	7.1	5.3	7.7	0.7	3.8

The study notes that where internal time benefits were achieved, drivers tended to use up this savings in inefficiencies external to the building. As a result of the relatively minor impacts on dwell time, the parking benefits were not definable. The total accumulation of PUD vehicles at any one time was slightly reduced, but even this benefit was not statistically validated. Further, the results of the before-and-after traffic speed analysis also show no statistical change attributable to the demonstration. The before-and-after analysis of the PUD vehicles that were left with their engines running for all or a portion of the time showed a significant decrease. However, the before study was conducted in November and the after study in June, and this is expected to be the explaining factor for this phenomenon.

Several interesting findings were generated from the attitudinal survey, especially of carriers and tenants. Detailed survey findings are available elsewhere (7). Carriers viewed the system positively; however, they have no influence in a system in which the tenant decides whether or not to participate. The tenants do not appear enthusiastic about the concept nor are developers. When cost was asked about, no group volunteered resources although the most popular response related to developer financing of any centralized operation.

Commentary

Overall, the experiment to provide a small office building with consolidated receiving and shipping cannot be viewed as a success in achieving the stated objectives. That only a minor number of tenants volunteered to be in the program was an indicator of the relative disinterest. It might have been interesting if the attitudinal survey had solicited responses about reasons for volunteering or not volunteering to be part of the system. It can only be assumed that the tenants who did not volunteer considered the system to be an erosion of the quality (increased time) of good access.

The preliminary nature of the results of the after study shows that, although hypothesized dwell time benefits are generally achievable, they are not realized because of average increases in external driver inefficiencies. If the building selected for the experiment had had loading docks, it could be hypothesized that the efficiencies gained with consolidated receiving would have resulted in sizable overall decreases in dwell time because drivers would have stayed at the dock and would usually have been monitored.

Only limited practical application is seen by this author for consolidated freight transfer in multitenant office buildings. Some characteristics of the ideal building for instituting centralized receiving are minimum size of 500,000 ft^2, poor elevator service (passenger and freight), problems with freight security, overused loading docks, and location in a street environment with little or no available curb space. The system cost would be borne by the building owner and the facility staffed by building personnel. Even under these ideal conditions, the final effectiveness of such a system would not be guaranteed.

Summary

This section has provided an overview of office building freight characteristics, problems, and possible solutions. As central areas of cities become increasingly service oriented, the rapid movement of small packages will increase in dominance. Two scenarios can be constructed for the future of this trend. The first scenario is the ever-increasingly large numbers of courier vehicles moving about the central area with small packages and documents. The second scenario is the emergence of technology in telecommunications that would be adapted to the "movement" of much of the currently transferred freight at office buildings. Characteristically, these scenarios are diametrically opposite and cannot easily be planned for simultaneously.

As municipalities try to come to grips with central area movement of freight, the recognition of the growth in service vehicles must be translated into the planning process. Offices (and other land uses for that matter) will continue to have more equipment (communications, computers, and so forth) that require specialized servicing. A casual walk through the central areas of larger cities will point out the significant presence of service vehicles at curb side and parked in off-street loading areas where permitted.

SUMMARY

In this paper an outline of examples of actions taken by municipalities to plan for and better manage freight transportation as a component of overall urban transportation has been presented. The number of actions available for presentation was limited by the real lack of overall consideration of freight transportation by most municipalities. New ideas were difficult to come by. Of particular note is the lack of any action in the traffic engineering and arterial management area, which presumably has the most impact on urban transportation. In the area of land use planning, certain municipalities, Chicago as the prime example, have taken actions to improve truck terminal access as well as terminal location planning. The only example of sidewalk management was found in the New York garment center where signposts are being eliminated to facilitate freight movement and building transfer. No municipality was found to have any program to supervise off-street loading facilities to ensure that these facilities are being used for their intended purpose. This has been a problem for some time.

The role of urban goods movement, already accounting for one-half of the nation's truck transportation bill, is expected to increase in the decades ahead. The concept of centralized manufacturing has been eroding as small automated plants located near the consuming market are proving to be a more cost-effective alternative to ever-increasing over-the-road transportation and distribution costs. In addition, the concept of zero inventory ("just-in-time") is expected to also increase in popularity in small establishments (manufacturing and retail alike) thereby placing more importance on the movement of decreasing shipment sizes.

The eight examples presented in this paper serve to identify some ideas and options for municipal goods movement project development. Because new goods movement projects are few, evidence of successful and unsuccessful techniques is needed and serves to improve the effectiveness of new projects. It is hoped that this paper satisfies a portion of these information-sharing needs.

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Directions for Urban Freight Transport Research in Australia

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ABSTRACT

Some results are reported of a project undertaken to (a) assess the need for further research in freight in Australia, (b) formulate research project statements and identify costs and benefits of such projects, and (c) develop recommendations for further research. The procedures used, which were found to be an effective way of identifying research needs and formulating research priorities and project statements, are documented. The findings of the study are also summarized.

Research in urban freight in Australia has been sustained at a relatively low level in recent years (1). In this sense, it mirrors the situation in North America (2) and Europe (3).

The value of undertaking urban freight research has sometimes been questioned in Australia, as it has in the United States (4). It is sometimes argued that there is little that can be done to influence freight activities, that there is no political or public pressure to tackle freight issues, and that there are few international precedents indicating "successful" freight research. The essential point that these arguments reflect is that there is uncertainty about the value of further freight research.

In the recognition that such uncertainty exists, the Australian Road Research Board (ARRB), together with the Transport Group in the Department of Civil Engineering at Monash University, recently conducted a study with the broad aim of assessing the desirability of further road freight transport system research and the likely payoffs from such research. The specific aims of this study were to

• Assess the need for further research to satisfy information requirements in the road freight transport field,
• Formulate research project statements and identify the nature and order of costs and benefits for particular research projects and programs, and
• Develop recommendations for ARRB involvement in further road freight transport research.

The scope of the study and the level of investigation were constrained in two important ways. First, it applied primarily to road freight transport, although the interface of road with other modes was also considered. Second, it applied to transport system research. The road technology side, which includes the design of pavements, structures, or vehicles, was considered outside the scope of the study.

This paper is oriented toward research in urban freight because the major research needs identified in the project related to urban problems. The only significant exception to this was intercity truck mass and dimension limits. In this way too the study and its findings reflect the U.S. situation, where, notwithstanding a concern for truck mass and dimension limits (5) and for statewide freight planning (6), the primary concerns in freight planning and research appear to be found in urban areas. The output of the present study should thus be of relevance and interest to a wider audience, in terms not only of research methodology (in which there were some fairly novel features) but also in terms of research findings.

INVESTIGATIVE PROCEDURE

Given the wide scope of the project and its broad objectives, it was necessary to develop a research methodology that would ensure that a broad range of inputs could be accommodated. The methodology also had to be compatible with ARRB's committee process (7) because eventually the research findings had to be processed and ranked by priority within this process. It was not considered appropriate to use this committee process in the usual way because, although it includes open forums (to allow discussion on selected research topics) and executive committees (to formulate recommendations on priorities), past experience has shown it is difficult to identify priorities and appropriate levels of research effort in the urban freight field using this process. The reason for this is thought to be that the relatively open-ended nature of freight research, the absence of precedents, and the lack of an ongoing research program have prevented the emergence of a clear consensus on freight priorities.

In the light of this experience, it was believed that the established procedures needed to be complemented by a more comprehensive investigation of freight transport issues and research needs. This project was initiated to undertake that investigation.

Delphi techniques are one means of identifying issues, developing understanding on a subject, and determining a consensus position about future actions. There have been several reported uses of them in the transport field in Australia (8,9). Consideration was given to using Delphi techniques in this study, and they were seen to be a suitable systematic process for developing understanding about freight transport issues and research needs. However, the resources available to the study were not sufficient to enable the effective use of a full Delphi analysis. An investigative procedure, which might be considered "partial Delphi," was adopted. It comprised the following primary stages and tasks:

• Stage 1. Develop a statement of issues and research needs. This was based on a literature review.
• Stage 2. Conduct a series of small discussion sessions. These refined the statement of issues and needs and identified research topics.
• Stage 3. Draft research proposals. These address the research topics that are of common interest in the road transport sector.
• Stage 4. Conduct a workshop. The task of the workshop was to consider the draft proposals and possible priorities with the aim of developing positive recommendations for further research. This provided input to the executive committees.

In the balance of this paper each of these tasks and the output from them are described.

IDENTIFYING ISSUES AND RESEARCH NEEDS

Investigative Framework

A preliminary though comprehensive review of Australian freight transport research was conducted as a means of focusing on issues of current concern (1). This revealed that freight research was being undertaken in several broad subject areas, but such a review in itself could not tell much about the current issues and emerging research priorities.

It was thus considered that a systematic investigative framework, based essentially on identifying issues in relation to freight transport objectives, was necessary to aid identification of research needs.

The investigative framework recognizes three distinct, though related, components of freight research:

1. Freight issues that are related to the objectives and constraints of the freight system.
2. Actions that may be taken to resolve one or more of the issues. These may be thought of as broad policy options (e.g., regulation) or specific schemes (e.g., traffic management).
3. Research tasks that are needed to either investigate the issue or appraise the application of action in response to an issue or issues.

These three components are related but quite distinct, and the challenge is to determine how research can be applied either to an issue or to assessing possible actions in relation to it. Their relationship is shown in Figure 1 in which X is the appropriate research project to appraise the effect of action P on issue A. Without loss of generality, X may also be considered an analysis of issue A, or an appraisal of action P, without any cross reference between A and P being involved.

Objectives and Constraints

The desirable starting point for any consideration of freight transport research is the identification of the objectives that the freight system is intended to serve and the constraints on the system.

This immediately raised the question of "whose objectives?" because the objectives of different participants in the freight process will be different and in many cases will be in conflict with those of other participants. Without being flippant, it may be said that the analysis of the objectives

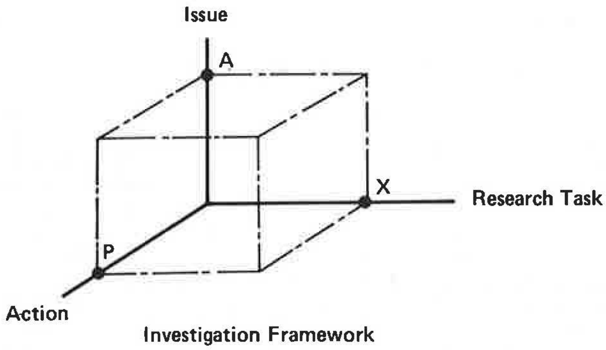

FIGURE 1 Investigative framework.

of these participants could be a major research activity in itself. However, for the purposes of this study, it was assumed that the primary viewpoint would be that of government (given ARRB's interest groups).

Objectives are not always set down or made explicit by government. They can nevertheless be identified by implication, by examining such aspects as resource allocation or areas where policy formulation is occurring. Objectives may be complemented by constraints (e.g., objectives that involve the operational efficiency of the freight sector are of importance because there are constraints on national resource allocations to freight, in terms of such things as investment and energy).

A number of primary objectives and constraints relevant to freight transport in Australia were identified on the basis of the literature, a priori reasoning, and preliminary discussion. The objectives can be broadly stated as

- Service quality. The freight system should meet the freight needs (forms and standards of service) of the community, now and in the future.
- Economic efficiency. Freight is a derived demand, and thus the requisite level of freight service should be provided for a minimum level of resource input.
- Environmental and safety impacts. The detrimental effects of the freight system on the natural and human environment should be minimized.
- Distributional effects. The freight system should feature an acceptable balance between societal and commercial (private) benefits and costs, and it should not hinder (and where possible should contribute to) national and regional development.
- Cost recovery. The taxes and charges paid by the freight sector to government should meet required levels of recovery of public costs (especially infrastructure costs).
- Energy. Appropriate energy resources should be supplied to the freight transport sector and these should be efficiently used within the sector.

Possible Actions

Governments have available a range of possible actions that can be taken in pursuit of these objectives or to satisfy the constraints (3,10). These options include

- Regulation of the industry structure, of the activities of the industry, of the driver, of the vehicle, of vehicle use, and of land use;
- Subsidy and taxation;
- Traffic management;
- Infrastructure for investment and maintenance;
- Training and education;
- Consultative mechanisms;
- Public ownership or divestment;
- Demonstration projects; and
- Technology and design (especially vehicles, pavements, and structures).

Research Tasks

As shown in Figure 1, research may be directed either at specific issues (which arise in relation to the objectives and constraints) or at particular actions (i.e., the application of particular schemes or policy options to those issues). The following list is considered indicative of the sorts of research that might be necessary to assist in the resolution of particular issues or to appraise particular actions that have been taken in practice.

- Development of analytical techniques: supply models, demand models, and impact models;
- Costing analysis;
- Development of information bases and monitoring techniques;
- Basic or exploratory investigation (i.e., assessment of the nature of an issue and its importance);
- Market research, especially in the commercial sector; and
- Development of general procedures methodology for planning, evaluation, impact assessment, and forecasting.

Determination of the appropriate research tasks and specification of the research method were major tasks in the research proposal development stage.

Statement of Issues and Research Needs

Using the investigative framework outlined previously, a discussion note was prepared that included details of the framework itself and statements that represented an initial attempt to define current freight transport issues and research needs. To facilitate the conduct of discussion sessions, this initial set of issues and needs was related to the objectives:

- Service quality,
- Economic efficiency,
- Environmental and safety impacts,
- Distributional effects,
- Cost recovery, and
- Energy.

RESEARCH TOPICS

Process

The statement of current issues and research needs constituted a working document to assist in the process of determining the perceptions of others in the freight transport field on issues and research needs. It specified relevant research topics and indicated the nature of possible payoffs.

To facilitate this process, a series of discussion sessions was arranged, in which the authors led a loosely structured discussion on the general topic of freight research. The discussion note was circulated ahead of time to stimulate response and to guide discussion.

Discussion sessions were conducted with persons from several Australian state road authorities, state and federal government transport agencies, and railway systems and with particular individuals with knowledge and expertise in the freight transport field.

It is of interest to note that, although in many cases the views of persons involved in the discussions were "predictable" given their affiliation, this was by no means universally so. In some sessions opinions varied significantly among individuals from the same organization, reflecting the varying perspectives on freight issues and research needs within an organization. This experience demonstrates the value of the discussion sessions in bringing to light different perspectives and opinions in a professional environment in which most individuals can feel free to express personal views, not necessarily "organizational" views.

Freight Transport Issues

A primary outcome of the discussion sessions was a clearer statement of current freight transport issues and their relationship to the broad transport objectives outlined previously. These are summarized hereafter. To emphasize the commonality of these issues among industrialized countries (11), recent research elsewhere is cited. No priority ranking is implied.

Service Quality

Three specific issues relating to service quality were identified:

1. Performance criteria and standards. It is generally recognized that the requirements from the freight transport system vary across user segments and thus the importance of particular performance criteria varies across segments. Three such criteria are price, service frequency, and reliability of time of delivery. These criteria also have importance for road infrastructure and urban structure planning because they could influence the amount of travel and the value placed on travel time. However, little hard information exists on either the relative importance of criteria or their inferences for road planning (12-15).
2. Industry structure and viability. The ability of the industry to deliver a desired service is influenced by its structure, as is its ability to conform with community expectations relating to such factors as safety, environmental protection, and cost recovery. Just as the freight market comprises numerous submarkets, so the freight sector is characterized by specialized activities and functions (e.g., forwarders, line-haul operators, local delivery firms, owner drivers, loading agents, own-account carriers). It is a necessary prerequisite to informed policy and planning for freight that the role and contribution of each sector of the industry (and indeed of the industry as a whole) be known and understood. Moreover, because freight movements can be a good indicator of wider economic performance, more attention to monitoring the freight sector could have wider benefits (2,16,17).
3. The freight task. An increased understanding of the size and patterns of freight movement, and of the factors affecting demand, is necessary to aid transport planning. Also, there are major deficiencies in current techniques for modeling the generation and flow of commodities and vehicles, modal split analysis, and freight forecasting (3,18-24).

Economic Efficiency

Four specific issues were identified:

1. Economic growth. Although it is known that transport costs are a significant component of the costs of production, it is not known whether savings in these costs would contribute to economic growth (i.e., the extent to which such savings are really transfer payments). This is particularly significant in that improving "efficiency" might lead only to a growth in unemployment. This does not negate the importance of efficiency objectives (especially where export traffic is concerned), but it does emphasize the importance of considering distribution effects (25).
2. Industry productivity. Transport costs are part of the costs that affect final prices of commodities. Their significance varies considerably from item to item. There is little comprehensive Australian data that would show how important physical distribution management (pdm) costs are in relation to other costs of production, nor of transport costs within pdm costs (26,27).
3. Urban transport network effects. That urban traffic congestion, terminal delays, and certain restrictive operating practices affect freight costs is axiomatic. What is not understood, however, is the effect that these costs have on such aspects as truck productivity (e.g., number of deliveries per day); viability of industry in the locality; and choice of mode or form of operation, including own-account operation (18,21,28,29).
4. Freight system efficiency. A periodic review of the suitability of the various industry parameters (e.g., vehicle mass and dimension limits) and related investment needs should be undertaken. Technological advances in road and vehicle design, or changes in the relative importance of production factors (e.g., labor, energy) mean that a revised set of conditions may be "optimum" (5,30).

Environment and Safety

In this case, four issues were thought to be important:

1. Significance of truck-related road safety. Although trucks are involved in some 15 percent of accidents in Australia involving fatalities, they are overrepresented relative to vehicle-kilometers of travel, and most fatalities are not participants in the road freight industry. There is some research activity on truck-related safety issues at present, but it would probably be true to say that these issues have not been pursued as vigorously as other aspects of safety research. Thus there is a need for improved understanding of the nature of the truck accident problem (17,31,32).
2. Development of truck accident countermeasures. This issue follows from the first; the difference is that this one is focused on development of countermeasures as a follow-on from the analysis conducted of accident patterns.
3. Noise, emissions, and vibration. These three environmental issues probably represent the three most noticeable forms of environmental problems associated with trucks, and, in each case, trucks are significant (or are perceived to be significant) contributors to the overall problem (26).
4. Intrusion into residential streets. Concerns related to the intrusion of extraneous vehicles in residential street networks have come into promi-

nence in Australia in recent years and in some cases trucks figure in those concerns. A range of measures to tackle traffic intrusion has been developed, but it is probably fair to say that trucks have not been treated as comprehensively as cars in these developments. Three aspects are involved: first, the development of means of keeping extraneous trucks out of residential neighborhoods; second, how best to cater for trucks that have legitimate business in the area; and, third, the problem of truck parking (33-35).

Distributional Effects

The two current issues of concern in relation to this objective were

1. Equity: beneficiaries of subsidies. Within the objective that the freight system should provide an acceptable balance between societal and private benefits, an issue of current concern is that of who benefits from existing freight subsidies. The presence of rail deficits and, perhaps, less-than-full road cost recovery implies subsidies, and it is not known to whom these subsidies are benefits, or what the social and economic effects of these subsidies might be (17,26).
2. Regional development. The issue here is the extent to which the availability and quality of freight services within a region (including a metropolitan region) contribute to the amount and location of economic growth, and rearrangement of the location of a given level of growth by transport system attributes (36-38).

Road Freight Cost Recovery

The primary issue was the contribution of heavy vehicles. It was generally agreed that the marketplace is the best determinant of mode use provided that the correct signals on true costs are transmitted to the market. If heavy road freight vehicles are not paying their way, the market may receive inappropriate signals. Moreover, governments are concerned, for financial reasons, that such vehicles should pay their full share of costs of infrastructure provision and maintenance. For both of these reasons, road freight cost recovery is important. However, at the moment there is little consensus on whether heavy commercial vehicles "pay their way." There is lack of agreement on both sides of the ledger; on the cost side, concerning the proportion of road costs allocatable to trucks and, on the revenue side, about which taxes should be regarded as "charges" for the use of roads (17,39-41).

Energy Consumption

Two issues were regarded as significant:

1. Energy consumption audit. Knowledge of the fuel consumption patterns in the road freight sector is essential to the formulation of policies relating to energy consumption. Although broad estimates of total fuel consumption by the road freight sector do exist, there is little knowledge of consumption patterns within the sector. That is, the relative contributions of interstate freight, local urban deliveries, and so forth are not known (42).
2. Fuel conservation. Although there is currently no oil crisis, the memory of past "shocks" remains. Thus strategies for conserving fuel within the freight transport sector and ensuring its availability to this vital sector remain important requirements (43-45).

Research Topics

The second outcome of the discussion sessions was a lengthy list of specific research topics and indications of the areas in which payoffs might accrue from research (these topics are listed in the Appendix). This information provided the basis for formulating specific research proposals.

Research Proposals

The list of research topics (Appendix) was examined critically with a view to the development of specific research proposals. This involved the implied priority ranking of research topics and, in some cases, the amalgamation of two or more related topics into a single research proposal.

The priority ranking of projects reflected the implicit or explicit importance attached to them by the participants in the previous phase, the extent to which they were judged to be capable of producing worthwhile output within an acceptance time and budget, and their potential relevance to ARRB's interest groups (primarily state road and traffic authorities).

In this way, five research proposals were prepared. The aim of each, and the links to the research topics listed in the Appendix, is as follows:

1. Freight system data and information needs. The aim of this project would be to assist the making of decisions relating to road policy development and road planning design and maintenance by establishing the forms and sources of freight transport information appropriate to assist such decision making. This proposal addresses research topics (g), (h) and (i) relating to Service Quality (Appendix).
2. Freight transport in urban road investment. The aim of this project would be to develop techniques to specifically evaluate freight-related benefits in urban road investment decisions. This proposal addresses research topics (b) and (p) relating to Economic Efficiency.
3. Criteria for management of trucks in urban areas. The aim of this project would be to develop guidelines for explicit consideration of trucks in urban traffic management schemes, both to facilitate freight flow and to reduce the adverse environmental impact of trucks. This proposal addresses research topic (k) relating to Economic Efficiency.
4. Heavy vehicle considerations in traffic signal design. The aim of this project would be to refine those parts of the Australian traffic signal design guides that are affected by trucks (in particular, settings for yellow and all-red) and to develop guidelines for the explicit inclusion of truck factors in area traffic control systems. This proposal addresses research topic (k) relating to Economic Efficiency.
5. Audit of cost recovery studies. The aim of this study would be to improve the information base for consideration of financial cost recovery in the transport sector by conducting a technical audit of network studies to establish a benchmark for further research or policy development. This proposal addresses research topic (g) relating to Road Cost Recovery.

RESEARCH RECOMMENDATIONS

The final phase of the project involved conducting a 1-day workshop at the Australian Road Research Centre in Melbourne to critically appraise, refine, and rank in priority order the research proposals. The invitees were, in the main, persons who had participated in the earlier round of discussion sessions, and the workshop provided an opportunity for interaction among people with different backgrounds and perspectives.

The research proposals were refined and modified as a result of the workshop deliberations, and three of the proposals were recommended to the executive committees for inclusion in ARRB's 1984-1985 research program:

- Freight system data and information needs,
- Freight transport in urban road investment, and
- Heavy vehicle considerations in traffic signal design.

The workshop also indicated that the other two proposals and several of the research topics in the Appendix were relevant to other traffic and transport agencies. Liaison with these agencies is continuing with a view to implementation of research to address these topics.

CONCLUSIONS

The primary conclusions of this paper relate to the procedure reported here for developing research priorities in freight transport in Australia. The procedure was found to be effective in that

- It facilitated the identification of a range of specific issues of current concern;
- It provided a mechanism for generating research topics, and based on those, for developing draft research proposals;
- It provided a means of refining these drafts into detailed research proposals;
- It proved to be an effective information exchange among persons from a range of organizations; and
- It served to heighten awareness of the importance of freight issues within transport planning agencies.

A general guideline might also be drawn for use of the procedures for formulating research directions: the effort to conduct a systematic investigation of issues and research needs would appear to be justified when a consensus on research directions in a particular area is proving difficult to attain.

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APPENDIX: IDENTIFIED FREIGHT TRANSPORT RESEARCH TOPICS

Those topics which led to research proposals are indicated by *.

A.I Service Quality

(a) Relationships between freedom of entry and perceived problems (accidents, overloading, bankruptcies, etc.)
(b) Effect of a quality licensing system on number of entrants to the industry, price, level of service, safety, etc.
(c) Effects on the industry, and on users, of "full," "correct" cost recovery [see (e) also]
(d) Relationships between freight activity and other indicators (including lags and leads)
(e) Effect of structural economic change on demand for freight
(f) Historical trends in service quality, interstate and intrastate
(g) *Identification of freight system data needs
(h) *Better knowledge of the urban freight task
(i) *Better knowledge of the rural freight task (flows, axle loads, commodities, etc.)
(j) Determinants of mode use
(k) Futures study: role of modes
(l) Health and stability of segments of the road freight industry

A.II Economic Efficiency

(a) Resource costs of urban traffic congestion causing delay to trucks
(b) *Truck benefits and costs in appraisal of urban road investment proposals
(c) Relative benefits of investment in transport viz-à-viz other sectors
(d) Case study involving appraisal of upgrading a route (or new route) in an urban corridor
(e) Resource costs of "poor" nonurban roads
(f) Benefits and costs of allowing new technology (e.g., doubles, triples)
(g) Means of funding road maintenance
(h) Costs of regulatory restrictions, of nonharmonious regulations, of limits on use of technology, etc.
(i) Truck considerations in geometric design (climbing lanes, lane widths, grades, sight distances, etc.)
(j) Effect of urban network (e.g., truck routes) on truck operations

(k) *Traffic management techniques directed at urban trucks
(l) Efficiency in resource allocations between modes
(m) Efficiency of terminal operations (including modal interchanges)
(n) Analysis of effects of past road freight deregulation
(o) Effects of transport efficiency on economic growth
(p) *Development of methods of incorporating freight considerations in urban transport planning
(q) Benefits and costs of large combination vehicles

A.III Environment and Safety

(a) Relationship between truck, driver, location, environment, and so forth (if accident data permit)
(b) Effect of quality licensing on safety
(c) Feasibility of public truck parks and bans on on-street truck parking
(d) Analysis of culpability in truck-involved accidents
(e) Effects of enforcement (loads, speeds, maintenance, etc.) on accidents
(f) Truck braking (especially LCVs)
(g) Truck noise

A.IV Distributional Effects

(a) Effect of transport system efficiency on level and location of economic activity in a city or region
(b) Effects of freight subsidy, deregulation, etc. on viability and social structure of country towns

A.V Road Freight Cost Recovery

(a) Technical and constitutional feasibility of introducing an NZ-type road user charges system
(b) Equity in road taxes between passenger and freight
(c) Development of an efficient, equitable method of collecting road user changes from trucks
(d) Deterioration of roads under load and overload
(e) Determination of "correct" level of charges for trucks
(f) Technology of road pricing for trucks
(g) *"Audit" of literature and studies on cost recovery
(h) "Social" cost component in roads expenditure

A.VI Energy

(a) Dissemination of energy research results to truck operators, in the form of guidelines, etc.
(b) Contingency planning against sudden energy shortfall
(c) Fuel economy performance of large combination vehicles

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Conducting Truck Routing Studies from a New Perspective

ROBERT E. STAMMER, Jr., CHARLES A. WRIGHT, and JOHN M. DONALDSON

ABSTRACT

The era in which transportation professionals could merely conduct analyses of truck traffic volumes, their associated impacts, and routing strategies no longer exists. A much broader and interactive transportation system management approach must be employed, along with innovative analytical procedures and carefully considered recommendations to be compatible with unique situations in each area. Documentation of a recent study of this type that was conducted in Nashville, Tennessee, is presented. This research used visual overlay techniques, sensitivity analyses by computer modeling, and some sketch planning methods to investigate several system alternatives. From these and other analyses, a wide range of innovative recommendations was suggested. This departure from traditional thinking to meeting today's problems innovatively resulted in findings, conclusions, and recommendations that should assist other analysts faced with similar challenges. Increased use of the news media, using nonuniform traffic signs, using available traffic volume data as a surrogate for unavailable origin-destination data, reformatting existing data to increase their utility, studying the evolution of truck terminal operations, and presenting a noise prediction model that local planners can understand and use at public meetings are examples of the innovations presented.

Urban transportation planning is concerned with the safe and efficient movement of both people and goods within an urban area. Heretofore, planning efforts directed toward transporting people within Nashville and Davidson County have received far more attention than planning for the transportation of goods. This disproportionate planning emphasis on the transportation of individuals, however, is certainly not unique to metropolitan Nashville. The movement of people has traditionally received much greater attention in all urban areas throughout the nation.

Urban transportation planners, however, have long recognized basic differences between goods movement and people movement. People make decisions as to how, when, and where they go, whereas goods do not. The parameters, explanatory variables, and associated interrelationships for goods movement are unique, and analysis techniques must be different from those used in passenger transport.

A fundamental and primary reason for conducting this truck route study was to evaluate the performance of future systems, reduce accidents, improve arterial street operations, and minimize harmful environmental impacts by considering the possible designation of truck routes on Nashville and Davidson County highways and streets. Truck transportation handles the greatest tonnage of commodities into and out of Davidson County. Because of the ubiquitous nature of highways and streets, truck routing and truck terminal locations have a significant impact on the performance of these local highways and streets.

BACKGROUND INFORMATION FOR ROUTING STUDY

Nashville and Davidson County have approximately 86 mi of Interstate highways and 267 mi of principal arterials to serve approximately 500,000 county residents and thousands more from neighboring counties (personal communication from Bonnie Brothers, Tennessee Department of Transportation, January 1984).

Nashville is one of only five cities in the entire nation that can boast of having three distinct Interstate highways that both enter and depart from the city. Such a large amount of Interstate mileage is a definite asset to the mobility of metropolitan Nashvillians and to the overall economic viability of Nashville and Davidson County. However, the abundance of Interstate mileage does have some associated drawbacks.

One drawback is that the preponderance of Interstate mileage and frequent interchanges encourage motorists to use the Interstate highways for purposes for which they were not designed (i.e., local trips). This problem, however, is certainly not unique to Nashville. Another drawback is that portions of Nashville's inner loop, the Interstate segments that redistribute traffic near the central business district (CBD), have some significant design problems associated with redirecting higher speed traffic around confined turning radii.

In summary, Nashville and Davidson County have a rather extensive and ubiquitous highway system that combines considerable Interstate mileage with numerous major arterials radiating away from the CBD. Overlay these principal roadways on (a) a CBD grid network, (b) a rather equally distributed network of collectors, and (c) improvements presently being constructed or programmed to start soon, such as the 440 Parkway circumferential and the extension of Briley Parkway, and the results are a highway system that has the potential to meet most of the transportation needs of Nashville and Davidson County. Transportation system management (TSM) improvements (e.g., truck routes, improved intersection design and signalization strategies, ridesharing, curb space management improvements) are just a few of the methods being used by local and state officials to ensure that system capacities satisfy user demands to a large extent.

Turning from the topic of supply to demand, the number of interstate terminals and the number of interstate truck lines serving Davidson County is abnormally large for a city of Nashville's size. This situation is due to (a) the unusually large number of firms and terminals that haul freight exclusively between Nashville and some other city and (b) the regional collection-distribution system of which Nashville is the focus. In addition to the firms and terminals that service general commodities freight, there are approximately 30 additional specialized firms with terminals providing specialized services to Nashville. Specific examples of these items and services are steel, refrigerated goods, household moving, and gasoline (1,p.9).

The intrastate trucking operations resemble the interstate trucking operations in many ways except that they are regulated by the Tennessee Public Service Commission (TPSC) instead of the Interstate Commerce Commission (ICC) and are licensed to haul only inside the state of Tennessee. Intrastate trucking operations provide the primary regional collector-distributor system for Tennessee. Interstate trucks usually deliver local and regional goods at the regional center, in this case Nashville, and smaller intrastate trucks disperse the goods to their final point of termination. Intrastate trucking also provides this distribution service to rail, water, air, and pipeline operations, as requested, because these modes individually do not have adequate collection or distribution systems outside of Nashville.

RESEARCH CONSIDERATIONS

The Metropolitan Nashville Traffic and Parking Commission initiated the truck routing study to

1. Assess the need for designated truck routes,
2. Make more informed automobile-truck planning decisions, and
3. Be more aware of likely consequences resulting from their decisions.

Operational and environmental reasons for conducting a truck routing study showed that

1. Existing terminal areas were heavily congested and the subsequent movements of goods were constrained.
2. Truck volumes represented a significant portion of all interstate traffic (12 to 27 percent trucks).
3. Geometric design deficiencies resulting in congestion, capacity reduction, and safety problems along roadway segments and at intersections were exacerbated at locales where heavy truck volumes exist.
4. Posted speed limits on some roads exceeded design speeds.
5. Commodity transportation originated and terminated in areas already experiencing certain environmental problems (i.e., industrial areas).
6. New truck terminals or expansion of existing terminals, or both, must be carefully studied through proper land use planning and recognition of impacts on residential and commercial development.
7. An excessive number of truck terminals near Interstate interchanges could have significant impacts on traffic operations and land use.
8. Truck traffic, by its very nature and different vehicle operating characteristics, requires special environmental considerations.

Researchers also recognized that a designated truck route system would channelize truck movements along a series of defined paths and thus limit truck access to nondesignated highways. Such a transportation system management (TSM) improvement would reduce automobile-truck traffic interaction on nondesignated highways. Secondary benefits include reductions in roadway maintenance and reconstruction costs from (a) reducing the proliferation of truck traffic on all urban roads while (b) encouraging truck traffic on those streets and roads that are most capable of structurally accommodating heavy-duty, multiaxle trucks.

Important considerations that researchers planned to review in designating truck routes involved the problems of (a) defining the beginning and ending terminals of designated routes (i.e., route access and egress) and (b) evaluating how a somewhat skeletal routing system would affect the economic costs of truck operations (1,p.3).

After these and several other factors were considered, the researchers stated (1) that the primary goal of the study was

> to investigate the feasibility of truck routes for Nashville-Davidson County which will meet the needs of local and through trucks, the general motoring public, and local residents.

RESEARCH RESULTS

During the course of the Nashville truck routing study, Vanderbilt University researchers used a variety of research techniques and discovered certain findings that should be helpful to others who might conduct truck routing analyses. These techniques and findings are reviewed in the following sections of this paper.

The last major analysis and classification of Nashville's truck terminals was performed in 1977. The 1983 research data showed that Nashville and Davidson County had added 84 new terminals and thus experienced a 70.6 percent (from 119 to 203) increase in truck terminals during this 7-year period (1,p.14). This percentage was initially thought to be much higher until careful investigative analyses were performed. When the 1983 data were compared to similar 1977 truck terminal information, an interesting phenomenon was discovered. An original estimate of 110 to 115 new terminals was reduced to the final 84 when it was discovered that what initially appeared to be new terminal operations were often merely variations or outgrowths of earlier 1977 operations. Even though names and often terminal addresses in telephone directories had changed, many 1983 terminal operations were not really "new operations" in the strictest sense.

Researchers discovered that a rather natural evolution was occurring among these terminal operations. The steps might be defined as

1. Creation,
2. Growth and expansion, and
3. Internal reorganization.

The majority of the trackable terminal operations from 1976 to 1983 demonstrated growth and expansion characteristics, followed by a tendency to combine with others to form an even larger operation. Sometimes these combination-expansions resembled partnerships, and others were complete buyouts or takeovers. The combination phase was often followed by internal reorganization leading to further growth or perhaps additional subdividing. Many companies that appeared to disappear were merely restructured organizationally with possibly a new name and central headquarters or mailing address, but little change actually occurred in their original operation.

Many truck routing studies face the problem of obtaining reliable truck origin-destination data for use in the traditional transportation forecasting models. Nashville was no exception because reliable truck origin-destination data were not available and would have been extremely costly to obtain. The data that were available consisted of

1. Comprehensive origin-destination travel data (circa 1959) well into its third decade of existence,
2. Aging truck travel forecasts from earlier studies, and
3. Almost yearly traffic volume counts.

The first reactions were that the earlier origin-destination (O-D) information and travel forecasts were too antiquated to be reliable and total traffic volumes, although current, were of little value. After further investigations and analyses, however, a rather innovative solution to developing more useful and current truck trip ends was improvised.

This process of generating updated truck trip ends began by multiplying recent Nashville vehicle classification counts per route by 1982 volume counts, which were the most currently available traffic data, to obtain realistic truck traffic volumes by route. The process continued by updating the 1959 land use data to reflect current land use, investigating the number of truck trip ends produced or attracted per zone for the earlier O-D data, determining the subsequent increases in truck traffic volumes, equating increases in truck traffic to required increases in truck trip ends, and then proportioning the additional truck trip ends among various zonal centroids and external stations using the earlier accumulated knowledge and data for guidance.

The entire process of developing updated truck trip-end projections (i.e., zonal truck productions and attractions) could be viewed as a backward modeling process whereby current, existing truck volumes were used in conjunction with earlier travel forecasts and O-D data to develop reasonable current truck trip-end projections. The resulting trip-end projections were then rechecked against existing land use data for reasonableness. The entire process required several iterations but the resulting truck productions and attractions proved useful in subsequent modeling procedures described later in this paper.

During the data collection phase of this research, three other types of data proved to be noteworthy and will be highlighted. The first set of data consisted of merely reformatting and alphabetizing the results of the combined vehicle classification counts and 1982 traffic volume counts. The result was a summary report in the study that has allowed researchers and local planners to almost instantaneously find the typical daily truck volumes by vehicle type that can be expected on Nashville's roads and streets. An analyst merely identifies the road of interest (e.g., Charlotte Avenue), turns to the alphabetical listing, finds the roadway segment or nearest approximate location, and then reads daily truck volumes and percentages for the three categories of single unit, multiple unit, or total trucks. This simple data reformatting process has proven extremely useful.

A second data set that resulted from this research was a summary of the vertical height restrictions along Nashville's streets and highways. Computer printouts of Tennessee's Roadway Information Management System (TRIMS) were analyzed and vertical height restrictions summarized in the following three increments: (a) 14 ft, (b) 14 to 15 ft, and (c) 15 to 16 ft. These data were compiled for use in eventual truck routing designations. Designating a truck route and then realizing later that it has a vertical height restriction is of little value to anyone.

The third, but perhaps the most useful, result of this research was the discovery of a simplified noise prediction model. Local planners are frequently questioned by local citizens about the changes in noise levels that will be likely to occur as a result of new or revised highway developments, land use changes, truck routings, construction projects, and numerous other activities. Until now, Nashville planners have not been able to satisfactorily answer these questions in a quantitative, yet inexpensive, fashion. Detailed computer modeling procedures are available but are usually not economically justifiable.

During this research, a simplified noise prediction method (2) was discovered. The method greatly simplifies complex mathematical Federal Highway Administration noise prediction models into understandable and easily usable nomographs. Using the nomographs with realistic input assumptions gives local planners a formalized analytical process whereby they can be more responsive to citizen concerns.

RESEARCH ANALYSIS TECHNIQUES

Three primary research techniques using overlays, sensitivity analyses, and sketch planning techniques were used in Nashville's truck routing study. Although these three techniques are not new and have been used before in various capacities, the manner in which they were used in this research should assist other researchers currently performing, or about to perform, additional truck routing studies.

The overlay process was used to identify existing problem areas where further truck traffic could be detrimental. The researchers' original intentions were to identify truck-sensitive areas and then avoid assigning truck routes through these areas, if possible. If truck routes had to include travel through these sensitive areas, special considerations would be studied.

Base maps of Nashville and Davidson County were prepared. Researchers determined that three particularly pertinent sets of data would be displayed on clear transparencies and then overlayed on one another to reveal the "darkened" or truck-sensitive areas. The three types of data selected were

1. Truck terminal locations,
2. Recognized areas of existing traffic congestion, and
3. High truck-automobile accident locations.

Residential, hospital, and school zone data were also compiled but could not be directly integrated into the final overlay process because their numerous, widespread locations negated the overlay technique. In other words, the entire study area was darkened because of the multiple and diverse location of schools, hospitals, and residential areas. Therefore this information was removed from the overlaying process, but would temper route-by-route decisions later.

The original overlay technique citing truck accidents, traffic congestion, and truck terminal locations revealed that there were seven truck-sensitive areas in Nashville. The overlay technique also dramatically revealed that researchers would have a difficult, if not impossible, task of avoiding all sensitive locations when designating specific truck routes. It is important to note that avoiding existing terminal locations when defining truck routes is not always desirable. Expanding existing terminal areas further instead of creating additional terminal areas may often be the most prudent strategy. Selection of truck terminal locations as one of the three criteria for transparency analyses does not preclude an expansion recommendation; it was merely intended to identify truck-sensitive areas.

Sketch planning techniques of combining Nashville's 248 traffic analysis zones into a more manageable number and use of general routes, instead of specific facilities, were coded into computer networks. Typically, four to seven original traffic analysis zones of similar homogeneous land use characteristics were aggregated to reduce the 248 zones to fewer than 50 zones for each network analysis. To avoid tedious coding of every individual road, comparable parallel roads within close proximity of each other were coded as a single facility.

The downtown street network and the Interstate networks were then tested using the earlier developed truck trip-end data, a gravity model with friction factors changed only slightly from those used in the initial trip distribution process, and an equilibrium assignment model. A model was considered to be "calibrated" when the trip assignments to each existing network link varied no more than ±10 percent from calculated existing truck traffic volumes and the total trip assignments for all links were within ±5 percent of the total estimated truck ground counts for the entire network.

When the sketch planning methodologies had been made final and an existing network assignment had been calibrated, sensitivity analyses testing various operating scenarios were performed on both the Interstate and downtown networks.

For example, Interstate sensitivity analyses were performed by assigning the same truck traffic volumes to different Interstate networks. The Interstate networks differed in the consideration of future major circumferential improvements and in the inclusion or relaxation of operating restrictions due to existing height restrictions on particular Interstate links. The resulting truck traffic volumes for each network assignment were then compared to each other on a link-by-link basis to evaluate the impacts of certain facility improvements and operational height restrictions. These sensitivity analyses resulted in truck traffic routings that were explainable and inherently logical and dramatically showed that completion of the 440 Parkway in approximately 2 years would greatly relieve Nashville's inner loop congestion and many associated problems.

Similarly, sensitivity analyses of truck traffic assignments to downtown street networks were performed. The researchers initially began performing downtown truck traffic assignments by increasing travel times on a few links per computer run to assess the impacts of these restrictions on truck travel patterns and the resulting changes in truck volumes assigned to parallel streets. It became quickly apparent that this rather arbitrary and piecemeal focusing on individual east-west or north-south streets was of questionable value in comparing the results from different networks and that the combinations needed would be almost endless. Nashville's rather symmetrical north-south and east-west grid network of downtown streets allowed the researchers to pursue a different approach.

The researchers decided to constrain all east-west travel or all north-south travel simultaneously in two separate truck traffic assignments. The constraining of truck traffic in the east-west or north-south directions was accomplished by reducing link travel speeds in the constrained directions to 5 mph and increasing travel distances per link approximately tenfold or 1000 percent. Thus a downtown travel link that originally had a travel speed between 15 and 25 mph was reduced to a 5-mph travel speed and an original link distance of 0.1 to 0.2 mi became 1 to 2 mi in the constrained network.

These directional sensitivity analyses revealed the propensity of individual streets in the unconstrained directions to gain or lose truck trips. This information provided valuable insights into a street's proclivity for accommodating truck traffic. Table 1 gives the results of these analyses. The north-south streets displayed much smaller resulting delays when east-west streets were constrained and north-south truck volumes increased. Thus most north-south streets should be considered more appropriate candidates for designated truck routes, when possible.

TABLE 1 Directional Sensitivity Analysis of Downtown Truck Routes

Street	Percentage Change[a] in Travel Propensity
North-South Travel Constrained[b,c]—Resulting East-West Assignments	
Jefferson	+18
James Robertson Parkway	−45.8
Charlotte	+3.8
Church	+54.6
Broadway	+28.7
Demombreum	−62.5
East-West Travel Constrained[b,e]—Resulting North-South Assignments	
Thirteenth	+32.7
Twelfth	−9.0
Eighth	+9.6
Hermitage	+9.4
First	+29.0

[a]Change is in terms of the "unconstrained, calibrated" base truck volume assignments by link.
[b]"Constrained" constitutes a reduction of link travel speeds to 5 mph and approximate travel distance increases of 1000 percent for links in the indicated constrained directions.
[c]Increase[d] in vehicle-miles of travel (VMT) = +10,157 vehicle-miles, increase[d] in travel times = +631,803 min., total VMT = 38,096 vehicle-miles, and total travel time = 2.37×10^6 min.
[d]Each "increase" is from a comparison with similar statistics from the original "unconstrained, calibrated" base truck volume assignments.
[e]Increase[d] in vehicle miles of travel (VMT) = +3,670 vehicle-miles, increase[d] in travel times = +226,270 min., total VMT = 33,373 vehicle-miles, and total travel time = 2.07×10^6 min.

Overall, the overlay, sensitivity analysis, and sketch planning techniques were useful and informative. They were also quite cost-effective in developing final recommendations.

RESEARCH RECOMMENDATIONS

As a result of field investigations, data analyses, and the modeling procedures previously described, this research resulted in several rather unconventional or perhaps surprising recommendations.

The first recommendation (1,p.57) prescribed truck prohibitions instead of truck routings:

> Because of the economical and temporal hardships a skeletonal truck routing system would impose on the trucking industry, improved system facilities that will open in the near future, and the scarcity of comparable parallel facilities; designating an entire system of truck routes for general trucking operations is not recommended at this time.

Requirements associated with this first recommendation include

1. Evaluating the impacts (hopefully improved truck-automobile operations) as new and improved highway facilities are implemented,
2. Improving the current operating conditions in the seven identified sensitive areas,
3. Restricting trucks from selected areas where their presence is not critical to their continued operational stability but where their operation could definitely be detrimental to the existing quality of life, and
4. Investigating the feasibility of designating specific truck routes for hazardous materials transport because these movements have more defined origins and destinations.

The remaining study recommendations more specifically addressed these four requirements. For example, the other recommendations identified various types of improvements, specific locales, and actual Nashville locations where prohibiting trucks might be appropriate.

Specifically, the second recommendation adopted a transportation system management philosophy that improvements to the seven identified sensitive areas were better than merely diverting traffic away from these areas. These site-specific recommendations involved improvement such as adding left-turn lanes, removing utility poles restricting right turns, constructing raised medians, and improving signalization along with simple improvements such as merely repainting intersection stoplines and other line restriping.

Recommendation 3 identified the fact that posted speeds on portions of Nashville's inner loop sometimes exceed design speeds and should be reduced. The fourth recommendation cited specific locations where better upstream signing was needed.

Recommendation 5 adopted the innovative approach of suggesting that nonstandard speed limit signs be adopted in addition to conventional standard ones. Only a few nonstandard signs were deemed appropriate at specific design-deficient inner loop locations. The basic rationale for this recommendation was that these "different" signs would better inform and possibly cause truck drivers and other motorists to reduce their speeds to safer levels as a result of the increased "shock effect" of these nonstandard signs. Limited use of such signs should maintain this shock effect, and having duplicative information on both uniform and noncompliance signs appears to be the most prudent action from a legal liability viewpoint.

Other study recommendations urged that

1. Truck traffic on north-south downtown streets was more appropriate than east-west traffic.
2. Public officials should make better use of local media and other communication techniques to fully inform the public of increased police efforts to ticket speeding and traffic signal violators, and
3. A specific study to investigate the movement of hazardous materials was needed.

EVALUATION OF RESEARCH RESULTS

Although the recommendations of this recent research are still being reviewed, general review comments have been favorable. Some intersection improvements have already occurred. Local officials concurred with the recommendation not to designate specific truck routes, and some of the resulting data and analyses generated from this research have been of immediate benefit to local transportation professionals and other public officials. The researchers fully intend, and expect, that implementation of the study recommendations will be instituted in conjunction with input and guidance from trucking industry representatives.

By looking beyond traditional analysis techniques and typical recommendations, it is hoped that sharing the lessons learned and the techniques used in this research will foster further innovativeness in forthcoming truck routing studies.

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Decision Support System for Trucking Break-Bulk Operations

MADISON M. DAILY, CHARLES DARE, and YILDIRIM OMURTAG

ABSTRACT

Motor carriers have had to make profound changes in their method of operations with the advent of deregulation. Before deregulation, operating inefficiencies could be passed on to the consumer through negotiated rate hikes with the Interstate Commerce Commission. However, in today's competitive environment improvements in productivity are a necessity. A survey of the needs of the industry was conducted and it was determined that one such improvement would be the use of a decision support system (DSS) in the day-to-day operational planning of a motor carrier break-bulk. A break-bulk facility is for the consolidation of less-than-truckload freight. A DSS was designed and developed in conjunction with a large motor carrier. The DSS was designed to use a personal computer at the break-bulk operation in conjunction with a data base maintained at a remote main frame. The data base consists of a file of labor used and productivity achieved as well as data from a tracking system. The DSS on a daily basis determines the best allocation of men, equipment, and facilities for various costs and service situations; it also determines a weekly forecast of manpower required. The DSS developed has been demonstrated at the motor carrier's facility and is to be implemented systemwide.

In July 1980 President Carter signed the Motor Carrier Act of 1980 that deregulated the trucking industry in the United States. The law provided for (a) easier entry into the industry, (b) easier access for new routes and elimination of inefficient route restriction, (c) increased pricing freedom, and (d) limits on rate bureau activities. The immediate result of this deregulation has been a scramble by common carriers for new route awards. Many large carriers picked up expanded authority. There has also been an increase in the number of carriers; for example, from 17,000 in 1979 to more than 25,000 in 1982. The new entrants were for the most part independent owner-operators who concentrated on truckload (TL) freight. The TL sector does not require capital investments in terminals, break-bulks, and sophisticated management information systems whereas the less-than-truckload (LTL) market does. As a result the existing companies saw a significant reduction in their TL share of the market. They have therefore been forced to concentrate on the LTL market where success depends primarily on two factors. First, the carrier must provide the service (fast delivery) that is required to attract and maintain customers and, second, the carrier must minimize costs. Unfortunately, the two conflict, which requires some form of trade-off.

Further compounding the problems of deregulation was the recession. In 1981 prices for TL shipments had fallen 26 percent, and LTL had fallen 15 percent by 1982. Under these circumstances there should have been a self-correcting situation in which the less-efficient carriers would have gone out of business. This was not the case, however, because of the Multi-Employer Pension Plan Amendment Act (MEPPA), which created a barrier to liquidations or mergers. MEPPA requires that a firm pay its unfunded vested share of the pension plan before going out of business. In many cases, this unfunded liability exceeded the net worth of the company; thus any liquidation was forestalled.

To survive under these conditions, increased efficiencies in operations are required. Before deregulation, inefficiencies in operations could be passed on to the consumer via negotiated rate hikes with the Interstate Commerce Commission (ICC); competition was based primarily on service rather than costs. As a result, the trucking industry has lagged far behind other industrial sectors in applying modern productivity practices. In the January 1982 TRB special committee report (1) to the TRB Executive Committee on Research Needs of the Motor Carrier Industry, productivity headed the five priority areas identified in which research was needed immediately.

The improvement of efficiencies in LTL operations is of course vital for the existing carriers, given the loss of their TL markets. Once such area that has great potential payoff for LTL operations is the break-bulk.

A break-bulk is a consolidation point for LTL freight and is part of a hub and spoke system as shown in Figure 1. Each hub acts as a consolidation point and distribution center for a specific territory. The terminals at the ends of the spokes are pickup and delivery points for specific localities. Connections between adjacent hubs are on a periodic basis. Thus a shipment of freight would be picked up at an outlying terminal and be forwarded to a break-bulk facility for consolidation with other shipments and be moved from hub to hub until the shipment reached the break-bulk facility servicing the territory of its destination. At that point it would be dispatched to the nearest terminal servicing the final destination. Efforts are made to minimize the breaking of freight at intervening hubs by consolidating shipments into TL shipments that can be forwarded directly to the final break-bulk facility or terminal. It is estimated to cost on the average $250 to consolidate one TL shipment (2).

Break-bulk facilities are characterized by being operated in a labor-intensive mode rather than being

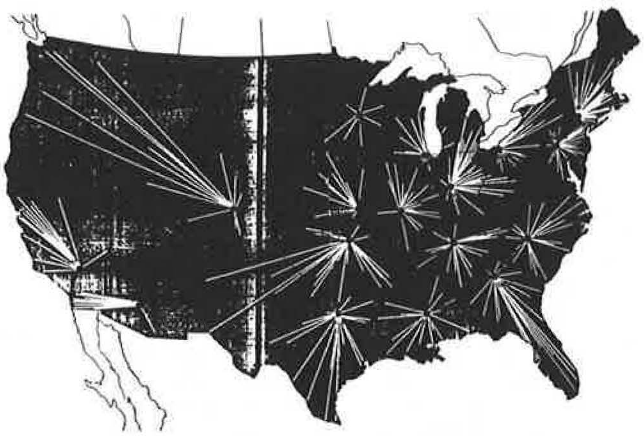

FIGURE 1 Break-bulk hub and spoke systems.

automated. This is true for two reasons: first, general freight is nonhomogeneous and, second, the labor force has not been cooperative in establishing automated systems. The labor force, which is dominated by the Teamsters Union, has some of the most stringent work rules in the American industrial sector and their average hourly wage including benefits has risen to $19 an hour. As a result, labor makes up 65 percent of the average motor carrier's operating costs.

The typical break-bulk facility is shown in Figure 2. Such a facility can have more than 150 doors for loading and unloading freight and can employ more than 50 dockhands per shift. Because service to the customer was the key competitive factor before deregulation, operations at a break-bulk facility have been such as to emphasize that factor to the detriment of efficiency. Thus, instead of trying to minimize the weight-distance through the terminal, the operations have focused on minimizing the mishandling or misrouting of freight. This has resulted in the establishment of specified doors and areas for loading and unloading and of traffic patterns that are normally across and lateral within the facility. Unloading is done on one side or area of the dock; quite often this involves the use of a dragline that then delivers the freight around the dock to the specified loading door. Unloading doors for specified locations tend to remain fixed.

The research being reported was based on apparent needs of the trucking industry with respect to increased productivity and quality of service. The study is limited to Class I general freight motor carriers.

The approach taken to accomplish the research was as follows: a literature survey was conducted to determine existing research on productivity in the transportation industry with emphasis on the motor carrier segment. It turned out that the amount of research documented in the literature was quite limited.

A written survey was conducted of the general freight motor carriers, and specific productivity needs were identified. These needs were further defined through telephone interviews and visits to several motor carriers.

From the information gained by a review of the literature, the written survey, and the visits it was concluded that a decision support system for break-bulk operations was desirable and would be developed. The decision support system would be designed and developed using the techniques and principles documented in existing literature. The rationale is then developed for the specific application of those principles to the decision support system that was created.

LITERATURE REVIEW

There are numerous articles and books concerning the economics of the trucking industry, the impact of deregulation on the industry and its customers, and operations research applications to specific transportation problems such as optimum pickup and delivery, location of fixed facilities in distribution systems, least-cost shipping patterns, and network analysis and design.

For instance, Perl (3) has an exhaustive summary of the applications of various operations research techniques to the transportation problems mentioned previously. Rakowski (4) and Muskin (5) have excellent summaries of the issues, importance, and impact of deregulation on the industry. An article by Stock (6) in 1979, which examined the role of motor carriers in forming new regulatory legislation, emphasized the necessity of using operations management methods to increase efficiency and profitability in the new deregulated environment. Barker, Sharon, and Sen (7) in a 1981 article discussed efforts to improve profitability through an understanding of factors contributing to LTL and TL costing. Decision-making rules were established for the routing of freight and trucks to replace traditional rules of

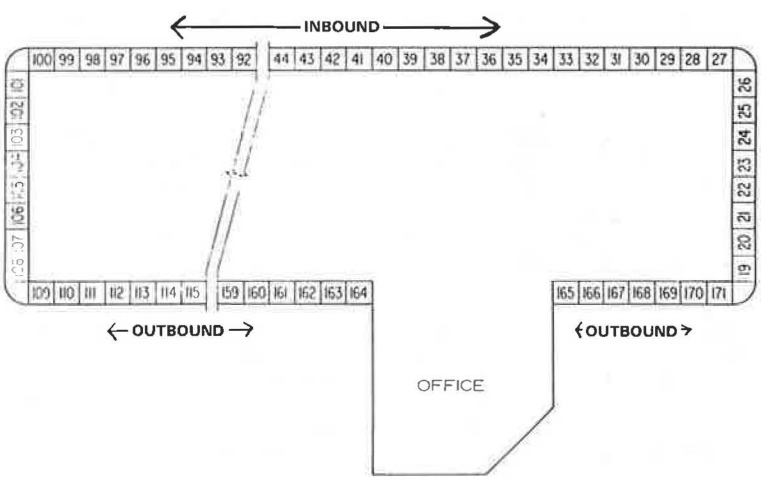

FIGURE 2 Typical break-bulk facility.

thumb for both TL and LTL shipments. A computer approach was developed and implemented with an estimated savings of $9 million annually.

Powell and Sheffi (2) in 1983 developed a heuristic approach to improving the load planning of LTL motor carriers. A trade-off of service versus costs was accomplished with the aim of gaining more direct shipments that bypass intermediate break-bulks. Starting with the existing network between terminals and break-bulks, the approach does the following: finds the best break-bulk to which an end-of-line terminal will be connected, adds links from an end-of-line to other break-bulks, and deletes links between break-bulks. One of the things noted was that the break-bulk closest to a terminal is not necessarily the best approach to linking a terminal to a break-bulk. None of the previously mentioned studies directly addressed the needs and wants of the motor carrier in day-to-day operational planning for the break-bulk facility.

Ferguson (8) came closest to a discussion of the problem in 1981 when he conducted an investigation of the use of operations management principles in the motor carrier industry. The objective was to determine the degree to which sophisticated computerized planning and control systems were used in the operations area and to determine how operations management principles were being applied in the motor carrier industry. Because of the dearth of recent academic or practitioner literature, he conducted a survey of more than 2,000 motor carriers of various sizes. He found that the larger carriers made extensive use of the computer but that the smaller carriers did not. He concluded that the area of computer applications needed to be thoroughly studied, particularly in day-to-day operational planning. He also identified the minicomputer as having potential application in the industry. (It should be noted that with the developments of the microcomputer since Ferguson's article, its impact should be studied as well.) He concluded that there was much to be done in the industry to improve operations management. Questions about the needs for forecasting, identifying facility bottlenecks, manpower allocation, "spotting" trailers in the unloading queue and at the dock to minimize the weight distance through the facility, optimum pickup and delivery, and the use of tracking systems in day-to-day planning were not addressed.

NEEDS SURVEY

To determine the needs of motor carriers with respect to improved productivity and to assess the use of operations management techniques in day-to-day LTL operations, a mail survey was conducted in April 1983. Figure 3 shows a copy of the survey form. The survey was limited to the top 141 Class I general freight carriers as listed in the American Trucking Associations' Financial and Operating Statistics (9).

There were 78 responses within 3 weeks of the mailing from 20 firms with revenues greater than $100 million and 58 firms with revenues less than $100 million as shown in Table 1. The survey revealed that more than 97 percent of the firms used computers in their operations with the primary use in the financial area, tractor and trailer control, and customer service. It also indicated the use of operations management principles in day-to-day planning. In those firms with annual revenues greater than $100 million a significant use was made of operations research in the areas of optimum routing for pickup and delivery, break-bulk operations, and forecasting workloads. Firms with less than $100 million in revenues were much more limited in their use.

The survey was limited in that it was impossible to determine how effective the firms were in their use of the techniques. To evaluate this effectiveness, eight firms were visited and numerous firms were contacted by telephone.

It was found that in most cases, although the importance of better use of operations management techniques was recognized, little was being done effectively because of a shortage of personnel with the required skills. Before deregulation most trucking firms did not even have industrial engineers or similar staff concerned with productivity improvements in their operations.

As a result of the survey, follow-up visits, and telephone interviews it was found that although many of the firms were using operations management techniques and the computer in day-to-day operations of their break-bulks, such use was at a primitive level. The largest use of the computer in break-bulk operations revolved around the use of the data in tracking systems. A tracking system provides customers with status information on their shipments. The information available in these tracking systems usually consists of the bill of lading number, the number of pieces, the weight, the final destination, the current location of the shipment in the system (on a trailer or at a facility), and the time of the next action (departure from or arrival at a facility). For the larger carrier, the system could identify the status of more than 100,000 shipments at any one time. Although this information is available to the break-bulk managers, there is no systematic use of it in a rapid manner or on a daily basis to aid in the improved allocation of manpower, equipment, and facilities.

DECISION SUPPORT SYSTEM DESIGN AND DEVELOPMENT

A decision support system (DSS) consists of a person and a computer working together in an interactive manner to arrive at a decision to a semistructured problem. The system has a model that develops alternatives allowing the person with his judgment to arrive at a more effective solution. Decision support systems are characterized by a large data base, the facility for the manipulation of that data base (the model), the importance of timeliness in arriving at a decision, and, finally a person in the loop to provide judgment in evaluating alternative solutions. The design, development, and implementation of a particular DSS is a function of the decision maker and the situation. Each must be carefully considered.

Role of Computer in Decision Support Systems

The role of the computer in the decision-making process may be described as

1. Assisting managers in their decision processes in semistructured tasks;
2. Supporting, not replacing, managerial judgment; and
3. Improving the effectiveness of decision making rather than its efficiency.

A semistructured task can be defined in terms of a structured or unstructured task. A structured task is one that can be completely defined and one for which a computer would arrive at a definitive solution; an unstructured task is one that cannot be defined analytically and the solution to which depends entirely on the judgment of an individual. Semistructured tasks are those tasks that fall in between the structured and the unstructured. Here,

SURVEY OF CLASS 1 COMMON CARRIERS OF GENERAL FREIGHT

Please complete the survey of current uses of computer aided decisions in the general freight motor carrier industry. Mail the results to Madison M. Daily, Transportation Institute, Univ of MO-Rolla, Rolla, MO 65401.

Are your annual intercity freight revenues: (check one)
- less than 10 million dollars annually ___
- greater than 10 million dollars but less than 100 million ___
- greater than 100 million dollars ___

Do you utilize automated data processing equipment: Yes___, No___.

Do you do your own software programming: Yes___, No___.

Do you use now or do you plan in the future to use the computer in day-to-day operational planning: Yes___, No___.

If yes, is it used for:	NOW	FUTURE
Financial Purposes (accounting, billing, etc.)	___	___
Electronic billing rather than mail (computer to computer)	___	___
Customer Service (status of shipments)	___	___
Direct access by your customers to shipment status information in your computer data base	___	___
Optimum routing for pickup and delivery	___	___
Routing of shipments for intercity freight (consolidate shipments to minimize breakbulk operations)	___	___
Tractor and trailer control (assign drivers, shipments and routes)	___	___
Breakbulk or terminal operations (minimize handling of shipments and queues for loading and unloading)	___	___
Forecast work load to optimize allocation of labor and equipment	___	___
Other______________________________	___	___

____

FIGURE 3 Survey form.

TABLE 1 Results of Survey

	> $100 Million		< $100 Million	
	Yes	Future	Yes	Future
Do you use ADP	100		96	
Do you do your own programming	94		95	
Use in operational planning				
Financial purposes	100		98	
Electronic billing	39	61	11	68
Customer service (shipment status)	94	6	51	42
Direct access by customers	72	22	6	66
Optimum routing (pickup and delivery)	28	55	8	66
Consolidate shipments	50	33	11	57
Tractor and trailer control	94	6	23	58
Break-bulk operations	61	28	9	62
Forecast workload	50	44	17	58

Note: All number are percentages.

although some aspects can be modeled, the problem as a whole cannot be defined in an optimum closed form.

Role of Manager in Decision Support Systems

When the output of the computerized models is combined with the judgment of an individual the combination can often lead to a more effective decision. A point should be made regarding the difference between effectiveness and efficiency in decision making. Efficiency is a quality of a task done well as determined by comparison to some predefined standard, whereas an effort's effectiveness is determined by its success in dealing with all the identified relevant criteria. The DSS under the control of the manager is used as a supportive tool to augment decision-making capability (10). Use of a DSS does not ensure more effective decisions; a manager who exhibited poor judgment would continue to make poor decisions when using a DSS although his decision-making efficiency might be increased.

Elements of a Decision Support System

Sprague and Carlson (11) describe a DSS in terms of its technological characteristics; that is, a DSS is aimed at solving a semistructured problem and requires a large data base, the manipulation of that data base by means of a model, and a system that is user friendly so that man and computer can operate in an interactive mode to evaluate alternatives. The components of the DSS are defined as the dialog subsystem that provides the interaction between the system and the user; the data subsystem that provides for the entry, storage, and retrieval of data; and the model subsystem that manipulates the data to arrive at various alternatives.

Decision Support System Development Methodology

The investigation of motor carrier needs indicated that all of the DSS elements were evident in break-bulk operations. First, the tracking system was a large data base containing all the essential information required for day-to-day effective planning, and there generally existed a historical record of manpower used and productivity achieved that could be used as a basis for forecasting. Second, there was certainly a need to manipulate that data in such a manner as to arrive at decisions that would lead to more effective use of men, equipment, and facilities. Third, timeliness was crucial in that, in order to be competitive, a firm must deliver freight with a minimum of delay; this constraint requires break-bulk personnel to unload, reload, and dispatch all inbound freight in less than 24 hr. Finally, the many variables involved, such as the daily variation in the amount of freight, the weather, the destination door loadings, and the requirements to handle hazardous and priority freight, necessitate that a person be in the loop to exercise judgment. This is an excellent example of a semistructured problem. It is one in which it is impossible to completely mathematically define an algorithm to arrive at an exact solution.

SELECTION OF A DESIGN AND IMPLEMENTATION STRATEGY

The implementation strategy selected for the design of the DSS was the evolutionary approach described by Boland (12) and Alavi and Henderson (13). That is, the user was to play an active role in the design and development.

The design and development were initiated by a meeting with the motor carrier's break-bulk managers and operation managers. At this first meeting a briefing was given about what a DSS is, what it can do, what it cannot do, and what the author hoped to accomplish. The break-bulk manager in turn presented what he thought to be his major problems. These were (a) forecasting his workload so as to be able to make an accurate weekly manpower bid, (b) a system that on a daily basis would identify where bottlenecks within the facility were going to occur, (c) the number and type of trailers required for each loading door, and (d) the number of personnel required for each shift.

At the conclusion of this meeting, it was agreed to observe the operation of the break-bulk in order to become better acquainted with the day-to-day decisions made by the break-bulk management staff. This was arranged and a day was spent observing the operations and shift managers as they carried out their various duties. Particular emphasis was placed on their decision-making processes.

Following this, the key decisions made by the break-bulk manager and his staff were to be identified and a series of questions was to be developed that needed to be answered in order to make those decisions. Based on the observations, there were two different time periods involved in the decision process. One occurred every Friday and involved the determination of the amount of manpower required for the next week. It was necessary to determine the manpower required for each shift in order to arrive at a bid. The bid was made to the local union and bound the motor carrier to guarantee the union work for at least 90 percent of the manpower bid. If the manpower required exceeded the bid, cost penalties would be applied to those hours worked beyond the bid.

The second time period occurred each morning before the start of the first shift. At this time the manager was faced with the task of determining the actual manpower that would be required for the day on the basis of the information in the tracking system about inbound freight and the freight already being unloaded at the dock. He then compared the required manpower with the bid for the day. If the required manpower fell outside the flexibility of the bid, he was then faced with the decision about a trade-off of costs versus service. The manager also needed to determine for the day how many and what type of trailers were required for the various freight destinations, the areas of congestion that might occur within the break-bulk, and how he could "spot" trailers at the dock to minimize his workload.

When this decision analysis had been done the author returned to the break-bulk where he and the management staff, using the decision analysis as a guide, arrived at the following agreed-on basis for the design of the DSS.

The key decision to be made by the break-bulk manager was how to make the best use of resources that consist of men, equipment, and facilities. The trade-off was service versus costs. The specific questions to be answered were:

1. How much manpower do I need for each shift?
2. How much manpower do I have bid?
3. How can I arrive at a good weekly bid?
4. How many and what type of trailers do I need for the various loading doors?
5. Where are my facility bottlenecks?
6. Where is my facility flexibility?
7. How can I spot my trailers in the arrival queue to minimize handling?
8. How can I assign unloading doors to minimize handling of freight?
9. Can I consolidate shipments to make a direct shipment to a final destination bypassing intermediate break-bulks?

It was also determined that because there was no local computing capability at a break-bulk the DSS would be developed on a personal computer. There are computer terminals (IBM 3278) available at the break-bulk that interact with the tracking system data base maintained at the corporate headquarters. However, these terminals are used in an edit mode only to keep the tracking system updated. The personal computer would be linked to the tracking system data via an existing communications network and the required data would be downloaded onto the personal computer storage disk as needed.

When a basis for the design had been determined, the next step was to arrive at a group of representations of what one would like to have appear on the computer CRT in either graphics or text form to answer the key questions. It was agreed that during preparation of these representations we would not be concerned with whether it would be actually possible to produce the representation on a computer but would rather concentrate on what was really required to arrive at a good decision.

This process was carried out over a period of about 2 months and was an interactive one in that the author would take sketches of the representations and have them made into finished drawings and then the managers would react to them with new or modified ideas of what would be helpful.

After the final representations, which were for the most part in graphical form, had been prepared they were taken to two other break-bulks in the motor carrier's system in order to test their applicability to the system as a whole. Again some new ideas were introduced and some modifications were incorporated, but for the most part they were minor, which indicated that the original ones were applicable system-wide. The next step was to actually develop the DSS.

SELECTION OF PERSONAL COMPUTER HARDWARE AND SOFTWARE

The first consideration was to decide which computer to use. There were several constraints to be considered. Most important, the only personal computers readily available to the research group were IBM PCs that ranged from a model with a 64K memory and one floppy disk drive to the IBM PC XT with a memory of 128K, one floppy disk drive, and a 10MB hard disk drive. Because the tracking data to be downloaded could be as much as two megabits; the historical manpower and productivity data one megabit; and the programs for the data base, model, and dialog system another megabit; the PC XT was selected. A description of the specific hardware is given in Table 2.

The next choice was that of the languages to be used. At first it was planned to use UCSD P code pascal because of its portability. Using the language would make the programs independent of the IBM PCs. However, because of the many commercial applications programs available under the IBM disk operating system (DOS 2.0) and their ease of use, the author selected DOS 2.0. Aston Tate's DBASE II was selected for the data base management system--it also has the capability of writing programs for mathematical manipulations. The slowness of the sort and file merging routines is offset by the fact that the PC is often more responsive to the user than is time sharing or batch processing on a large main frame. The graphics package chosen was Business & Professional Software, Inc.'s business graphics. This is an excellent interactive, user friendly software package. The menu-driven dialog system linked the user to the various models and was written in IBM BASICA.

The model system consisted of the routines to sort, merge, and manipulate the data. The most crucial effort was the selection and development of the forecasting technique to be used. This was because of its importance in reducing costs by limiting the cost penalties that occur when the manpower bid deviates by more than 10 percent from the required. Further complicating the forecasting task is the large random component in historical data. Simple exponential smoothing with decomposition and correction for trend was selected as the best technique for forecasting.

APPLICATION

In this section the DSS that was developed is presented. The DSS is menu driven; the user responds to the items listed. The DSS, when running a particular model, often requires an interactive response from the user. This allows the user to address "what if?" and "what was?" queries to the system.

Log-on Procedure

The first step is to enter the command "yellow" that will be followed by the logo and request for a password. Because the DSS is a management tool it should be protected by proper password identification.

Top-Level Menu

The top-level menu allows one to accomplish three different procedures. The first selection allows one to produce the forecast for the week. The forecast is done using exponential smoothing in an interactive manner. The interactive variables are the alpha parameter and the productivity. These can be varied and displayed in various combinations along with past actual and forecast data to allow the manager to use his judgment in arriving at a correct forecast.

The second selection deals with the break-bulk operations planning for the day. It determines the actual manpower required; the number and type of trailers for the various loading doors; and the doorloading for each door in terms of weight, pieces, and number of shipments and allows the manager to interactively vary costs versus the amount of freight dispatched for the day.

The third selection allows the IBM PC XT to function as an IBM 3278 terminal. This allows for the interface between the data maintained at corporate headquarters and the PC. One can also return to the DOS 2.0 operating environment if desired.

TABLE 2 Personal Computer Hardware and Software Used

Item	Vendor	Model
Hardware		
Personal computer	International Business Machines	XT (128K Memory)
Printer	International Business Machines	Dot Matrix
Plotter	Hewlett Packard	7470A
Software		
Data base system	Aston Tate	DBASE II
Graphics	Business & Professional Software, Inc.	DOS 2.0
Disk operating system	International Business Machines	2.0
Other	International Business Machines	BASICA

Forecasting Menu

The forecasting menu allows for the accomplishment of two procedures. The first procedure develops the weekly forecast through an interactive process with each day of the week forecast separately. First the alpha to use as the parameter in the exponential smoothing algorithm must be selected. Alpha would be selected on the basis of a judgment about what the current environment required. For example, in a period of rapid growth or decline, an alpha near one would be used whereas in a period of little change an alpha near zero would be used. To determine which alpha to use, one can use the second selection, the graphics mode. One can display past actual data along with the forecasts based on various alphas to determine which is appropriate.

When an alpha has been selected using the first procedure, a forecast is generated along with the average productivity achieved. The amount of past data to be averaged for the productivity is a function of the alpha and is related by the following formula:

N = (2 - alpha)/alpha

where N represents the number of past weeks to be averaged. The formula is derived from equating the mean value of the age of a moving average to the mean value of the age of the exponentially smoothed data. This value is also used to determine how far back one should go in the actuals file before starting the forecasting process. Should the manager decide that another productivity standard would be more appropriate, he can revise the forecast using those figures. When the forecast has been developed for the week it can then be compared graphically with past weekly forecasts or actuals for any week in the historical file. Again the manager can use his judgment to determine if the forecast is appropriate. This feature is useful for weeks that have holidays that create transients in the orderly movement of freight.

Representations for this procedure consist of

1. Menu;
2. Command sequence;
3. Manpower used each day of the week in 1983 overlaid with the forecast for an alpha of 0.1 and 0.9;
4. A forecast for each day of the week based on a selected alpha; the productivity achieved for this period in bills per hour per person and pounds per hour per person is also indicated;
5. Command sequence to revise forecast based on a different productivity number; and
6. A forecast based on the standard productivity of 2.8 bills per hour per person versus the actual productivity achieved.

In the graphics mode, the manager has the option of calling up a historical file of information. Past data on manpower used and productivity achieved can be displayed in various graphic formats. This information can be used to decompose the data into seasonal and cyclical patterns, to fit various curves to the data to determine trends, and to compare the current weekly forecast to past actual data for the same week of the year. The capability exists to limit the data shown to a selected portion of the data for detailed analysis. This again allows the determination of specific seasonal patterns. In addition, one can overlay the labor used with the productivity achieved for the same period; this allows one not only to see how much labor was used but also to see how efficiently it was used.

The BPS graphics package has the capability of fitting the following curves to the data: linear, second order polynomial, exponential, log, and sine. The normalized standard error that is the ratio of the deviation of the points from the curve to the data's standard deviations is determined. A zero would indicate a perfect fit and a one would indicate no fit at all.

The representations for the forecasting graphics consist of the following:

1. Command sequence;
2. Current week's forecast overlaid with the same week for the past 2 years;
3. Average weekly manpower used in 1981, 1982, and the first 39 weeks of 1983 overlaid with the best curve fit to the data; a normalized standard error is indicated;
4. Average weekly manpower used for 1983 overlaid with the best curve fit to the data;
5. A plot of the average weekly labor used in 1983 overlaid with the average weekly productivity achieved in bills per hour per person and pounds per hour per person;
6. A plot of the actual weekly labor used overlaid with the bills and pounds moved across the dock;
7. A histogram of the productivity achieved in bills per hour per person for 1981, 1982, and the first 39 weeks of 1983;
8. A side-by-side bar chart of average weekly labor used for each quarter for the years 1981, 1982, and 1983;
9. A side-by-side bar chart of average productivity achieved in each quarter of 1981, 1982, and 1983 for both bills per hour per person and pounds per hour per person;
10. A plot of the average weekly labor used for the early shift as a percentage of the total average weekly labor used; and
11. A conversion from the specific number of the week of the year to an actual date for 1981, 1982, and 1983.

BREAK-BULK OPERATIONS PLANNING MENU

The break-bulk operations planning menu allows for the following procedures.

Coding of Bills

This procedure asks the operator to enter a trailer number from those trailers in an inbound or arrival status. The procedure then takes each shipment on the trailer and assigns it to the appropriate loading door for the shipment's next destination. A printout is provided that indicates the shipment number (pro number), the pieces, the weight, the final terminal for which the shipment is destined, the door through which the shipment will be dispatched, and an indication of whether the shipment is hazardous or hot (priority). This allows dock personnel to direct each shipment to the proper door for dispatching. A second printout is also provided that summarizes the weight and pieces for the various destinations and loading doors--the summary is sorted by weight. This allows the manager to spot the trailer at an unloading door nearest to the loading door through which the largest amount of freight is to be dispatched. This procedure, which uses a heuristic approach, attempts to minimize the weight distance of the freight across the dock.

Estimate Status of Trailers Unloading at Dock

The tracking system data do not reflect the correct status of those trailers unloading at the dock. The system reflects what the trailers contained when they arrived--as soon as they are unloaded the data are purged from the system. Some motor carriers are investigating the use of bar codes similar to those used in a grocery store check-out counter to keep an accurate account of freight within terminals. Without such a system one is forced to estimate the status of the trailers in order to be able to answer the questions posed by the DSS. This is accomplished by having the manager respond to a query on the CRT for each trailer in an unloading status. As each trailer is listed, a response is solicited about the percentage of the freight that remains on the trailer. The weight and shipments for each trailer are then adjusted by this percentage.

Weight for Next Destination and Final Destination

This procedure scans all the inbound trailers and the trailers that are in an arrival status plus the updated status of those trailers at the dock and combines all of the information into a single file. It then summarizes the data by the final destination terminal or break-bulk. This allows for the determination of any direct shipments to a terminal or break-bulk bypassing any intermediate break-bulks. It does this by listing any shipment of more than 10,000 lb destined for a terminal not directly serviced by the local break-bulk. Following this the file is then summarized by those destinations normally serviced on a daily basis by the local break-bulk. This gives the door loading by weight and pieces for each unloading door. Because of CRT size limitations only 13 destinations can be printed on the screen at any one time in graphic form. With this information the manager can reassign an extra door for a destination that is overloaded by deleting a door that has little freight scheduled. It also allows him to assign extra personnel to those areas where the need for immediate assistance is indicated. The information developed by this procedure is used in the trailer and manpower procedures that follow.

Trailer Needs

This procedure takes the door loading information gathered in the weight by destination and final destination procedure and uses it to estimate the number and type of trailers required for each door. It does this by using a table of weight versus trailers required. It also estimates the weight remaining that is not sufficient to fill a trailer.

Manpower Needs

This procedure determines the personnel required for the next 24 hr. To run this procedure, one must answer the following questions as prompted on the CRT:

- What productivity figure do you wish to use? Enter bills per hour______
- How many bills do you have to unload at the beginning of the period for those trailers now unloading at the dock? Enter bills______
- How many bills do you want to have to unload at the end of the period for those trailers unloading at the dock? Enter bills______
- What is your 90 percent bid for the day? Enter number of people bid______
- What is the average regular pay? Enter pay______
- What is the average premium pay? Enter pay______

The procedure then responds with the number of personnel required and any associated unplanned productivity costs. These productivity costs are computed whenever the manpower required falls outside the range of 90 to 100 percent of the bid for the day. If the number is below 90 percent the extra productivity costs are based on the regular pay times the number of hours the excess people would work. If the number is greater than 100 percent the extra productivity costs are based on the premium pay times the number of hours worked above 100 percent. These calculations are in accordance with the current union work rules. This procedure can be run with various combinations of entries to arrive at a best figure for productivity cost. The major tradeoff is the amount of bills one has on hand at the end of the period versus the number of people required--this relates to costs versus service.

DEMONSTRATION

The software package was demonstrated using data furnished by a large motor carrier. The data consisted of all the tracking system data for one of the break-bulks for September 7, 1983. In addition, historical data consisting of the number of people used and the productivity achieved in terms of shipments per hour per person and pounds per hour per person for each shift for the years 1981, 1982, and the first three quarters of 1983 were furnished in tabular form. This information was then manually entered into the PC XT's hard disk. It was then decided to furnish the data in tabular form instead of trying to establish a real-time temporary communication link between the campus and the corporate office tracking system. After the expected minor software glitches were corrected, the DSS was found to operate quite well. The software was then taken to the motor carrier's corporate headquarters where it was placed on the hard disk of an IBM PC XT. It was then demonstrated several times to break-bulk management and various corporate staff personnel.

The demonstration used the previously furnished tracking system and historical labor used and productivity achieved data bases. The reception was quite positive. The break-bulk managers were pleased with the speed and ease of displaying decision-making information and stated that they had gained new insights into the historical data. Several new areas of potential application for the DSS were explored; for example, the use of a DSS in the day-to-day planning of maintenance operations was suggested. It was also noted that the processed information in the various break-bulk DSS data bases could be off-loaded to the corporate main frame for consolidation to provide a daily systemwide report on break-bulk effectiveness. Other improvements to the DSS were also suggested; for example, it was suggested that the condition of the weather be indicated in the historical files.

SUMMARY

The productivity gains wanted and needed by motor carriers have been identified as forecasting workloads, planning break-bulk operations, establishing sound work standards, optimum pickup and delivery of freight, and techniques for more effective consolidation of LTL freight. A DSS was developed that dealt with short-term forecasting and break-bulk operations planning. The evaluation criteria selected to determine the effectiveness of the DSS were improvements associated with decision outputs, improved cost benefits, and a change in the decision process of the break-bulk managers.

It was shown that the DSS has great potential for improving the productivity of motor carrier break-bulks. The DSS represents the application of a new technology to an area that has not traditionally used operational management principles. The great interest shown by the motor carrier industry in responding to the survey and voiced during the author's visits clearly demonstrates the new importance motor carriers have placed on increasing productivity. They have recognized that to be competitive in today's deregulated environment they must apply sound operational management principles. The motor carriers are trying to rectify their past neglect either by hiring personnel with the required expertise or by seeking the expertise from outside the industry. This presents an excellent opportunity for the academic community to fulfill a substantiated need.

The management of Yellow Freight System, Inc., has recognized the potential benefits of the DSS and plans to implement the DSS at its break-bulks. After the DSS is placed in the field and the managers gain experience in its use there will undoubtedly be many improvements suggested. Because this need for improvement was recognized, a conscious effort was made during the design to keep the system simple and flexible to facilitate rapid and easy changes.

The following specific benefits were identified during the demonstration. First, the DSS allows the manager to organize and plan his day-to-day operations to make the best use of his men, equipment, and facilities. The DSS provides information that allows the manager to pinpoint potential problem areas. With this information the manager can then take corrective action to minimize the impact of the problems. For example, if a particular loading area of the break-bulk is a potential bottleneck, he can divert his resources to that area from areas that are underused. This benefit should be confirmed through increased productivity reflected in the bills per hour or pounds per hour numbers. The DSS also allows the manager to trade off service versus costs in those instances when his manpower needs do not match his manpower bid.

The second major benefit confirmed involved forecasting workloads. By means of the graphic representations, the managers were able to gain new insights into the importance of seasonal and random variations in the historical data. The managers who for the most part do not have a formal education in management science techniques were nevertheless able to quickly grasp the fundamentals of exponential smoothing. The importance of adjusting the smoothing constant and the fittings of curves to the data to determine trends were easily understood when several examples were demonstrated for various conditions. This benefit should be confirmed through reduced costs of penalties associated with incorrect bids.

The managers expressed great interest in the productivity achieved versus labor used for the different time frames. They were able to identify problems of which they had previously been unaware. For example, when overlaying productivity achieved (both bills per hour per person and pounds per hour per person) with labor used, it was determined that while the labor was going up the productivity was going down. Because the change was occurring so slowly over time the change did not become evident until it was presented graphically. Before the DSS managers did not have an easy method of generating the graphics for analysis.

One area that has great potential for the saving of money is that of coding the bills. The bills are now manually coded; if this were done by computer, it is estimated that more than $200,000 per break-bulk could be saved annually in reduced manpower costs.

A saving of only one manyear of effort will pay for the system at a break-bulk. It is estimated to cost approximately $25,000 for two PC XT 370s, peripherals, and software that will interface with the existing communications network.

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Greater Efficiency or Predation: The CSX-ACBL Merger

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ABSTRACT

In June 1983 the CSX Corporation offered to buy Texas Gas Resources. Texas Gas was the parent company of American Commercial Barge Line (ACBL), the nation's largest barge line. If the merger proceeds to fruition, CSX will control two major railroads, Chessie and Seaboard; a major barge line; and a trucking company. Because this multimodal ownership includes both barge and rail, the acquisition raised legal questions concerning the Panama Canal Act specifically and competition generally.

Merger policy, as part of broad economic policy, should aim to maximize society's net economic surplus. In short, that means producing at lowest cost the goods and services a society demands. Actions that contribute to achieving that goal are worthwhile; those that do not are not.

Competition is frequently used as an index of whether net economic surplus is increasing or decreasing. The reason competition is an index is that under perfect competition, firms are forced to produce at lowest cost and also to price their goods at that cost. It can be argued that (a) if mergers do not harm competition or if they improve it, they should not be discouraged or (b) if mergers harm competition they must at least produce efficiency gains that lower costs enough to offset the harm done to competition. If both are true (i.e., no harm plus efficiency gains) then there will be compelling motives (from a sound public policy viewpoint) to approve a merger.

Merger opponents contend that the merger of CSX Gas Corporation and Texas Gas Resources would be predation and would lead to the demise of independent barge lines. They assert that the independents are responsible for maintaining competition in transportation and that without the independents the railroads will be able to greatly raise rates and reap monopoly profits. This, they claim, will lead to the type of rate abuses that brought Congress to pass the Panama Canal Act in the first place.

Consider one notion of how the railroads will conduct a predatory pricing campaign. John Donnelly, president of Ingram Barge Co., presented this example in The Journal of Commerce (June 27, 1983):

> Take a normal intermodal move which works out to $5 per ton for the rail portion and $3 per ton for the barge portion. With an in-house barge line the rates could change to $7 per ton for rail, and $1 per ton for barge. The transportation company would make the same amount of money, but other barge lines trying to compete with the $1 rate would go broke.

If the firm is a profit maximizer, it is already making as much as it can in each market it serves. It cannot, as the Donnelly example asserts, suddenly offset losses in one market with higher prices in some other market. In the Donnelly example the railroad should already be charging $7 for the rail movement. A firm could try to finance below cost service in one market from profits in other markets, but not from increased profits in those other markets.

Robert Bork points this principle out in his work on antitrust (1,pp. 144-145):

> An equally foolish theory holds that predation is possible for a multi-market or conglomerate firm because it can lower prices to uneconomic levels in one market and avoid the costs of predation by raising its prices elsewhere. This theory rests upon the often-exploded recoupment fallacy. The predator would already be maximizing profits in all markets and so would have no way of increasing profits elsewhere to finance predation. That statement holds, of course, whether or not the predator has a monopoly in the other markets.

Consider the two stages of a predatory pricing campaign: (a) the price war itself and (b) the "postwar" attempt to reap monopoly profits. Not only can the price war itself be expensive for the predator, but the extremely low probability of permanent victory further discourages his undertaking the campaign. Consider first the costs and then the impermanence.

The costs for the predator during price wars are of three types: first, he must set prices below cost; second, he must extend these below-cost rates to a larger market share than he had when he started; and third, his above-cost revenue--if he ever achieves it--is in the future and must be discounted to present worth (1,pp. 153-154).

If a firm is pricing below cost in order to drive its competition into bankruptcy, that is predation. If a firm is covering costs and can provide service at lower cost, that is not predation. The latter should be encouraged because it represents increased efficiency.

As to the second cost factor, expanding operations, Bork can again be cited (1,p. 149):

> Losses during a price war will be proportionately higher for the predator because he faces the necessity of expanding his output at even higher costs, while the victim not only will not expand output but has the option of reducing it and so decreasing his costs.

Hence as the would-be predator expands his market share, his losses grow.

One should add that the assets and financial strength of the competing carriers in the barge industry can be substantial. The nation's largest steel, grain, chemical, and petroleum companies own or operate a significant portion of the competing inland waterway carriers. Table 1 gives some illustrations of this. Given the financial strength of some of these barge company parents, chances of successful predation appear to be slim.

Consider conditions following a price war. The issues are ease of entry and exit for competing firms, and ultimately these can be reduced to entry alone. For a firm to enjoy monopoly profits, firms driven out plus other would-be firms must be excluded from entering and capturing these monopoly profits. Impediments to entry typically include government, unique production factors, high costs, and conditions relating to exit. None is significant in the barge industry (3,pp. 270-276).

Government procedures and regulations provide minimal barriers to entry of new firms in the waterway industry. Also the Interstate Commerce Commission (ICC) requires barge operators to file tariffs and seek approval of general rate increases only for non-bulk commodities such as newsprint and scrap iron. This traffic amounts to less than 10 percent of waterway tonnage.

Another entry barrier is presented when a firm has a unique production factor such as the tracks of a railroad, but no unique production factor like an exclusive right-of-way is required to operate a barge company. The right-of-way is provided by the federal government substantially below cost to all comers.

Capital is not a significant barrier in the barge industry either. New towboats range in price from about $500,000 for a 500-horsepower boat to more than $6 million for a 10,000-horsepower towboat. New barges range in price from about $250,000 for a standard, open hopper barge (195 x 35 ft) to about $2.5 million for a jumbo, refrigerated cylindrical tank barge. This equipment, moreover, is generally long lived and used equipment is available at prices that are far below original purchase prices.

The link between exit and entry is an important one. If it is difficult because of high or unusual costs to leave an industry, knowledgeable firms are unlikely to enter. Lengthy and complicated abandonment procedures, conditions that have long plagued the railroads, are an example. Such requirements to continue providing unprofitable service, however, do not apply to water carriers.

Liquidity of assets, also important to entry and exit decisions, is not relevant here. Notably, the barges' most unique, most valuable, and least transferable asset is the right-of-way. If traffic goes elsewhere, the waterways--in theory--cannot be moved to follow the market. Barge companies do not own such rights-of-way. Thus they cannot be caught holding high-cost, suddenly low-value assets.

For other barge assets, there is a resale market. Although it is true that prices for used equipment are presently depressed, due to reduced economic activity and the late 1970s' overinvestment in barge capacity, inherent demand for these assets will remain.

Thus none of the typical entry barriers would appear to prevent firms from immediately entering the waterway industry if a rail firm were foolish enough to wage a price war and try reaping monopoly profits.

It can be concluded that predatory pricing is a risky tactic for the predator. Economic studies of alleged cases of predation strongly suggest that predatory pricing is unlikely to occur (4).

POSSIBILITY OF EFFICIENCY GAINS

The basic savings from the CSX-ACBL merger come under the category of reduction of transaction costs. Transaction costs are the expenses a firm or individual incurs when they use markets to make exchanges. Transaction costs include several kinds of expenses: negotiating expenses involved in completing the exchange, costs of traveling to and from the marketplace, time consumed using the market (for example time spent to price shop), and expenses of communicating work or quality specifications. Ronald Coase in a seminal article pointed out that firms grow vertically, up and down the production and distribution chain, to save transaction costs: the costs of using the market to buy production inputs and services (5).

Many transaction costs saved by this merger involve the expenses of communicating work or quality specifications. Leon Moses described another kind of transaction costs this merger is designed to eliminate. These revolve around the uncertainty of equipment availability and equipment quality for intermodal movements by separate entities (6).

The problems and the attendant limitations on achieving intermodal efficiencies without joint ownership were made evident in Ben Allen's study of the Milwaukee Road-Alter Barge Company joint tariff in the late 70s (7). The tariff permitted independent grain elevators off river in Iowa to ship grain to the Gulf using a rail-barge movement. Milwaukee gathered the shipments and brought them to the river for Alter to take down to the Gulf. Although many efficiencies in equipment use were realized under

TABLE 1 Illustrations of Major Corporations with Barge Transport Operations *(2, p. 19)*

Barge Line	No. of Barges	Owner (Parent)	Parent's 1982 Sales Revenue ($)
ORCO	1,805	Eastern Gas & Fuel Associates	1,325,621,000
Valley	855	Chromally American	1,177,253,000
Ohio Barge Line/Warrior & Gulf	825	U.S. Steel Corporation	18,375,000,000
Dravo Mechling	658	Dravo Corporation	1,151,617,000
Federal	625	Houston Natural Gas Corporation	3,180,718,000
Artco	566	Archer Daniels Midland	3,712,977,000
American Electric Power	511	American Electric Power	4,179,955,000
ContiCarriers	426	Continental Grain	15,000,000,000[a]
ConAgra	325	ConAgra	1,709,599,000
Cargo Carriers, Inc.	317	Cargill	28,000,000,000[a]
TPC Transportation	302	Pillsbury	3,385,100,000
Exxon	151	Exxon Corporation	97,172,523,000
Dow Chemical	111	Dow Chemical Corporation	10,618,000,000

[a] 1981 estimate by *Fortune*.

the Milwaukee-Alter tariff, the tariff could not eliminate coordination problems.

There are three basic types of rail-barge movements, the second of which was attempted under the joint Milwaukee-Alter tariff. First and most common, the rail and barge portions of the movement are handled separately with the shipper responsible for coordinating the rail and barge transshipment, paying separate tariffs, and absorbing the car hire charges or demurrage. The second type is a joint tariff like the Milwaukee-Alter tariff. The third type would be rail-barge movements handled by one intermodal company.

In a rail-barge move paying separate tariffs, if the loaded railcars reach the river terminal and no barges are waiting for loads, the shipper pays demurrage for the cars. If the barge waits at the terminal because there are not enough loaded cars, the shipper pays demurrage for the barge. Under the Milwaukee-Alter tariff, the Milwaukee was supposed to drop off 15 loaded cars, enough to fill a barge, at the river but frequently only five or ten cars reached the river and did not fill the waiting barge; coordination clearly was a problem. The barge company absorbed the demurrage instead of the shipper; nonetheless that either party has to pay underscores the coordination problem.

It is quite possible that placing the whole movement and its costs (including delay costs) within one company would have made equipment coordination much easier. Similarly, having the movement under one corporate entity avoids splitting the underlying incentive structure. It is possible to show mathematically that whether or not joint entity equipment coordination problems are difficult (as in the Milwaukee Road-Alter Barge case), the divided incentive structure exacerbates inefficiency because of the separate pricing decisions. A single-entity operation eliminates this inefficiency.

PRICING PROBLEM

William J. Baumol (8) shows that when joint rail-barge rates are set by a consolidated entity these rates usually are lower and the output is greater than when rates are set by two separate entities. Transportation evidences important characteristics that produce this result. Suppose a movement from Point A to Point C requires two carriers and an interchange at Point B. The demand for the movement has two components: demand for transportation from A to B and demand for transportation from B to C. For transportation from A to C, the demand for each component must be equal.

Because transportation from A to C is made up of two equal components, demand for either component individually is less price sensitive or elastic than for the service as a whole. If the carrier on the A-B leg alone raises its rates 10 percent, total freight will fall less than if both carriers simultaneously raised their rates 10 percent. Assuming that scale economies are not significant over the relevant portion of demand and that coordination is weak between the two carriers, each carrier has an incentive to increase its own rates and profits from the joint profit maximizing level of rates.

A numerical example will help illustrate this phenomenon. This example is given in Table 2. Suppose the current charge for a journey from A to C is $20 per ton, and this is divided equally between two carriers, X and Y. Total traffic is initially 10 million tons. Suppose further that demand is such that a 1 percent increase in the total rate will reduce demand 3 percent, and that total cost for the movement is $70 million for each carrier for 10 million tons or $140 million total. Costs for 8.5 million tons and 7 million tons are $59.5 million and $49 million, respectively (i.e., the relationship is linear).

A comparison of lines 1 and 2 in Table 2 reveals that the carriers each lose $2 million in profits if they both raise their rates 10 percent. Consider lines 3 and 4. If one carrier can raise its rates without a corresponding increase from the other carrier, the carrier that raises its rates can increase its profits by $4 million. Note that the total profit on the move is less in this case than if each carrier charged $10 per ton; also the tonnage carried is less, and the total charge is higher (1,pp. 22-27; 3,pp. 258-259). This conclusion is not unique to the illustrative numbers.

In theory a railroad and a barge line could set and maintain a joint rate that maximized total profit. This would require that each carrier share information on cost and demand estimates. Not surprisingly, carriers are reluctant to pool such information (1,pp. 28-29). At least these two modes have not cooperated much in the past so that joint rate-making has been difficult. Consolidation could be a way to ensure joint rates that are the most efficient for the shipping public (9).

INVESTMENT CONSIDERATIONS

Consider though the implications, particularly that of less intermodal traffic, of higher rates and lower traffic levels in the long term. With lower traffic levels, intermodal capacity eventually is smaller. There is less investment in intermodal capacity and in maintenance of that capacity.

Rodney Eyster observed that prohibitions on intermodal ownership kept railroads from investing in airlines and barges. Early in this century this lack of railroad investment probably retarded growth for both modes (10,pp. 14-15; 11,p. 40). Consider the aftermath of the Panama Canal Act and the Lake Line Applications case [33 ICC 699 (1915)], which set the precedent for the separation of rail-water ownership. Inland carriage was so insignificant that the federal government was compelled to initiate its own barge operations during World War I and established the Inland Waterways Corporation in 1924.

Investment for intermodal facilities might be less than optimal because the benefits from facility improvement are generally shared among several parties: rail, barge, terminal company, and facility

TABLE 2 Numerical Example

	Rate ($/ton)			Revenue ($ millions)		Cost ($ millions)		Profit ($ millions)	
Case	X	Y	Freight Carried (millions of tons)	X	Y	X	Y	X	Y
1	10	10	10	100	100	70	70	30	30
2	11	11	7	77	77	49	49	28	28
3	11	10	8.5	93.5	85	59.5	59.5	34.0	25.5
4	10	11	8.5	85	93.5	59.5	59.5	25.5	34.0

host (i.e., local or state entity). Thus incentives to make such improvements are diffuse. Single corporate ownership could produce significantly improved or innovative facilities and operations because the incentives are more concentrated.

The CSX-ACBL application operating plan does identify new investment potential at three locations: Louisville, Philadelphia, and probably Decatur, Alabama. The Louisville facility will be improved to handle a larger rail-barge interchange of coal. CSX plans to extend the market of eastern Kentucky coal into the upper Midwest and Texas. A Philadelphia truck and rail location will be expanded because CSX intends to use it for interchanging increased chemical traffic from Texas and Louisville to the Northeast.

COORDINATION AND SCALE ECONOMIES

This merger also holds the potential for increased efficiency due to specific fleet coordination improvements and scale economies. A key potential efficiency gain in the operating plan involves loading phosphates onto ACBL barges on the Tennessee River probably at Decatur, Alabama. Currently, ACBL has to bring 12 empty barges back from the upper Tennessee River so this movement would reduce ACBL's empty backhauls. The Tennessee River terminal would also serve to interchange Canadian potash and grain (12).

The better coordination brought by the merger would allow the use of more unit trains and the saving of car time and barge time in loading and unloading. These cost reductions are estimated at $1.09 per ton for coal and more than $1.75 million annually in total (13). Similar reductions can be expected for phosphate and potash traffic.

Other efficiencies are possible from joint purchasing. In particular CSX-ACBL could save as much as $2 million annually from joint purchase of steel plates. Other joint purchase savings are possible on computer hardware and software through CSX's computer subsidiary (12,pp. 4-6).

From a customer service viewpoint, one-stop shipping can provide significant streamlining--billing, record keeping, marketing research. Monitoring shipments and dealing with loss and damage claims would also be simplified.

EFFICIENCY GAINS CAN INCREASE COMPETITION

Competition will not be harmed; moreover, efficiency gains are likely. And the public policy case for encouraging rail-barge mergers is further strengthened by the prospect that efficiency gains will spur more competition.

Under conditions of unregulated monopoly, efficiency gains generally go to the supplier in the form of increased profits. Under regulated monopolies, efficiency gains are typically shared with both the supplier and the consumers. In an industry that is already competitive, some efficiency gains might go initially to the supplier, but competition would quickly force suppliers to pass these gains on to consumers in the form of lower rates, which would spur further competition.

The low entry barriers and the highly competitive nature of the barge industry seem to preclude any harm to competition from this merger. There is every reason to believe that these same forces would cause efficiency gains--where they result--to produce further competition and add to net economic surplus.

Until the CSX-ACBL case is decided and perhaps for some time thereafter, parties will continue to debate who benefits and how from various gambits and responses possible in the intermodal transport sector. This debate is clearly constructive in that it forces continued examination and reevaluation of how public policy should shape the outcome of these activities.

In this context, one concern expressed is that a rail-barge company could unduly favor its own barge carrier, excluding other carriers. Such concern, however, appears to be unwarranted. First, the precedent for that behavior pervades the free market. Contracts, which for their duration exclude competitors, exist throughout the economy. An even closer example is shippers on the inland waterways. Cargill is not accused of br barge companies when it elects to use its own private carriage instead of some for-hire barge operator.

Consider also that the market encourages even integrated firms to behave efficiently, not to coddle inefficiency. When total costs of using a second unaffiliated carrier are lower than the costs of using the services of a merger partner, the firm has an incentive to select the low-cost carrier. Economically, total profits are not increased by selecting higher cost alternatives.

CONCLUSION

Fears that rail-barge mergers would cause predation appear unfounded. Besides the disproportionate losses a railroad would incur in a predatory pricing campaign, it would be almost impossible to maintain a monopoly on the waterways because of the ease of entry into the barge industry. There are also the potential efficiency gains from more effective coordination and organization of intermodal operations inside a multimodal transportation company. In addition, there is the possibility that any efficiency gains would spur further competition and add to net economic surplus.

In the absence of specific evidence of overriding social disadvantages, rail-barge mergers--like other mergers--should be permitted. There is no credible evidence of such disadvantages. On the contrary there is reason to hope for greater efficiency. Public policy should apply to rail-barge mergers the same standards that are applied in the nontransportation sectors of the economy. And it appears that such standards would permit the CSX-ACBL merger to take place.

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Possible Impacts of International Registration Plan on Trucking Industry and State Economy: A Case Study of Indiana

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ABSTRACT

An evaluation of possible impacts of Indiana's participation in the International Registration Plan (IRP) on resident trucking industry and state economy is presented. The IRP is a multijurisdictional compact to share interstate truck registration fees among the member states and provinces. It is important to consider the total package of user taxes in making a decision about a possible IRP entry, which may change the registration fees for resident carriers. A careful consideration of any additional tax burden on resident carriers is particularly critical for states with a large number of registered trucks such as Indiana. The bottom line for any state is that it must capture fees from out-of-state carriers more closely representative of highway use. The issue is how this can be achieved without jeopardizing the sustenance and growth of local trucking and warehousing industry.

Over the years reciprocity among the states with respect to the use of highways by out-of-state trucks has become a complicated set of arrangements. There has been a proliferation of agreements and requirements on motor carriers for registering their fleet of vehicles. Truckers and shippers point out that the system has become complex and cumbersome. This leads to time delays, increased paperwork and regulation costs, and an imbalance between jurisdiction of road use and jurisdiction of fee payment.

The International Registration Plan (IRP), initiated in 1973 and administered by the American Association of Motor Vehicle Administrators (AAMVA), is an attempt to simplify and unify interstate truck registration. Two earlier multilateral reciprocity agreements were the Multistate Agreement of 1948 and the Proration Agreement of 1956. Under IRP, carriers pay registration fees through their base jurisdiction to jurisdictions in which they travel according to the percentage of fleet miles traveled and the fee schedule operative in each jurisdiction. As of the end of 1983, 28 states and 1 province, Alberta, had joined IRP.

Mandated by the House Enrolled Act 1006 of the 103rd Indiana General Assembly, a study was undertaken to assess the consequences of Indiana's joining the IRP (1). In addition to a determination of the truck registration revenue impact for Indiana, this study also examined the possible effect of the IRP on Indiana trucking industry. Furthermore, an identification was made of the relevant issues associated with Indiana's joining IRP in the context of goals related to state economic growth. That is, what effect might an alternative truck registration policy have on Indiana's present trucking industry? Would it promote survival, health, and growth of the industry and how would that affect the economic well-being of Indiana?

A summary of the part of the study that dealt with the impact of IRP on trucking industry and state economy is presented, beginning with the recognition that the states are in competition with each other for job creation and economic growth. Major shifts in the manufacturing base of the United States, in population movements to the South, and in international competitiveness have forced many Midwestern and Northeastern states into serious problems of unemployment, disinvestment, and general economic malaise.

To counteract that trend many states have initiated economic development programs and are developing "strategic plans" whereby each attempts to capitalize on its comparative advantages. Indiana, one such state with an aggressive package of incentives for economic development, has recently released its first ever statewide strategic plan (2).

Every public policy proposal that affects the bottom line of business such as tax rates, tax abatements, loans, and regulatory fees (including vehicle registration) must be reviewed in the light of its impact on the local and statewide economy and how it changes the competitive position of a state vis-à-vis other states. Economic and social conditions change so rapidly that it is easy for a state with some competitive edge to lose it through misconceived public policies. Although Indiana's "crossroads" characteristics lend it to truck and warehousing industrial growth, tax and regulatory policies could provoke firm relocations to adjoining states.

ROLE OF TRUCKING IN INDIANA'S ECONOMY

To evaluate the role of an industry in state economy, both stability and growth of that industry need to be considered. Stability refers to how much employment fluctuates with business cycles, and growth refers to the increase in number employed averaged over good and bad times.

According to a recent study (3), for the period 1970-1980, employment stability in SIC 42, Trucking and Warehousing, has been identical with that of employment in Indiana as a whole. That is, fluctuations have been no better or worse than those in the Indiana economy. Employment growth, however, has been below the average annual Indiana growth of 3 percent for the 1970-1980 period. Thus, relative to the Indiana employment growth rate, jobs in trucking and warehousing have been shrinking. The plot of Indiana employment in trucking and warehousing in Figure 1 shows the growth rate between the peaks of 1969 and 1979 as 2.45 percent. During the economic troughs between 1975 and 1982, the growth rate was 0.58 percent. Growth rates nationally were 2.36 and 1.32 percent, respectively. Such intrastate and national comparisons show Indiana's trucking and warehousing industry in a "hold" position during the past 10 to 15 years.

The trucking industry in Indiana is presently undergoing a major shake-up reflective of the industry nationally. Three significant forces are at work.

Malarial Economy

Trucking directly feels the impacts of the malarial economy of the last few years (repeated chills and

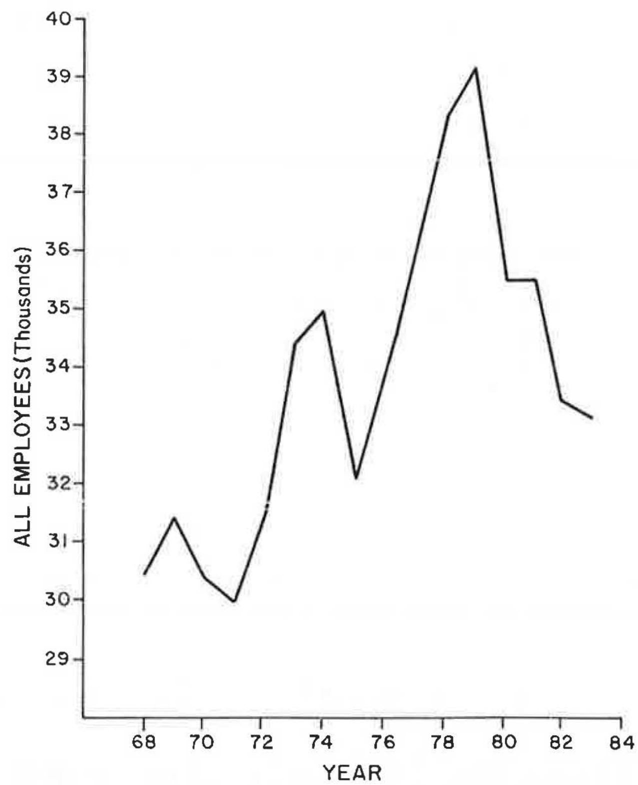

FIGURE 1 Indiana employment in trucking and warehousing from *Employment and Earnings, States and Areas,* U.S. Department of Labor, various years.

fevers). The American Trucking Association reports that in 1982 the industry experienced the worst financial results in its history. The composite operating ratio (operating expenses/operating revenues) for motor carriers stood at 98.29 in 1982 and the net after-tax margin at 0.5 percent of operating revenues (4).

Deregulation--1980 Motor Carrier Act

The aftermath of the 1980 Motor Carrier Act is causing significant adjustments and realignments in the industry. The influencing factors are ease of entry, flexibility in operation, and competitive freight rates.

Surface Transportation Assistance Act of 1982

Congress allowed truckers to increase their productivity by increasing truck size and weight and by providing for more flexible trailer configurations (double bottoms). In return, federal truck user fees are to increase considerably. New truck size, weight, and configuration provisions enhance productivity for general carriers but may not make much difference to specialty carriers (e.g., tanker, bulk grain, motor vehicle carrier).

There is an emerging consensus that these three forces will lead to major adjustments in the structure and composition of the trucking industry including growth in small new firms, exit of inefficient firms, and growth opportunities for national diversified companies. Any state interested in protecting and enhancing its resident trucking industry, as Indiana must, especially given relative employment losses during the 1970s, should carefully examine the impacts IRP entry might have on these trends, as discussed in the next section.

IRP ENTRY ISSUES

An IRP entry decision by Indiana is complicated by the following issues:

1. Base-plate state: Interstate motor carriers have some discretion over their state of base-plate registration. A trucking enterprise is potentially more mobile than most forms of business. For large firms, headquarters can be relocated at branch locations and branch locations can be relocated across state borders. For single location firms, base-state registration might be changed by merging with other firms. In short, the institution of registration compacts between states introduces a degree of elasticity into the demand for headquarter truck registrations.

2. Capturing out-of-state carrier user taxes: As a form of taxation, it is extremely difficult to design a registration system whereby there is a desirable relationship between fees and use or between jurisdictions receiving fees and jurisdictions of use. This is largely because the unit of payment of fees is not the vehicle per se but the firm that owns the vehicle. Research by Hoffer and Gallegher suggests that the effective user tax rates (in dollars per mile) is less for out-of-state carriers than for resident carriers (5).

3. Multiple user taxes: A carrier's plant location decision cannot be based solely on base-plate registration fees but must be concerned with all costs associated with a vehicle operating in a particular state. For example, the tax and regulatory costs of operating a five-axle combination 10,000 miles in Indiana for an Ohio-based carrier is about $222 (fuel tax plus $1.00 permit), whereas the cost of operating the same vehicle for the same mileage in Ohio for an Indiana-based carrier is about $443 (fuel tax, ton-mile tax, plus $1.00 permit).

Registration fees cannot be considered in isolation from the total package of user and property taxes imposed on the trucking business. At least four major groupings of taxes are of particular concern to the trucking firms in making locational and operational decisions: first-, second-, and third-structure taxes and property taxes. These are in addition to income, real property, and sales taxes common to all businesses in most states.

First-structure taxes are those on fuels and related surcharges. Second-structure taxes are motor vehicle revenues and include registration and license fees. The third group is imposed on the motor carrier and relates to level of business activity. This group includes vehicle-mile, ton-mile, axle-mile, and gross receipts taxes.

A fourth category of general taxes must be included because of its similarity to registration fees, namely business personal property taxes. Both are levied against the vehicle and are paid annually. Approximately one-half of the states levy a property tax on motor freight vehicles. The revenues from this tax are frequently appropriated to general rather than highway uses. However, to disregard them creates an illusory comparative advantage in a state such as Indiana that has relatively moderate registration fees but a sizable property tax, as discussed later.

4. State retaliatory action: Any reciprocity decision by Indiana must be considered in the light of how other states will respond. Retaliatory action can be taken by increasing trip permit fees in reciprocity states. The survey shows truckers in southern Indiana complaining about the high permit fees to operate in Kentucky.

INDIANA'S COMPETITION

Top 10 Trucking States

Table 1 gives the top 10 states ranked by private and commercial truck registrations. These 10 states account for 46.6 percent of all U.S. truck registrations. The heaviest concentrations of trucks are in a few border states (California, Florida, North Carolina, Texas) and in the corridor and heartland Great Lakes states (Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania).

TABLE 1 Top 10 Truck States by Registration (private and commercial) in 1981 *(6)*

State	IRP Membership Entry	1981 Truck Registration
California		3,404,991
Texas	1973	3,085,800
Florida	Expected (1983)	1,363,380
Ohio	Expected (1983)	1,274,890
Illinois	1977	1,208,221
Michigan	1983	1,081,114
North Carolina	1977	1,054,746
Pennsylvania	1982	1,018,591
Indiana		968,143
New York		925,133

IRP and Non-IRP Competition

As of the end of 1983 there were 29 members of IRP including the Province of Alberta. Six were big-10 trucking states. The majority are corridor states in the heartland, mountain, and plains regions. IRP is particularly attractive to states with relatively few registered trucks, relatively long road distances, and high truck operating costs for domiciled vehicles (of which road user tax costs are a component).

States remaining outside the IRP at the end of 1983 fall neatly into three groups, each of which has unique geographic characteristics. The first group (Group 1) belongs to New England and Mid-Atlantic regions (Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont). These states have not participated in any multilateral agreement.

The second group (Group 2) comprises Indiana and those states that primarily belong to Mid-South Atlantic regions (Georgia, Maryland, New Jersey, Ohio, South Carolina, West Virginia, and Florida). These states all use the Multistate Agreement.

The third group (Group 3) consists of four Pacific and Mountain states (California, Nevada, New Mexico, Washington). They all use the Proration Agreement.

COMPARISON OF USER TAX STRUCTURES OF THE STATES

As mentioned earlier, it is important to consider the total package of user taxes (first, second, and third structure) as well as property taxes when making comparisons across states. Table 2 gives a summary of the tax structures of the 48 contiguous states under two major groupings: IRP and non-IRP states. This has been done to highlight possible similarities and differences within and between these two groups. From this table, the following observations can be drawn:

1. Tax structure Type 1: Indiana has a tax structure common to 26 of the 48 states--a diesel fuel tax, a property tax, no major third-structure tax, and a registration fee. This tax structure predominates among non-IRP states.

2. Tax structure Type 2: The other most common structure is no property tax usually coupled with either a diesel fuel tax or a high registration fee. This type is found in about equal numbers as Type 1 among IRP states.

3. Four states have no diesel fuel tax. Three are among the IRP group. The fourth, Vermont, has an unusual structure in that it is the only state to

TABLE 2 Comparison of Tax Structure for Tractor-Trailer Combinations for the 48 Contiguous States *(7)*

	State Sales Tax on Motor Fuel[a]	Diesel Tax[b]	Property Tax[c]	Third Structure[d] (major only)	Road User Taxes[e] (ranked by attractiveness)	Registration Fee[f]	Tax Structure Type[g]
IRP States							
AL	X		X		M	m	I
AZ			X	Carrier	L	h	*cf WV
AR	X		X		M	m	I
CO			X	Mileage	L	v low	*
ID		None		Mileage	L	v low	*cf OR
IL	X				M	h	II
IA					L	h	II
KS	X		X		M	h	I
KY	X		X		M	m	I
LA					M	m	II
MI	X				H	m	II
MN					M	h	II
MS	X		X		M	h	I
MO			X		H	m	I
MT			X		M	m	I
NB			X		M	m	I
NC			X		M	m	I
ND					M	h	II
OH				Mileage	L	m	*cf NY
OK					H	m	II
OR		None		Mileage	L	v low	*cf ID
PA					L	h	II
SD					M	h	II
TN					M	h	II
TX					H	m	II
UT			X		M	l	I
VA			X		M	m	I
WI					L	v high	II
WY		None	X	Mileage	H	v low	*
Total (for 29 states)			14	6	5H 8 L		11 I 12 II
Non-IRP States							
Group 1							
CT			X		M	m	I
DE					H	l	II
ME			X		M	m	I
MA			X		M	m	I
NH			X		M	m	I
NY	X			Mileage	L	m	*cf OH
RI			X		M	l	I
VT		None			M	v high	*
Group 2							
FL					H	l	II
GA	X		X		H	m	I
IN	X		X		M	m	I
MD					H	l	II
SC			X		M	m	I
WV			X	Carrier	L	m	*cf AZ
NJ					H	m	II
Group 3							
CA	X		X		M	h	I
NV			X		M	v low	I
NM				Mileage	M	v low	*
WA			X		M	m	I
Total for 19 states			12	3	5H 2L		11 I 4 II

[a]States that have some form of add-on sales tax on motor fuel are shown with X.
[b]All states have diesel fuel tax except where shown.
[c]X indicates state has property tax.
[d]"Carrier" means motor carrier taxes or fees over $1,000. "Mileage" means mileage, axle-mile, ton-mile taxes over $1,000.
[e]This is an indication of road user tax attractiveness for intrastate operations (low, moderate, high attractiveness). Total road user taxes for an in-state vehicle are ranked: "L" refers to 10 states with lowest total road user taxes, "H" refers to states with highest, and "M" is remaining 38 states.
[f]Example for a 78,000-lb tractor-trailer: "l" is less than $500, "m" is moderate—$500 to $1,000—and "h" is high—greater than $1,000.
[g]Unusual structures are shown with *.

base its total road use revenues on a registration fee.

4. Nine states have some form of third-structure tax. Six are found in the IRP group and three in the non-IRP group. The third structure provides for some unusual tax combinations:

- Both Arizona and West Virginia have property and third-structure (motor carrier-type) taxes coupled with moderate-to-high registration fees. Colorado is similar except that the registration fee is kept low. However, all three rank low in overall road user tax attractiveness for intrastate carriers.
- Idaho and Oregon are another pair with unusual structures. Neither has a diesel fuel tax or a property tax. Both have an extremely high third-structure (mileage-type) tax and a low registration fee. Both rank low in overall road use tax attractiveness. Wyoming is similar to Idaho except that its mileage tax is much lower and a property tax is included. Overall this allows Wyoming still to have an attractive total road user tax for intrastate operators. New Mexico is another variant on the theme of high third-structure taxes and low registration fee, but diesel fuel tax is included.
- Both New York and Ohio have a high third-structure tax and moderate registration fee and diesel fuel tax leading to low overall road user tax attractiveness.

In Tables 3-6 Indiana's truck tax structure is compared with two groups of states: first-tier competition (Illinois, Michigan, Ohio, and Wisconsin) and second-tier competition (Iowa, Kentucky, Minnesota, Missouri, Pennsylvania, Tennessee, West Virginia). The comparisons are made on four different truck classes by weight and type on the basis of the data as of January 1, 1982 (7). In each case, intrastate truck operation only has been considered.

The last two columns of these tables compare a state's overall rank (lowest tax is 1) based on total road user taxes and on total road user taxes plus property taxes. For each vehicle class, Indiana's rank drops when property taxes are included. Because none of the first-tier states impose property taxes, their relative position by rank improves when property taxes are taken into account. Illinois and Michigan rank particularly strong.

Indiana's ranking based on user taxes plus property taxes is generally comparable with the leaders in the second-tier states. For lighter weight vehicles, Minnesota, Missouri, and Tennessee rank considerably better than Indiana. For heavier weight

TABLE 3 State Road User and Personal Property Taxes on a Gasoline-Powered, Three-Axle Tractor-Semitrailer Combination, 40,000 lb Gross Vehicle Weight (intrastate, contract carrier, annual 40,000 mi) *(7)*

	Property Tax	Registration Fee	Other Taxes and Fees	Carrier Taxes and Fees	Mileage or Ton-Mile Tax	Fuel Tax	Total Road User Taxes	Total Fees and Taxes	Rank of State[a]: Total Road User Taxes	Rank of State[a]: Total Fees and Taxes
Indiana	342.00	390.50				837.72	1,228.22	1,570.22	2	7
1st-tier competition										
Illinois		842.00	1.20	19.00		566.03	1,428.23	1,428.23	5	3
Michigan		460.00	1.00	60.00		830.17	1,351.17	1,351.17	3	2
Ohio		350.00		30.00	400.00	777.34	1,557.34	1,557.34	8	6
Wisconsin		628.00		80.00		981.11	1,689.11	1,689.11	10	9
2nd-tier competition										
Iowa		685.00		10.00		981.11	1,676.11	1,676.11	9	8
Kentucky	275.00	495.50				932.05	1,427.55	1,702.55	4	10
Minnesota		500.00		50.00		981.11	1,531.11	1,531.11	7	5
Missouri	225.68	308.00	1.00	25.00		528.29	862.29	1,087.97	1	1
Pennsylvania		465.00	4.00	279.52		1,120.72	1,869.24	1,869.24	11	11
Tennessee		750.75		27.50		679.23	1,457.48	1,457.48	6	4
West Virginia	271.53	318.50	3.00	1,265.05		792.44	2,378.99	2,650.52	12	12

[a]Rank 1 is lowest total.

TABLE 4 State Road User and Personal Property Taxes on a Diesel-Powered, Four-Axle Tractor-Semitrailer Combination, 60,000 lb Gross Vehicle Weight (intrastate, contract carrier, annual 60,000 mi) *(7)*

	Property Tax	Registration Fee	Other Taxes and Fees	Carrier Taxes and Fees	Mileage or Ton-Mile Tax	Fuel Tax	Total Road User Taxes	Total Fees and Taxes	Rank of State[a]: Total Road User Taxes	Rank of State[a]: Total Fees and Taxes
Indiana	480.32	515.25				1,148.30	1,663.55	2,143.87	3	4
1st-tier competition										
Illinois		1,296.00	1.20	19.00		775.87	2,092.07	2,092.07	5	3
Michigan		663.00	93.00	60.00		517.25	1,333.25	1,333.25	1	1
Ohio		496.00		30.00	900.00	1,065.54	2,491.54	2,491.54	10	10
Wisconsin		921.00		80.00		1,344.85	2,345.85	2,345.85	9	9
2nd-tier competition										
Iowa		1,210.00		10.00		1,396.58	2,616.58	2,616.58	11	11
Kentucky	357.50	609.50				1,277.61	1,887.11	2,244.61	4	6
Minnesota		848.00		50.00		1,344.85	2,242.85	2,242.85	6	5
Missouri	223.13	608.00	1.00	25.00		724.15	1,358.15	1,581.28	2	2
Pennsylvania		693.00	4.00	82.76		1,536.23	2,315.99	2,315.99	8	8
Tennessee		975.75		27.50		1,241.40	2,244.65	2,244.65	7	7
West Virginia	378.71	518.50	3.00	3,245.80		1,086.23	4,853.53	5,232.24	12	12

[a]Rank 1 is lowest total.

TABLE 5 State Road and Personal Property Taxes on Diesel-Powered, Five-Axle Tractor-Semitrailer Combination, 78,000 lb Gross Vehicle Weight (intrastate, contract carrier, annual 70,000 mi) *(7)*

	Property Tax	Registration Fee	Other Taxes and Fees	Carrier Taxes and Fees	Mileage or Ton-Mile Tax	Fuel Tax	Total Road User Taxes	Total Fees and Taxes	Rank of State[a]: Total Road User Taxes	Rank of State[a]: Total Fees and Taxes
Indiana	676.46	790.25				1,618.71	3,408.96	3,085.42	2	3
1st-tier competition										
Illinois										
Michigan		865.00	93.00	60.00		729.15	1,747.15	1,747.15	1	1
Ohio		673.50		30.00	1,400.00	1,502.05	3,605.55	3,605.55	7	7
Wisconsin		1,705.00		80.00		1,895.79	3,680.79	3,680.79	8	9
2nd-tier competition										
Iowa		1,660.00		10.00		1,968.71	3,638.71	7,638.71	9	8
Kentucky	451.00	861.50				1,801.00	2,662.50	3,113.50	3	4
Minnesota		1,272.00		50.00		1,895.79	3,217.79	3,217.79	5	5
Missouri										
Pennsylvania		1,116.00	4.00	136.16		2,165.57	3,421.73	3,421.73	6	6
Tennessee		1,300.75		27.50		1,749.96	3,078.21	3,078.21	3	2
West Virginia	450.17	698.50	3.00	4,963.03		1,531.22	7,195.75	7,645.92	10	10

[a]Rank 1 is lowest total.

TABLE 6 State Road User and Personal Property Taxes on a Diesel-Powered, Five-Axle Truck and Full Trailer Combination, 80,000 lb Gross Vehicle Weight (intrastate, contract carrier, annual 80,000 mi) *(7)*

	Property Tax	Registration Fee	Other Taxes and Fees	Carrier Taxes and Fees	Mileage or Ton-Mile Tax	Fuel Tax	Total Road User Taxes	Total Fees and Taxes	Rank of State[a]: Total Road User Taxes	Rank of State[a]: Total Fees and Taxes
Indiana	1,005.07	734.75				1,889.33	2,624.08	3,629.15	2	5
1st-tier competition										
Illinois										
Michigan		865.00	93.00	60.00		851.05	1,869.05	1,869.05	1	1
Ohio		614.85		30.00	2,000.00	1,753.16	4,398.01	4,398.01	8	8
Wisconsin		1,210.00		80.00		2,212.73	3,502.73	3,502.73	5	3
2nd-tier competition										
Iowa		1,705.00		10.00		2,297.84	4,012.84	4,012.84	7	7
Kentucky	660.00	861.50				2,102.09	2,963.59	3,623.59	3	4
Minnesota		667.00		125.00		2,212.73	3,004.73	3,004.73	4	2
Missouri										
Pennsylvania		1,152.00	4.00	136.16		2,527.62	3,819.78	3,819.78	6	6
Tennessee										
West Virginia										

[a]Rank 1 is lowest total.

trucks, Indiana ranks close to the leaders: Kentucky, Minnesota, and Tennessee.

If Indiana registration fees were increased without any reduction in property tax or any other fiscal relief, and if it were assumed that the taxes of other states did not change after 1982, Indiana's ranking among the neighboring states would drop (Table 7). However, the relative ranking of Indiana does not change significantly with a registration fee increase of 25 percent. It should be pointed out that the data used for this comparison are as of January 1982, and there may have been significant increases in taxes for some of the states.

IMPACT OF REGISTRATION ON COST OF DOING BUSINESS

In view of the preceding discussion, the results obtained from the opinion survey of Indiana-based trucking firms used in the study (1) regarding the perceived impact of an effective increase in registration fees on trucking industry can be relevant.

Operating taxes and licenses account for about 2 to 3 percent of operating revenues for trucking. Because this is a small component, how significant is the impact of a change in registration fees on business decisions? Although the amount is small, marginally it may be significant because the trucking industry is becoming highly cost competitive under deregulation as discussed earlier.

A subjective assessment of the impact of registration fees was obtained from the mail survey and is summarized in Table 8. This shows the percentage response to four alternative business decisions based on five registration fee alternatives. Major shifts in the response patterns can be observed after registration fees increase more than 10 percent. The percentage of possible business closures and relocations to other states increases considerably, whereas possible expansion of firms decreases considerably. Also worth noting is that if registration cost increased more than 10 percent, the percentage that would move to another state remains fairly steady (between 11 and 14.6 percent). It should be noted that the responses to this question are highly subjective in nature. Furthermore, they represent less than the total sample because of missing information.

REACTIONS OF INDIANA-BASED INTERSTATE CARRIERS

The open remarks and comments made by some survey respondents with respect to registration fees in

TABLE 7 Rank of Indiana Among the States Considered Under Various Registration Fee Levels[a]

Registration Fee	40,000-lb Tractor-Semi-trailer		60,000-lb Tractor-Semi-trailer		78,000-lb Tractor-Semi-trailer		80,000-lb Truck-Trailer	
	Total Road Use Taxes	Total Fees and Taxes	Total Road Use Taxes	Total Fees and Taxes	Total Road Use Taxes	Total Fees and Taxes	Total Road Use Taxes	Total Fees and Taxes
Base level	2	7	3	4	2	3	2	5
25% increase	2	7	3	7	2	5	2	5
35% increase	3	10	3	8	3	6	2	6
50% increase	3	10	4	8	3	6	3	6

Note: Rank 1 is lowest total.

[a]States include Indiana, Illinois, Michigan, Ohio, Wisconsin, Iowa, Kentucky, Minnesota, Pennsylvania, Tennessee, and West Virginia.

TABLE 8 Reported Impact of Registration Costs on Trucking Firm Decisions (N = 160)

	Registration Costs				
	Same	Increase 10%	Increase 10-25%	Increase 25-50%	Increase +50%
Phase out of business	2.6	4.7	16.5	31.2	42.1
Move to another state	0.5	1.9	11.0	14.6	12.3
Remain in Indiana at same level of operation	56.1	68.0	57.5	43.4	35.5
Remain in Indiana and expand business	40.8	25.4	15.0	10.8	10.1

general and IRP in particular provide further insight into the pros and cons of Indiana joining IRP:

Pros

1. IRP would allow Indiana-based trucks interstate operations in other states without another plate.

2. Administratively, the current system of registration is time consuming, wasteful, and confusing. IRP would improve efficiency for truckers.

3. IRP would be one step closer to a national system. Why not start a motor truck transportation program under which all state regulations are the same, all permit fees are the same, or have one fee charged per year to operate in all states? Proceeds would be divided by the federal government and distributed to the states.

4. IRP avoids retaliatory actions. It would be a great achievement if Indiana trucks did not have to pay reciprocity permits when picking up and delivering equipment in Kentucky. This cost runs about $45.00 each trip and costs construction companies a great deal of time and money.

Cons

1. Increased tax liability: If Indiana joins without rearrangement of its total tax structure, resident interstate truckers will, in general, incur greater registration fee liability, because the registration fee in most surrounding states is higher than in Indiana and because the property tax would be difficult to change.

2. Out-of-state base-plated trucks: Even with high Indiana mileages, out-of-state base-plated trucks could still be better off than resident trucking firms, because of the relatively high Indiana property tax.

CARRIERS' PREFERENCES ON INTERSTATE COMPACTS

In the mail survey, Indiana-based carriers were asked to indicate their preference among free reciprocity (such as under the Multistate Agreement), proration, and IRP. About 75 percent indicated free reciprocity, 2 percent proration, 13 percent IRP, and 10 percent had no response.

Overall, carriers in all groups, except large carriers, showed a strong preference for free reciprocity. A majority of large carriers, however, preferred IRP. Proration had little support. This might be in part because Indiana-based firms are not familiar with proration.

Preference for free reciprocity over IRP is strongest among those with smaller fleets. This is understandable. Those large firms that operate interstate and intrastate nationally would prefer the convenience, efficiency, and reduced cost of IRP. On the other hand, small firms that operate within Indiana or in one or two neighboring states would usually prefer the low Indiana registration fees offered under free reciprocity.

POSSIBLE OPTIONS FOR INDIANA

On the basis of the results of a fiscal impact analysis and subsequent discussion on tax structure and Indiana trucking industry, the following options for Indiana can be considered.

Option	Expected Impacts
Do nothing	May cause continued loss of employment and economic growth in Indiana's trucking and warehousing; shortfalls in highway revenue expected; large firms may move to nearby IRP jurisdictions such as Michigan (and Ohio if it joins IRP) to take advantage of apportionment of fees without affecting movement flexibility.
Join IRP, leave tax structure and rates alone	Increased revenues from out-of-state carriers; will increase financial burden on Indiana-based carriers somewhat; may encourage retention of some large carriers and discourage other moderate-sized ones.

Option	Expected Impacts
Join IRP, raise registration fee	Increased revenues from out-of-state traffic so as to more closely match fees with use by these carriers; somewhat increased tax burden on resident truckers both intrastate and interstate.
Join IRP, restructure total tax package	In this case the property tax on trucking would have to be altered or eliminated. Because business personal property taxes are an important source of local revenues in Indiana, and because of real property tax control, this option is not politically feasible in the foreseeable future.

CONCLUSIONS

The present system of state highway reciprocity is complex and burdensome. There are troubling inconsistencies among the permitting practices of Indiana and its neighboring reciprocity states. Indiana's entry in IRP would eliminate many of these inconsistencies. It might also improve the productivity of the trucking industry, because the trucking firms would no longer have to register separately in member states for either interstate or intrastate operations. Indiana trucking firms would also benefit through increased flexibility of routing and scheduling. Furthermore, IRP would make the enforcement of trucking laws much easier.

A fiscal impact analysis estimated that Indiana's participation in IRP under any level of registration fee will add to the cost of registration for Indiana-based truckers (1). An increase in registration fee will affect Indiana's ranking relative to other midwestern states with respect to total fees and taxes. However, if the increase is 25 percent or less, Indiana's competitive standing will not be affected to a considerable extent. Any change in truck registration fees may trigger realignments in the resident trucking industry, and some shift and relocation of individual firms may be expected. However, an increase of up to 10 percent would appear to have little impact on locational or operational decisions.

This paper illustrates the subtleties associated with a state's deliberation over IRP entry. Although joining IRP would appear to be a rational step in the direction of advancing interstate commerce and national productivity, it is fraught with nuances from each state's perspective. From Indiana's point of view the central concerns are

- Indiana's present truck tax structure is not conducive to taking full advantage of IRP entry. Indiana has a sizable business personal property tax with a low registration fee. The registration fee would be apportioned under IRP, but not the property tax. For those states with a similar truck tax structure, the property tax acts as an impedance to joining IRP.
- A decision to change truck registration fee structure should be taken with the goal of improving Indiana's highway revenue as well as of positioning the state with an attractive business climate for trucking and warehousing. These two goals are partly in conflict.
- How formula variations are exercised within a bid for IRP entry will determine how well Indiana takes advantage of IRP membership. In particular, the decision to include or exclude non-IRP miles in base-mile computation could have a significant effect on the amount of revenue retained as well as on the tax burden on the Indiana-based carriers.

The bottom line for any state is that it must capture fees from out-of-state carriers more closely representative of highway use. For Indiana this can be done by raising registration fees and joining IRP. A "trucking" state must also seek to sustain and encourage its local trucking and warehousing industry. In Indiana, this could be achieved in part by revamping Indiana's property taxes on plant, machinery, and inventories, but political and fiscal barriers prevail.

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Assessment of the Geographical Accuracy of the Carload Waybill Sample for State Rail Planning

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ABSTRACT

Carload waybill statistics as collected by the Interstate Commerce Commission and the Federal Railroad Administration have been the primary data source on railroad commodity flows for more than three decades, and a considerable amount of geographic research during that time period has made use of these data. Using recently released carload waybill data at the freight station level and actual flow data for the Penn Central, Norfolk and Western, and Southern railroads, a statistical comparison of the two data sets is undertaken. On the basis of correlation coefficients the waybill sample does a good job of estimating the universe. However, an examination of the standard errors indicates values large enough to cause some concern.

It has been 30 years since Ullman (1) introduced geographers and transport planners and analysts to a set of state-to-state railroad flow data referred to as the 1 percent Carload Waybill Sample. He used the sample as his major data source in the classic American Commodity Flow (2), and in later years he was involved in efforts to improve the quality of these data (3).

Over the years these data have been used to analyze commodity flows in the United States (4), to study the demand for transportation (5), and to examine the economics of light density rail lines (6). Public sector state and national railroad planning studies have made extensive use of these data (7,8). Regional rail traffic statistics (9) and projections (10) are based primarily on data of the Waybill Sample. According to Rhodes and Briggs (11) the sample is also used by the rail industry to evaluate the effects of rate changes, to identify possible merger impacts, and to develop marketing strategies. More recently researchers have used the sample to analyze hazardous materials routing procedures (12,p.39) and to evaluate the temporal stability of certain spatial interaction flows (13,p.190; 14) and models (15,p.191). Some of these studies have used the state-to-state flows and others have worked with the individual waybill sample elements before aggregation, or aggregated in an atypical fashion (e.g., on a line basis).

In spite of this high level of usage there is little in the literature regarding these data and their level of accuracy in geographical and regional research. It is the purpose of this paper to remedy this shortcoming. To this end, in the paper that follows the historical background of the 1 percent Carload Waybill Sample and the attributes of the data obtained are discussed. This is followed by some statistical checks of the accuracy of these data. Before proceeding, some comments on the nature of the waybills are merited.

A waybill is a document that accompanies a rail freight shipment from origin to destination and specifies: originating railroad, originating station (FSAC and SPLC), terminating railroad, terminating station (FSAC and SPLC), waybill number and date, commodity (STCC), freight charges, billing weight, short lines miles, and number of carloads. The waybill may also specify up to eight interchanges and bridge lines used in shipping the commodity. Although additional information is provided (16), these elements are the ones of interest to most researchers. As the list implies, most of the data are coded with freight stations identified by their freight station accounting code (FSAC) and standard point location code (SPLC) and commodities represented by their standard transportation commodity classification (STCC) code.

BACKGROUND OF THE SAMPLE

It should be evident that such a waybill would be useful for many types of transportation research. This has been recognized since the early years of this century when waybills were compiled on an irregular basis to identify the volume of traffic moving between different points or the total volume of a given commodity type that was being carried. Such compilations involved the universe of information and there were no problems of sampling.

According to Smith (17) the first national sample of these data was collected in 1932 by the Federal Coordinator of Transportation. It covered all terminations on a single day in 1932 and it was recognized that such a sample had considerable bias and, as a result, it was used little. Smith also noted that the Board of Investigation and Research undertook the collection of a national sample of waybills in 1939. That sample involved all traffic terminating on one day of each month for all Class I railroads. Because of the staggering of days in the sample, it represented a significant improvement over the previous sampling effort.

It was in 1946 that the Interstate Commerce Commission (ICC) began work on the sampling design of a national waybill sample. After considerable debate and discussion the ICC decided that the sample would consist of all waybills ending in "01." It was believed that this would yield an unbiased 1 percent sample of total carload rail shipments in the United States.

The sample and sampling design have been altered over the years since it was first collected [ICC order issued September 6, 1946 (11,p.235)]. Through

1966 the sample was collected and published annually by the ICC. Due to budgetary problems there was no sample collected in 1969. In 1970 the Federal Railroad Administration of the U.S. Department of Transportation took over the processing of the sample although the data were still collected by the ICC. Due to these changes the data are referred to as the ICC Waybill Sample, the FRA Waybill Sample, or the DOT Waybill Sample. Regardless of the titles, all references are to the same sample data.

For several years the data collected were published by the ICC in their State to State Distribution series. This series gave the carloads and tonnages of nearly three dozen commodity groups moving between the states of the United States. Beginning in September 1971 the U.S. Department of Transportation took over the publishing function with the appearance of waybill statistics for the year 1969 (18). They continued this practice until 1972. Due to a low level of demand the U.S. DOT ceased publishing the data, but they remained available in computer printout form and this continues to be the case. It should be noted that the bulk of the research undertaken to date has involved the use of these state-to-state flows.

Although the individual elements of the 1 percent sample, that is the sample waybills, were not available to planners and researchers in that disaggregated form in the past, this policy was altered in 1982. At that time the ICC ordered that individual waybills (as stored on computer) for current and previous years could be made available to states and railroads for planning and analysis purpose (19).

ACCURACY OF THE SAMPLE

Despite the broad use of waybill data, there has not been a large volume of research done on their accuracy. As the agency charged with ensuring the quality of the data, the FRA requires each rail carrier to submit a sample tape for one quarter of the year. Information that is given on the tape is compared with the carrier's Quarterly Commodity Statistics (QCS) report filed for that same quarter. This latter report gives the total carloads terminated on the railroad's lines for each carload commodity class. If the sample information, expanded to represent the QCS universe, falls within an acceptable confidence interval as identified by FRA, the sample is deemed complete.

Whether or not the data submitted on the waybills is correct is checked by the ICC. That agency may require hard copies of the waybills to check against data submitted on computer tape. Neither this check nor the QCS check necessarily ensures the geographical accuracy of the waybill sample.

This shortcoming was recognized by Harris (20) in research that he undertook before examining the cost savings of rail line abandonment in the United States (6). In his preliminary research Harris sought to examine statistical aspects of the waybill sample because it was to be the data source for his subsequent research. He wanted to identify whether the waybill data were biased based on the size of station, or biased based on line traffic density. In addition he wanted to know whether the waybill sample could reliably predict actual carloadings originating and terminating on a line.

Using FRA-supplied waybill data from the sample for 1973, 1974, and 1975, as well as actual data for those years supplied by the Southern Pacific Transportation Company for their rail operations, Harris examined his research questions using a series of statistical tests. On the basis of this research he concluded that there is no significant bias in the waybill sampling distribution by size of station; there was a slight bias in the waybill sampling distribution by size of line segment (i.e., there was a significant undersampling of traffic originating on high-density lines and an oversampling of low-density lines); errors of prediction were large for individual lines having few observations in the waybill sample; aggregation to increase total traffic on lines or to increase the size of the line resulted in error levels of about 20 percent; and pooling of traffic for several years increases the accuracy of the line estimates (20,pp.42-43). Aside from Harris's work on the accuracy of the waybill when aggregated to rail lines, there does not appear to be any research in this area.

From a geographical perspective it is possible to work with waybill data on a station basis. This is a type of minimal aggregation level that usually represents the traffic of several rail users (shippers and receivers). It is the finest level of detail for which this type of data is available, and it is at this level that the data were evaluated for accuracy.

It would also be of interest to evaluate the accuracy of the waybill data when they are aggregated to the state level because a significant amount of research has been undertaken using the state-to-state rail flows. However, this would be extremely difficult because railroads do not usually keep data on a state basis. In addition, most states are usually served by several railroads. As a result one would have to set up a "universe" of data aggregated by states in order to have something to compare with the state-level waybill data. This is hardly practical.

At the highest level of aggregation the national rail data compiled by the Association of American Railroads (21) may be compared with the waybill data from the sample that has been aggregated to the national level. Comparing the carloads and tonnages of these two data sets results in the data given in Table 1. During the period from 1972 to 1981 the expanded sample data for carloads were consistently less than the universe. The same was true of tonnage information. One possible reason for the observed differences is that the waybill data exclude originated traffic from Mexico or Canada. It is unlikely that such international rail trade would account for from 1.6 to 4.9 million carloads or from 90 to 276 million tons of traffic per year during the 1972 to 1981 time period. Although there are other reasons for the difference according to the U.S. Department of Transportation (22), the fact that the difference is so small in 1982 (see Table 1) suggests that the previous differences were due to error. That the level of difference between the data sets is decreasing for recent years, and particularly for 1982, does not necessarily mean that the error is decreasing. It may simply mean that the traffic of certain railroads may have been oversampled. In effect, the observed differences in the data imply the existence of error, but perfect agreement would not necessarily mean an absence of such error.

DATA USED

One of the major barriers to assessing the accuracy of the waybill sample data in the past has been the unavailability of data on actual rail operations that were comparable to some aggregation level of the waybill sample. Although such data are available to the rail industry and federal agencies and such analyses may have been undertaken by corporate and governmental planners, the results of such analyses, if they were undertaken, have not been made public.

Release of the sample data at the individual way-

TABLE 1 Comparison of National "Universe" and Expanded Waybill Sample[a]

Year	Carloads	Sample Carloads	Tonnage	Sample Tonnage
1972	26.1	22.8	1,448	1,296
1973	27.3	23.3	1,532	1,340
1974	26.2	21.3	1,531	1,255
1975	23.2	19.2	1,395	1,177
1976	23.5	20.3	1,407	1,255
1977	23.2	20.1	1,395	1,248
1978	23.4	21.0	1,390	1,320
1979	23.9	22.0	1,502	1,412
1980	22.6	20.7	1,492	1,402
1981	21.6	20.0	1,453	1,363
1982	18.5	18.4	1,269	1,271

Note: Actual carload data are from the Association of American Railroads; sample carloads were compiled by the authors from printouts of the state-to-state flows. Data for 1982 were supplied by the ICC.

[a]Carloads and tonnages are in millions.

bill level by the Interstate Commerce Commission (19) provided waybill data from the sample. "Universe" data on rail operations were drawn from state-level rail planning studies (23,7) in Indiana. The first planning study provided data on all Penn Central Railroad operations in Indiana for 1973. Those data consisted of information on tonnages, commodities, and revenues for every carload of traffic originating or terminating at stations within the state. The 1982 study provided selected data for stations of the Norfolk and Western Railway and the Southern Railway in Indiana for 1980 and 1981, respectively.

RESEARCH DESIGN

Using the 1973 Penn Central Railroad data and the other data sources noted, three series of statistical tests were run. The first series of tests was as follows:

1. All carloads for all Penn Central stations in Indiana were estimated using the 1 percent waybill sample carloads for those stations. Stations not in the waybill sample were read as zero carloads. There were 493 stations in this test.
2. All Penn Central stations that had equal to or greater than 100 carloads were estimated using their corresponding waybill estimate. In this test there were 195 stations.
3. All stations in the 1 percent waybill sample, which would be all stations with more than one carload (or as expanded, 100 carloads), were used to estimate their corresponding station totals in the Penn Central "universe." There were 180 stations in this test.
4. The fourth test involved all Penn Central stations with fewer than 40,000 annual carloads being estimated by their corresponding carloads from the waybill sample data.

The purpose of this fourth test was to ensure that the results of the analysis were not being biased by large stations in Indiana.

A second series of tests sought to assess the accuracy of estimating rail branch line carloads by station. For these tests four samples of 15, 30, and 45 stations were created; these were treated as branch lines. Each of the 12 samples of stations was then estimated using the corresponding station traffic levels in the waybill sample.

The third series of tests involved data from the Norfolk and Western Railway (N&W) in 1980 and the Southern Railway (SR) in 1981. As in the case of the Penn Central tests these tests involved

1. All carloads for the N&W and SR stations were estimated by the corresponding waybill sample carloads for those stations. As before, stations not in the waybill data were read as zero carloads. These tests involved 146 N&W and 39 SR stations.
2. All stations of the N&W and SR in the waybill sample, which would be all stations with more than one carload, were compared with their corresponding values in the railroad-supplied data. These tests involved 64 N&W and 23 SR stations.

One point that should be noted before proceeding is that before the collection of the 1981 data there were some major changes in the sampling design of the waybill sample. These changes were brought about by the failure of the 1 percent sample to do a reasonable job of picking up unit trains and resulted in a variable percentage sampling rate in the case of multiple-car shipments.

There is also some question about exactly how comparisons of this type should be carried out. It is obvious that the waybill sample is not statistically independent of the universe from which it was drawn. Because of this there are problems of a philosophical nature regarding statistical inference. But the present study seeks only to analyze the accuracy of the sample data and as a result it appears to be appropriate to use correlation and regression analysis to indicate the accuracy of the sample. At the same time considerable attention will be given to the regression parameters and the standard error of estimate in the comparisons that follow.

RESULTS OF THE TESTS

Table 2 gives the results of the first series of tests undertaken. Certain facts should be noted from the table. Each of the four Penn Central tests displays an amazingly accurate and consistent performance. Explained variation, as measured by the coefficient of determination (r^2), ranges from 98.35 to 99.19 percent. The intercepts (a) are near zero, and the regression coefficients (b) range from 111.987 to 115.451. In theory these latter values should be 100 because the sample is 1 percent of total carloads. As was true for Table 1 the differences there and the departure of the regression coefficients from 100 is believed to be due to the absence of certain data from the waybill sample. Finally, the standard errors (SE) are reasonably small but still large enough that they should not be ignored. As expected, this error tends to be less for the largest samples. In the best case (Test 4) the estimates derived from the regression expanded sample would tend to miss actual values by 457 carloads or less in nearly two-thirds of the estimates.

TABLE 2 Accuracy of the Waybill Sample for Estimating 1973 Penn Central Rail Traffic by Station—Summary Statistics[a]

Test	N	$\bar{Y}$	r^2	a	b	SE
1	493	1,252	0.9919	21	112.123	481
2	195	3,127	0.9914	54	111.987	759
3	180	3,369	0.9913	38	112.062	788
4	491	1,001	0.9835	−2	115.451	457

[a]Letters in the table are defined as follows: N = number of observations (stations), $\bar{Y}$ = average number of carloads per station based on railroad-supplied data, r^2 = coefficient of determination, a = intercept of the regression equation, b = regression coefficient of slope value, and SE = standard error of estimate.

The second series of experiments involved the analysis of small sample accuracy and accordingly of whether the waybill sample will yield reasonable estimates for stations along individual branch lines. Results of the 12 small sample tests are given in Table 3. As the data in the table indicate, the average traffic per station on the 12 generated lines, Y, ranged from 635 to 3,249 carloads. In all cases the results were good with the majority of r^2 values exceeding 0.990. None of the intercept (a) values differed significantly from the expected 0.0 and the regression coefficients (b) were similar to those obtained earlier and averaged about 116. The standard errors (SE) were also reasonably good and ranged from 158 to 742 carloads with an average of 351.7 carloads.

TABLE 3 Tests of Small Sample Accuracy—Summary Statistics[a]

Sample	N	$\bar{Y}$	r^2	a	b	SE
1	15	1,736	0.997	−17.933	101.602	251
2	15	1,031	0.991	8.636	127.804	186
3	15	1,157	0.978	−70.219	105.196	442
4	15	3,249	0.999	32.151	119.167	259
5	30	1,521	0.987	4.721	107.046	426
6	30	1,311	0.969	−82.060	115.447	571
7	30	635	0.988	−6.947	127.605	158
8	30	2,155	0.999	54.079	119.389	230
9	45	2,126	0.928	−134.219	123.051	742
10	45	3,019	0.998	−116.219	111.528	558
11	45	861	0.994	38.735	119.435	178
12	45	1,893	0.999	35.886	119.221	219

[a]For column heading identification see Table 2.

The third series of tests was not as promising (Table 4). These were the tests involving the 1980 and 1981 station data of the N&W and Southern Railways, respectively. In the case of the N&W these tests were not as good with coefficients of determination in the neighborhood of 92 percent and standard errors that were too large for the flows involved. Nevertheless, the (a) intercept values were reasonably close to zero and the regression coefficients in the vicinity of 106 were reasonable. The Southern tests were less conclusive with explained variation in the vicinity of 95 percent, but with standard errors in excess of 1,100 carloads in the best case and intercept and slope values that can only be described as unacceptable.

The generally poorer results of these last four tests may be attributable to a number of factors. First, the "universe" data used in these tests were not audited and as a result are not nearly of the quality of the Penn Central data. Second, there has been a considerable increase in the amount of unit

TABLE 4 Accuracy of the Waybill Sample for Estimating 1980 Norfolk and Western and 1981 Southern Rail Traffic by Station—Summary Statistics[a]

Test	N	$\bar{Y}$[b]	r^2	a	b	SE
N&W (1)	146		0.917	47.324	105.897	661
N&W (2)	64		0.919	1.591	106.509	950
Southern (1)	39		0.952	−254.598	207.049[c]	1132
Southern (2)	23		0.949	−547.493	211.752	1456

[a]For column heading identification see Table 2.
[b]The mean flow per station has been deleted to avoid disclosure of confidential shipper information.
[c]Due to changes in sampling and weighting, the 1981 Southern data are no longer a 1 percent sample but rather a weighted estimate. The actual values obtained for b were 2.07049 and 2.11752. They are presented in the table as though they were for a 1 percent sample for comparability.

train traffic. This might account for greater error levels in 1980 and 1981 in comparison to the 1973 Penn Central case. Third, as previously noted, the sampling procedure was changed before the 1981 sample and it can only be assumed that the 1980 sample was considered too poor to continue with the existing sampling design. Fourth, errors in the 1981 results may simply indicate that more work needs to be done on the current sampling methods because parameter values indicate a tendency toward undersampling. Continuing this final point it should be noted that the newer sampling procedures will not necessarily increase the quality of the data at the station level although it may do this at the state level.

CONCLUSIONS

The purpose of this paper has been to evaluate how accurate the carload waybill sample is in relation to actual carload data by station. Three series of tests were undertaken between the sample and actual flow data; a total of 20 comparisons were performed. On the basis of these comparisons and tests it may be stated that

1. The 1973 sample was good and the 1980 and 1981 samples were good (based on correlation coefficients) at estimating the actual number of carloads by station for large numbers of stations.
2. Even in the best of the large sample cases regression estimates of actual carloads yield standard errors that range from 450 to nearly 800 carloads per estimate. Although this does not completely undermine the utility of the waybill sample, it is something of which researchers and planners should be aware.
3. For small numbers of stations the results also appear to be good in terms of standard errors. This would suggest that the estimates may be good for branch line economic analysis provided the branch lines have a large volume of carloads.
4. It is not at all clear that the current sampling procedures are doing as good a job of estimating station traffic levels as former methods did. Differences observed here may be due to the sampling procedures, or to a substantive change in the character or nature of rail traffic (e.g., more multiple car moves per waybill), or to the quality of the more recent data used for the tests.

The first three conclusions suggest that the waybill sample may be used with some confidence for estimating traffic at stations within a state, estimating traffic for stations on branch lines and for the economic analysis of these, representing rail traffic at places in correlation studies, developing maps of potential rail traffic for state-size areas, and analyzing interstate rail flows for different commodities. Although this last point does not stem directly from this research, it is a reasonable inference because the aggregation of the station sample data used here can only serve to smooth out errors that may exist due to minor over- or undersampling.

Although the results of the tests described here appear to elevate the waybill sample to a much higher level of credibility, there is still the fourth conclusion that should make researchers hesitate to rest easy about the current sampling methods. Whenever possible researchers and planners should attempt to assess the accuracy of the data from the waybill sample before using it for major policy decisions of a public or corporate nature. It is apparent that a major evaluation of the current sampling procedure needs to be undertaken before analysts use it as the basis for substantial empirical work. In the interim a considerable amount of insight may be provided by the analysis of earlier waybill sample data.

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Analysis of Air Freight Transportation Associated with High Technology Manufacturing Development

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ABSTRACT

Transportation has been largely overlooked as a support infrastructure to high technology economic development. Some recent state and local initiatives and technical articles show an increased awareness of transportation's role in high technology economic development in such areas as air passenger service and air freight, proximity to freeways, and access to campuslike industrial sites and suburban housing. To date, transportation planning for high technology has been hampered by lack of specificity (e.g., what are the high technology air freight sensitive industries?). The utility of conventional definitions of high technology manufacturing is examined. With the aid of the Commodity Transportation Survey of the Census of Transportation, 1977, a list of high technology, high air freight commodities is obtained. These commodity types, at the five-digit level, prove to be useful for the study of geographic variability in air freight utilization between production areas in the United States. The list is shown to be sufficiently discriminatory to provide a starting point for local planning of air freight demand by high technology manufacturing.

The role of high technology in local, regional, and national economic development has been hotly debated in recent years. State and local governments have rushed to attract high technology growth with a multiplicity of initiatives, including research and development (R&D) tax incentives, R&D grants, publicly initiated venture capital pools, business and technical assistance, industry-university joint ventures, and state science and technology policy councils (1). In an earlier paper (2), the authors pointed out that transportation, and physical infrastructure in general, have been overlooked as tools to promote the economic development of advanced technologies. This probably stems from the misconception that high technology is a footloose industry. In fact, more recent and integrative strategies for high technology industrial development have been including transportation and land development considerations (e.g., the "technology corridor" concept in Tennessee, transportation planning for a high technology corridor by the Delaware Valley Regional Planning Commission in Pennsylvania, and the location of technology parks and foreign trade zones in the vicinity of international airports such as in Boston).

One aspect of high technology transportation requirements, that of air freight and related value- and time-sensitive modes (e.g., parcel delivery) are addressed in this paper. High technology industries present spatial and production characteristics that differ from those of traditional (heavy) industries and highlight increased demand for air passenger and air freight services, proximity to Interstates and major arterials, and access to affordable campuslike industrial sites and spacious suburban housing. Although transportation costs may not be highly significant in high technology firm location decisions, access to particular modes and levels and quantity of service appear to be (2).

The scope of the paper is further refined by focusing on high technology manufacturing. High technology industrial activity is a function of stage in the technological innovation process. Differing transportation requirements can be identified with R&D or research and evaluation (R&E) park development, commercial start-up stage, and mass production and marketing (2). Furthermore, high technology is not so much a group of end products as tools that will revolutionize all sectors of the economy. Despite this breadth of high technology industrial activity, a majority of studies focus on high technology manufacturing because census data are readily available. This paper will likewise be concerned with high technology manufacturing but will draw on a hitherto little used source of information, the Census of Transportation.

The purpose of this paper is to characterize the implications of high technology manufacturing for freight transportation patterns, particularly the greater reliance on air freight and special delivery services (e.g., courier). This calls for disaggregation of high technology commodities at the five-digit Transportation Commodity Code (TCC) level. Progress in research on high technology manufacturing is hampered by lack of clear definitions. Without improved specificity concerning particular manufacturing industries, little advance in transportation planning methods and techniques is possible.

The paper begins with a brief description of definitional and data concerns, followed by a description of the utility of high technology manufacturing definitions for air freight analysis. This leads into the generation of a list of high technology-high air freight commodities. Geographic variability in air plus parcel delivery mode share for high technology commodities is discussed in the fifth section. In conclusion, implications are drawn for transportation planning and for further research on metropolitan high technology development.

DEFINITIONAL AND DATA CONCERNS

In generic terms, "high technology" refers to those advanced products and processes emerging from recent scientific discoveries in microelectronics, electro-optics, biogenetics, and nuclear and materials science. High technology firms are those that develop new technologies, find new applications for existing advanced technologies, manufacture products incorporating advanced technology, commercially market advanced technology products, and provide services related to high technology products. The fuzziness of this definition becomes evident when one considers a "low tech" product such as a household water meter undergoing total transformation from traditional mechanical components to silicon chips. Similarly, in a "heavy" industry such as automobile manufacturing, microelectronics now control ignition, fuel injection, turbocharging, and even suspension systems. Furthermore, probably the greatest advances in high technology applications will be in the service industries via revolutions in office automation, communications, and data transmission. In short, by the early 1990s, all healthy and prosperous U.S. industries will be high tech (3).

To avoid the problem of defining high technology manufacturing in terms of specific technologies or processes, it has become common practice to define it in terms of the technology infrastructure. Two common criteria are number of scientists, engineers, and technicians as a percentage of total employment and R&D expenditures as a percentage of sales. Depending on the cutoffs, industries can be grouped by Standard Industrial Classification (SIC), as shown in Table 1, according to a narrow, middle-of-the-road (Massachusetts Division of Employment Security), or broad definition. As one moves from Definition 1 to Definition 3, there is a corresponding increase in the percentage of employment both in manufacturing and in wage and salary employment as a whole.

However, this definitional approach also has its limitations. Although it identifies high technology manufacturing and related R&D establishments, it fails to capture the high technology services sector such as technical repairs and communications, computer, and data processing services. Furthermore, these definitions include industries that are commonly referred to as traditional, heavy, or smokestack. For example, Definition 2 includes all of SIC 36 (Electrical and Electronic Equipment), thereby classifying heavy-duty generators, transformers, and washing machines as high technology.

The utility of these three definitions in addressing air freight sensitivity in high technology industries is discussed in the next section.

The source of data for the ensuing sections is the Census of Transportation's Commodity Transportation Survey, both tabular summary and data tape. The 1982 Census of Transportation data are not yet available. Although the 1977 data are limited for a current study of high technology, they can provide a basis for classification, planning methodology development, and trend analysis when the 1982 data become available. The Census of Transportation data were obtained from a stratified sample of the mail file of the 1977 Census of Manufacturers. The data file was built from a sampling of shipments not from respondents' estimates.

TABLE 1 Three Definitions of High Technology Manufacturing in the United States, 1982 (4)

SIC		Total Wage and Salary Employment (%)	Manufacturing Employment (%)
Core/Narrow Definition		2.8	13.1
283	Drugs		
357	Office and computing machines		
366	Communication equipment		
367	Electronic components and accessories		
381	Engineering and scientific instruments		
382	Measuring and controlling devices		
383	Optical instruments and lenses		
384	Medical instruments and supplies		
386	Photographic equipment and supplies		
Mass. DES Definition		4.11	19.3
283	Drugs		
348	Ordnance		
357	Office and computing machines		
All 36	Electrical and electronic equipment		
376	Guided missiles, space vehicles		
379	Miscellaneous transportation equipment		
All 38	Instruments		
Broad Definition		5.7	27.2
All 28	Definition 2 + Rest of chemicals		
372	Aircraft and parts		

UTILITY OF HIGH TECHNOLOGY MANUFACTURING DEFINITIONS FOR AIR FREIGHT ANALYSIS

In an earlier paper, the authors hypothesized that high technology industries are more sensitive to air freight services than are traditional, smokestack industries (2). The time-sensitivity, high value, low bulk, and fragile characteristics of many high tech supplies and products are frequently associated with air freight service. Such a generalization is inadequate and even misleading for transportation improvement planning. To begin with, each of the high technology definitions discussed in the preceding section must be tested for its utility from an air freight perspective.

The air freight mode shares for Definitions 1, 2, and 3 are given in Table 2 for aggregated U.S. data. Using any of the criteria of value of shipment, tonnage, or ton-miles, the percentage using air freight declines as the definition broadens. This fits with expectations because the broader the definition the more it includes traditional, heavy industries.

A comparison of Definitions 1, 2, and 3 with all commodities and with a representative group of heavy industries is possible by cross-examining Tables 2 and 3. The heavy industry group is defined as textiles, rubber, primary metals, fabricated metals, and machinery (corresponding to SICs 22, 30, 33, 34, and 35, respectively). Only the mode share under Definition 1 stands out clearly above that for all commodities and heavy industries by all three criteria of value, tonnage, and ton-miles.

This result implies that, by and large, Definition 1 contains air freight sensitive industries. However, at this level of aggregation, the mode share calculation tends to conceal a number of important factors that account for mode choice variability for air freight at the local or regional level. Air freight mode choice is not only a function of the characteristics of the commodity but of the size and frequency of shipment, reliability, shipment distance, availability of overnight services, the purchaser's inventory strategies such as just-in-time purchasing, and so forth (5,6).

Another factor washed out in this result is geographical concentration of the air freight market. In 1979 almost 80 percent of commercial air cargo service was between four cities (Chicago, Los An-

TABLE 2 Air Freight Mode Share for Three Definitions of High Technology Manufacturing, United States, 1977[a]

TCC		Value: Mode Share (%)	Value: Definition Mode Share	Tons: Mode Share (%)	Tons: Definition Mode Share	Ton-Miles: Mode Share (%)	Ton-Miles: Definition Mode Share
Core/Narrow Definition			14.5		2.3		4.1
283	Drugs	4.9		0.4		0.6	
357	Office and computing machines	20.0		9.8		16.6	
366	Communication equipment	17.1		3.6		5.6	
367	Electronic components and accessories	21.6		7.1		13.7	
381	Engineering and scientific instruments	26.3		5.1		6.3	
382	Measuring and controlling devices	10.0		3.4		5.0	
383	Optical instruments and lenses	9.6		2.4		4.0	
384	Medical instruments and supplies	9.4		1.7		2.7	
386	Photographic equipment and supplies	2.5		0.4		0.4	
Mass. DES Definition			11.1		1.3		2.5
283	Drugs	4.9		0.4		0.6	
348	Ordnance	(most commodities classified—not in CTS)					
357	Office and computing machines	20.0		9.8		16.6	
All 36	Electrical and electronic equipment	10.5		1.1		2.2	
37691	Guided missiles, space vehicles	24.9		6.1		10.4	
379	Miscellaneous transportation equipment	(missing data)					
All 38	Instruments	9.0		1.6		2.6	
Broad Definition			7.7		0.1		0.4
All 28	Chemicals and allied products	0.9		0.2		0.07	
357	Office and computing machines	20.0		9.8		16.6	
All 36	Electrical and electronic equipment	10.5		1.1		2.2	
37691	Guided missiles, space vehicles	24.9		6.1		10.4	
All 38	Instruments	9.0		1.6		2.6	
372	Aircraft and parts	16.8		11.1		26.5	

[a] From *Census of Transportation Commodity Survey*, Bureau of the Census, 1977.

TABLE 3 Air Freight Mode Share Comparison with All Commodities and Heavy Industries[a]

TCC	Commodity	Value: Mode Share	Value: Group Mode Share	Tons: Mode Share	Tons: Group Mode Share	Ton-Miles: Mode Share	Ton-Miles: Group Mode Share
	All commodities		2.3		0.04		1.8
	Heavy industries		2.1		0.1		0.5
22	Textile mill products	0.4		0.2		0.5	
30	Rubber and miscellaneous plastics	1.0		0.3		0.4	
33	Primary metals	0.5		0.02		0.1	
34	Fabricated metals	1.0		0.1		0.4	
35	Machines except electrical	4.4		0.9		1.9	

[a] From *Census of Transportation Commodity Survey*, Bureau of the Census, 1977.

geles, New York, and San Francisco) and only some dozen airports received daily air freight service (5). Table 4 gives this variability in relative mode shares for Definitions 1, 2, and 3 by each of eight origin production areas (PAs). Interestingly, the reputed high technology cities of Boston, Minneapolis, and San Francisco show higher than average air freight mode share. This geographic variability is taken up in more detail in a later section.

This U.S.-wide trend of a decline in air share as the definition of high technology broadens from Definition 1 through Definition 3 is also observable for smaller geographic areas, although with some aberrations (Table 4). In a number of production areas, air share remains approximately constant for Definitions 1 and 2. This suggests that at least some commodities within Definition 2 should be included in a high technology-high air share listing.

The data in Table 4 also point to the limited utility for planning purposes of any two- or three-digit definitional grouping. Air freight share, even in Definition 1, varies from area to area, partly because of different mixes in commodities broadly grouped at the three-digit level. It follows that each definitional group should be searched for high air share commodities at a higher level of industry or commodity discrimination. This examination is presented in the next section.

LISTING OF HIGH TECHNOLOGY-HIGH AIR FREIGHT COMMODITIES

In this section the results are presented of a search of Definitions 1, 2, and 3 for air freight sensitive commodities. The results are given in Table 5--a listing of high technology-high air freight commodities at the five-digit level. To begin with all two- and three-digit SICs in Definitions 1, 2, and 3 were translated into equivalent five-digit TCCs.

The following criteria were employed in the selection of air freight sensitive commodities:

1. Commodities that display clear air freight dependence: As a general rule, these commodities had an air freight mode share of 10 percent or more based on value or 5 percent or more based on ton-

TABLE 4 Mode Shares for Select U.S. Production Areas for Three High Technology Definitions[a]

Production Area	Production Area Description	Mode	Mode Share Percentage Base on Tonnage for High Technology Definition 1	2	3
25	Allentown-Bethelhem-Easton Reading	Rail	0.0	No change	7.1
		Common carrier	92.2	No change	67.3
		Private truck	0.4	No change	15.2
		Air	1.4	No change	0.9
		Parcel delivery	2.0	No change	0.1
		Other and unknown	4.0	No change	9.4
11	Boston, Worchester Providence-Warwick-Pawtucket Brockton Lawrence-Haverhill Lowell	Rail	0.7	0.6	0.4
		Common carrier	82.5	80.7	74.9
		Private truck	3.8	3.5	11.4
		Air	4.5	4.5	2.8
		Parcel delivery	5.5	7.0	4.1
		Other and unknown	3.0	3.7	6.4
38	Chicago Gary-Hammond-East Chicago	Rail	12.3	12.1	23.4
		Common carrier	66.8	66.3	57.5
		Private truck	15.2	15.9	15.0
		Air	2.0	1.9	0.4
		Parcel delivery	2.1	2.1	0.5
		Other and unknown	1.6	1.7	3.2
33	Cincinnati Dayton Hamilton-Middletown	Rail	8.0	2.5	5.9
		Common carrier	69.4	62.1	75.1
		Private truck	0.6	29.5	14.0
		Air	0.1	0.3	0.2
		Parcel delivery	19.2	4.6	2.3
		Other and unknown	2.6	1.0	2.5
34	Detroit Flint Toledo Ann Arbor	Rail	0.0	0.0	21.3
		Common carrier	96.9	95.7	51.0
		Private truck	0.7	1.6	26.6
		Air	0.3	0.3	0.03
		Parcel delivery	0.4	0.8	0.1
		Other and unknown	1.7	1.6	0.9
43	Minneapolis-St. Paul	Rail	0.0	3.6	20.3
		Common carrier	70.4	61.0	66.2
		Private truck	3.9	17.2	9.3
		Air	17.0	11.9	2.7
		Parcel delivery	5.9	4.3	1.0
		Other and unknown	2.8	2.0	0.5
83	Phoenix Tucson	Rail	0.0	No change	No change
		Common carrier	3.5	No change	No change
		Private truck	93.3	No change	No change
		Air	1.8	No change	No change
		Parcel delivery	0.6	No change	No change
		Other and unknown	0.8	No change	No change
93	San Francisco-Oakland Vallejo-Fairfield-Napa-San Jose Santa Rosa-Santa Cruz	Rail	2.3	2.5	27.9
		Common carrier	47.1	47.1	59.4
		Private truck	22.5	22.1	7.4
		Air	18.4	18.5	1.5
		Parcel delivery	2.8	3.1	0.4
		Other and unknown	6.9	6.7	3.4

[a] From *Commodity Transportation Survey Data Tape*, Bureau of the Census, 1977.

nage, or both. Examples of such commodities are TCC 35731, electronic data processing machines, and TCC 36741, solid-state semiconductors.

2. Commodities that did not display clear air freight dependence but showed by value or weight per shipment that within the spectrum of products for a particular TCC there is a potentially air-dependent subgroup: This is evidenced in Table 5 by a median value for air mode above the air mode average or a median weight for air mode below the air mode average, or both; for example, TCC 36221, industrial controls, and TCC 38119, engineering instruments not elsewhere classified (NEC). It can also be evidenced by a significant change in median value or median weight between the "all modes" column and the "air mode" column; examples include TCC 28311, drugs for human use, and TCC 38421, orthopedic and prosthetic appliances.

3. Commodities that marginally fit under either 1 or 2 and are considered to be undergoing high technology product changes such as revolutionary downsizing and microcircuitry: This rather subjective category includes TCC 36231, arc welding machines, and TCC 38612, photographic developing equipment.

The listing generated as Table 5 should not be considered fixed. Air freight dependence will change over time depending, among other things, on changing product technology and air service characteristics. However, it provides a base group disaggregated sufficiently for transportation planning analysis. The utility of this listing is demonstrated in the next section in which air freight use is examined for different production areas in the United States.

TABLE 5 Select Characteristics of High Technology-High Air Freight Commodities by Five-Digit TCC[a]

Definition	TCC	Commodity Description	All Modes Median Value ($/lb)	All Modes Median Weight (lb)	Air Median Value ($/lb)	Air Median Weight (lb)	Air Mode Share Value (%)	Air Mode Share Tons (%)
		All commodities	1.3	775	19.36	24	2.8	0.04
1, 2, 3	28311	Drugs for human use	5.00	104	26.94	16	5.1	0.4
1, 2, 3	35731	Electronic data processing machines	24.18	80	36.28	40	23.8	16.5
1, 2, 3	35741	Accounting and calculating machines	15.00	26	28.07	32	18.0	9.4
1, 2, 3	35761	Scales and balances	3.58	125	25.00	25	6.4	2.0
1, 2, 3	35791	Addressing, dictating, duplicating machines	6.36	124	10.36	18	4.2	4.2
1, 2, 3	35799	Office machines NEC	5.09	68	15.16	13	5.7	2.3
2, 3	36112	Test equipment for electronics	32.33	20	83.33	13	29.1	7.9
2, 3	36113	Electronic indicating instruments	42.50	8	52.08	22	33.5	16.7
2, 3	35221	Industrial controls	8.00	55	22.50	12	7.1	4.9
2, 3	36231	Arc welding machinery	5.08	78	26.81	16	6.6	0.7
2, 3	36292	Rectifying apparatus	6.70	215	14.16	93	8.2	3.2
2, 3	36299	Electrical industrial apparatus NEC	9.86	53	23.00	31	10.7	2.1
1, 2, 3	36612	Telephone equipment	16.65	50	22.88	34	5.4	1.8
1, 2, 3	36621	Radio, TV transmission	39.95	19	77.06	16	23.9	6.0
1, 2, 3	36711	Electronic tubes	32.00	35	171.18	19	15.3	0.5
1, 2, 3	36741	Solid-state semiconductors	120.00	4	167.75	5	27.0	32.6
1, 2, 3	36791	Miscellaneous electronics	25.60	12	48.75	7	19.5	5.7
3	37221	Aircraft engines and parts	53.50	36	81.78	35	21.2	4.6
3	37222	Missile and space vehicle engines and parts	21.30	30	72.92	12	18.9	46.3
3	37231	Aircraft propellers	19.65	20	25.00	14	13.6	12.5
3	37299	Aircraft parts NEC	45.78	15	50.00	11	20.5	9.7
2, 3	37691	Guided missile and space vehicle parts	17.66	24	25.00	9	24.9	6.1
1, 2, 3	38111	Aircraft flight and nautical equipment	164.85	5	196.30	5	36.9	14.3
1, 2, 3	38112	Surveying and drafting instruments	333.33	4	337.52	4	48.3	—
1, 2, 3	38113	Laboratory and scientific instruments	31.00	32	54.31	49	20.9	4.4
1, 2, 3	38119	Engineering instruments NEC	38.25	6	54.00	13	3.7	—
1, 2, 3	38212	Meters and recording devices	5.48	120	28.26	21	16.8	26.8
1, 2, 3	38213	Weather measuring instruments	7.79	139	11.20	86	11.2	—
1, 2, 3	38219	Mechanical measuring instruments	22.50	23	37.32	19	12.5	3.9
1, 2, 3	38221	Automatic temperature controls	8.13	108	8.86	40	9.8	4.6
1, 2, 3	38311	Optical instruments and lenses	34.16	9	54.88	13	9.6	2.4
1, 2, 3	38411	Surgical, medical instruments	8.89	60	34.40	9	11.5	1.9
1, 2, 3	38421	Orthopedic, prosthetic appliances	7.35	36	95.00	3	6.3	0.8
1, 2, 3	38431	Dental equipment and supplies	19.22	4	45.00	1	5.5	1.5
2, 3	38511	Opthalamic and opticians goods	16.88	3	21.88	3	8.1	8.3
1, 2, 3	38612	Photo development equipment	10.00	76	15.50	16	5.2	0.7
1, 2, 3	38613	Still and motion picture equipment	10.00	37	34.31	26	4.1	—
1, 2, 3	38619	Photo equipment NEC	11.98	40	51.42	42	4.6	—
2, 3	38711	Watches, clocks, etc.	17.96	10	25.00	24	9.3	4.7

Note: NEC = Not elsewhere classified.

[a]From *Census of Transportation*, Bureau of the Census, 1977.

GEOGRAPHIC VARIABILITY IN AIR FREIGHT USE FOR HIGH TECHNOLOGY COMMODITIES

As briefly discussed previously, variability in air freight use is partly a function of geographical location and transportation characteristics of production areas. To further illustrate this variability and to demonstrate the utility of the listing in Table 5, selected high tech-high air freight commodities are examined for production areas of origin and corresponding air freight mode share. Table 6 is generated from the CTS tape. For each of five commodity types, the major production areas by origin are ranked using tonnage, and the mode share for air freight plus parcel delivery is calculated.

In general, those production areas that border the United States, such as Miami, Newark, and San Francisco, have higher air and parcel freight mode shares. Conversely, heartland industrial areas, such as Detroit, Allentown, and even Chicago, do not depend on air freight nearly as much as the border production areas or as the average for each high tech-high air freight commodity (in most cases).

A second observation is that this "distance" factor varies by commodity. For example, Hartford's air and parcel freight mode share is considerably higher than the average for industrial instruments (38219) and considerably below the average for electronic components (36791). Furthermore, some "heartland" production areas such as Cincinnati, Cleveland, and Tulsa are prime air and parcel mode locations for certain high technology commodities. These observations suggest that the peculiar characteristics of a commodity within a five-digit group, coupled with local air freight transportation characteristics, influence mode choice.

Information of this kind could be an aid in the design of local air transportation strategies intended to enhance or encourage particular high tech manufacturing. Mode shares and rankings for each commodity, as given in Table 6, provide an indicator of competitiveness for air freight sensitive commodities. They could also prompt studies of the strengths and weaknesses of air freight systems serving local high tech industries.

CONCLUSION

A widely used definition of high technology manufacturing is based on two criteria: R&D expenditures to sales and employment of scientists, engineers, and technicians to total employment. Depending on the cutoff points for these criteria, three definitional groups of manufacturing industries comprising two- and three-digit SICs can be obtained.

These three definitional groupings were found to be of little use in the analysis of air freight mode share in the high technology sector. Only the narrow definition showed a marked air freight dependence above the norm. A listing of high technology-high air freight commodities was obtained using the Commodity Transportation Survey of the 1977 Census of Transportation. Thirty-nine commodities at the five-digit level were identified as air freight sensitive. This sensitivity was found to vary considerably between production areas in the United States. Not unexpectedly, several "border" cities such as San Francisco were more air freight dependent in high technology than the norm.

TABLE 6 Time- and Value-Sensitive Mode Shares by Production Area for Select Commodities

Production Area	Abridged Name of Production Area	Total Originating Tons	Tonnage by Air and Parcel Delivery	Mode Share (%) for Air Plus Parcel	Four Highest Mode Shares
Commodity 28311: Drugs for Human Use					
72	Houston	156	3	1.9	
58	Miami	7,809	316	4.0	*
33	Cincinnati	8,368	2,588	30.9	*
11	Boston	11,565	218	1.9	
93	San Francisco	28,532	1,731	6.1	*
41	St. Louis	59,014	540	0.9	
34	Detroit	114,772	481	0.4	
22	Newark	124,340	6,035	4.9	*
21	New York	130,862	2,490	1.9	
38	Chicago	218,056	1,628	0.7	
	Total (Commodity mode share)	703,474	16,030	(2.3)	
Commodity 35731: Electronic Data Processing Machines and Equipment					
22	Newark	1,212	412	34.0	*
74	Dallas	1,926	624	32.4	*
23	Philadelphia	2,790	2,299	82.7	*
34	Detroit	8,062	336	4.2	
43	Minneapolis	24,050	5,958	24.8	
12	Hartford	28,616	1,562	5.6	
95	Los Angeles	32,588	5,204	16.0	
93	San Francisco	41,152	13,209	32.1	*
	Total (Commodity mode share)	140,396	29,604	(21.1)	
Commodity 36621: Radio and Television Communication Equipment					
91	Seattle	37	—	—	
39	Milwaukee	407	96	23.6	
81	Denver	655	231	35.3	
83	Phoenix	684	174	25.4	
41	St. Louis	920	73	7.93	
57	Daytona	2,485	1,302	52.4	*
58	Miami	2,697	1,096	40.6	*
54	Greensboro	3,016	90	3.0	
82	Salt Lake City	3,722	1,002	26.9	
11	Boston	4,936	689	14.0	
23	Philadelphia	5,141	1,137	22.1	
93	San Francisco	5,190	2,472	47.6	*
33	Cincinnati	5,290	53	1.0	
52	Washington, D.C.	7,151	124	1.7	
38	Chicago	8,765	1,315	15.0	
21	New York	9,101	394	4.3	
26	Northeast Pennsylvania	11,147	647	5.8	
96	San Diego	12,210	947	7.8	
29	Pittsburgh	12,698	78	0.6	
22	Newark	15,307	10,530	68.8	*
74	Dallas	16,812	1,504	8.9	
95	Los Angeles	23,146	3,438	14.8	
	Total (Commodity mode share)	151,517	27,394	(18.1)	
Commodity 36971: Electronic Components					
27	Syracuse/Albany	4	1	25.0	*
34	Detroit	36	5	13.9	
91	Seattle	86	21	24.4	*
92	Portland	721	676	93.8	*
74	Dallas	831	175	21.1	
31	Cleveland	1,315	306	23.3	*
42	Kansas City	1,521	154	10.1	
25	Allentown	2,261	77	3.4	
55	Charlotte	2,349	442	18.8	
39	Milwaukee	3,235	163	5.0	
24	Harrisburg	7,101	451	6.4	
11	Boston	10,101	1,228	12.2	
12	Hartford	12,930	1,039	8.0	
21	New York	14,137	2,226	15.7	
95	Los Angeles	21,399	4,173	19.5	
93	San Francisco	37,648	6,738	17.9	
38	Chicago	51,975	7,503	14.4	
	Total (Commodity mode share)	167,632	25,378	(15.1)	

TABLE 6 continued

Production Area	Abridged Name of Production Area	Total Originating Tons	Tonnage by Air and Parcel Delivery	Mode Share (%) for Air Plus Parcel	Four Highest Mode Shares
Commodity 38219: Industrial Instruments					
81	Denver	15	3	20.0	
64	Birmingham	51	0	0.0	
96	San Diego	320	148	46.25	*
22	Newark	1,790	638	35.6	*
29	Pittsburgh	1,846	232	12.6	
93	San Francisco	1,984	87	4.4	
75	Tulsa/Oklahoma City	2,316	544	23.5	*
28	Buffalo	2,413	542	22.5	
34	Detroit	2,559	95	3.7	
12	Hartford	3,220	1,057	32.8	*
23	Philadelphia	10,332	720	7.0	
11	Boston	18,512	2,077	11.2	
	Total (Commodity mode share)	45,358	6,143	(13.5)	

The implications of this analysis for transportation planning are as follows:

• Not all high tech industries are air freight sensitive. A definitive listing of high technology-high air freight commodities is now available for use in local freight demand and capital improvement studies.

• The Commodity Transportation Survey has been shown to be a useful tool with which to examine high technology transportation implications. Analysis beyond the five-digit level may be necessary in some localities for some commodities. This is also possible with the CTS data tape.

• The examination of air freight mode shares for identical high technology commodities across production areas might prove useful in developing a competitive high technology strategy linked to air freight.

Additional implications for further research are as follows:

• The Commodity Transportation Survey provides an alternative data base for the study of high technology growth in metropolitan areas. For example, it provides opportunity for the study of high technology commodity flows.

• Trend line analysis of the role of air freight in metropolitan growth might be possible by comparing 1982 with 1977 data, when the former become available. For example, one might look for shifts in air freight mode share between early and later stages of emerging high technology production areas such as Phoenix, Arizona, and Austin, Texas.

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Issues in the Deregulation of Oil Pipelines: An Empirical Analysis

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ABSTRACT

An overview of the issues involved in the deregulation of oil pipelines is presented. The most recent market structure and concentration data are reviewed, and, for the first time, a summary of the U.S. Department of Justice data is given in the Appendix.

The purpose of this paper is to present an overview and analysis of the major issues involved in the debate over the deregulation of oil pipelines. Recently, several bills for deregulation and regulatory reform have been introduced in Congress (HR.2677, S.1626). Moreover, the oil pipeline industry (1), the U.S. Department of Justice (DOJ), and the Federal Energy Regulatory Commission (FERC) have all suggested that oil pipelines be partly or fully deregulated. Although the courts have not accepted the regulatory procedures recently proposed by the FERC or those of its predecessor, the Interstate Commerce Commission (ICC), in 1982 they supported the vacation of the DOJ consent decree that had been entered in 1941 and provided for a constraint on dividends. At this juncture it is useful to review the evidence for and against oil pipeline deregulation. In the first section of this paper, the issue of whether oil pipelines are natural monopolies is examined. The second section is a review of the methods used in the three most recent studies on oil pipeline market structure. In the third section the results of these studies are compared. In the final section further qualifying factors are discussed and a conclusion is offered.

NATURAL MONOPOLY

An important question recently raised in debate about deregulation of oil pipelines is whether natural monopoly conditions exist in the industry. Although it has been established that economies of scale or cost subadditivity exist in oil pipelines due to the technological nature of production (2), there are factors that mitigate the import of these decreasing cost conditions. In particular, if the relevant market is identified as the corridor over which a pipeline extends, the dynamic conditions of market growth will tend to reduce the natural monopoly effects. For example, the initial pipeline constructed along a corridor might have had excess capacity in early years; however, in later years demand may substantially outgrow the initial pipeline's capacity so that construction of a new line or lines along the same corridor is mandated. If this new construction is by another firm, competition should prevail along the corridor. Second, because pipelines may face competition from other pipelines, from seaports, and from other rivals at each end of the line, the exercise of natural monopoly power may be mitigated. Indeed, the natural monopoly power of a pipeline may exist only insofar as the pipeline (a) has monopoly power at one end, (b) has monopoly power at the other end, (c) is large enough to carry all the traffic between both points, and (d) enjoys cost subadditivity conditions (i.e., a single pipeline can satisfy the demand along the corridor at a lower total cost than a larger number of pipelines). Only under these conditions will a single pipeline segment have a natural monopoly. Thus it appears unlikely that natural monopoly conditions exist in the oil pipeline industry.

MARKET STRUCTURE AND CONCENTRATION IN OIL PIPELINES

In this section an analysis of three recent studies of market concentration and competition in the oil pipeline industry is presented. These studies are (a) A Study of Oil Pipeline Competition by Mitchell (unpublished study), (b) Competition in Oil Pipeline Markets by Anderson and Rapp of the National Economic Research Associates (NERA) (3), and (c) Competition in the Oil Pipeline Industry: A Preliminary Report by the Antitrust Division of the U.S. Department of Justice (hereafter referred to as the DOJ study) (4). Before examining the actual results of these studies, it is necessary to examine the market definitions, rivalries, and measures of market concentration used in each study.

All three studies focused on the origin-destination market definition rather than the corridor definition, although NERA believed that the corridor definition of a market still had some merit. The origin-destination market definition examines the market structure at each end of the pipeline, whereas the corridor definition considers only those modes that run along the same corridor to be rivals. All three studies considered only petroleum-based commodities that can be transported via pipelines. These included gasoline, jet fuel, kerosene, diesel fuel, and distillate heating oil. Table 1 gives a comparison of oil pipeline markets used in each of the three studies examined here. As can be seen from this table, Mitchell used producing areas, refining centers, and standard metropolitan statistical areas. NERA used producing areas, refining centers, and BEAs (the 183 geographic markets in the lower 48 states established by the U.S. Department of Commerce, Bureau of Economic Analysis), and the DOJ consistently used BEAs for all markets. The relative narrowness of market definitions will have a significant influence on the level of concentration found in a particular market. As both the DOJ study and Mitchell study point out, using a BEA may understate competition (e.g., if the densely populated areas of

TABLE 1 Oil Pipeline Markets Used in Various Studies

	Mitchell	NERA	DOJ
Crude origin	27 producing areas	50 largest oil fields[a]	61 BEAs[b]
Crude destination	48 refining centers	42 refining centers	65 BEAs[c]
Product origin	48 refining centers	44 refining centers	50 BEAs[d]
Product destination	59 standard metropolitan statistical areas	50 BEAs[e]	115 BEAs[f]

[a]NERA used a random sample of 182 large oil fields.
[b]Only 61 of the 183 BEAs had crude pipeline origins.
[c]Only 65 BEAs had crude pipelines in destination markets.
[d]Only 50 of 183 BEAs had pipelines in product origin markets.
[e]NERA used a random sample of 183 BEAs.
[f]Only 115 of 183 BEAs had product pipeline delivery.

a highly concentrated BEA are in close proximity to facilities in another highly competitive BEA, the concentration of the former BEA will be overestimated).

Another important consideration in the determination of concentration of economic power is the handling of joint ventures and undivided interest pipelines. NERA combines two or more pipelines as a single rival if they have any owners in common. In the DOJ and Mitchell studies, if no member of the joint venture line owns more than 50 percent of the pipeline, it is treated as a single independent rival, irrespective of whether its owners also own a competing pipeline in the market.

Because these studies have chosen to use an origin-destination definition of markets rather than a corridor definition, four categories of markets must be studied: (a) crude origin (collection), (b) crude destination (delivery), (c) product origin (collection), and (d) product destination (delivery). Therefore another difference among the three studies concerns the delineation of the relevant rivals in terms of intermodal competition in each of these four market categories.

In the crude collection market, NERA and the DOJ raw data included trunk pipelines, local refineries, and barges and tankers as relevant rivals, and Mitchell added trucks.

In the crude delivery market, NERA and the DOJ included trunk pipelines, local crude producers, and barges and tankers, and Mitchell added trucks, pipelines within the refinery market, and volumes of crude shipped by water, not measured by NERA.

In the product collection market, NERA and the DOJ raw data used trunk pipelines, local consumption, and barges and tankers.

Finally, in product delivery, NERA and DOJ included trunk pipelines, local refineries, and barges and tankers. Again, Mitchell added trucks to this list.

Therefore, overall, the NERA study and the raw data of the DOJ study place less emphasis on the role of truck and water competition than does the Mitchell study. Indeed, the DOJ study (4,p.17) states:

> Most shipments via railroad and trucks are intra-market shipments, whose volumes have already been accounted for by the inter-market pipeline or water transportation or by local production or consumption activity. Thus, rail and truck facilities are excluded from the analysis of relevant competitors.

For measures of concentration, the Mitchell study examines the number and market power of rivals in each market. NERA and the DOJ used the Herfindahl index to measure concentration in each market. In general, for both these studies, a Herfindahl index greater than 2,500 was suggestive of a concentrated market that therefore was classified as a high risk market, which may need regulation. Moreover, NERA had several categories of risk. For example, markets with Herfindahl indexes of 0 to 2,500, 2,500 to 5,000, and 5,000 to 10,000 were considered low, medium, and high risk markets, respectively. In addition, NERA provided for further subclassification depending on the extent of water competition in the crude origin, crude collection, and product delivery markets and the size of local consumption in the product collection market.

Because two of the three studies examined used the Herfindahl index, a brief description of this index is appropriate. In June 1982 the Antitrust Division of the Department of Justice announced that in antitrust cases they would use the Herfindahl index to measure market power. The Herfindahl index is defined as

$$HI = \sum_{i=1}^{n} S_i^2$$

where n is the number of firms in the industry and S_i is the market share of the ith firm (i = 1 . . . n). That is to say, the Herfindahl index (HI) is calculated by summing the square of each firm's market share as measured by throughput capacity. Consider a hypothetical pipeline market with four firms such that their market shares are as follows:

Firm No.	Market Share (%)	Market Share Squared
1	10	100
2	35	1,225
3	5	25
4	50	2,500
	HI =	3,850

As can be seen in this particular market, the squared market shares of each firm sum to 3,850. Thus the DOJ would consider this a high risk or concentrated market, whereas NERA would consider it a moderate risk market. The Herfindahl index technically has a maximum of 10,000 and a minimum close to zero and is thought to have numerous advantages over other measures of market concentration.

These differences account for some of the deviations in the conclusions of the various studies, but, as will be seen, there are additional differences noted by Mitchell and the DOJ study (although not accounted for in the DOJ preliminary report). Before examining these other qualifying features, let us turn to an examination of the results of these three studies on market concentration.

RESULTS OF MARKET STRUCTURE AND COMPETITION STUDIES

In this section is presented a summary of the results of the three most recent market concentration studies, those by Mitchell, NERA, and the Department of Justice. It should be noted, however, that in summarizing the DOJ study, the 2,500 Herfindahl index level is used as a cutoff point (i.e., if a BEA in the DOJ study had a Herfindahl index greater than 2,500, it was automatically placed in a high risk category). As will be noted, the DOJ study and others have recognized the many limitations in such a simple application of this arbitrary rule. The DOJ intends to examine each market more fully for qualifying features.

Results of Studies on Competition in the Crude Origin or Collection Market

Mitchell's findings indicated that the crude collection market was sufficiently competitive. He found for 27 producing areas that local refinery capacity was large relative to crude production in 20 of the 27 areas, and that refinery capacity exceeded production in 14 of the 27 producing centers. In only three cases was a market served by a single pipeline. Examining each of these three cases in detail, Mitchell indicates that sufficient competition exists.

The NERA study of 50 crude collection markets, on the other hand, found seven high risk markets, 26 moderate risk markets, and only 17 low risk markets. Thus, using the DOJ threshold, the NERA study implies that 33 of 50 crude collection markets should be regulated.

Similarly, the DOJ data indicated that 46 of 61 crude collection markets in which pipeline transportation was available were high risk markets. Thus, on the basis of the NERA and DOJ statistics, it appears that most of the crude markets are uncompetitive, whereas the Mitchell study indicates that competition is sufficient and that deregulation is an appropriate strategy for these markets.

Results of Studies on Competition in the Crude Delivery (or destination) Markets

In these markets, Mitchell found that of the 48 refining centers, only 11 were served by a single crude pipeline. In studying each of these 11 centers in more detail, Mitchell argues for a variety of reasons that these markets are still competitive.

The NERA study of 42 crude delivery markets finds that 15 are in the high risk category, 15 in the medium risk, and only 12 in the low risk category. However, when NERA adjusted these data by assuming that a refinery center located on a seaport should be considered in the low risk class regardless of the number of pipelines serving the market, they concluded that almost two-thirds of refinery centers were located in the low risk category, leaving only one-third in the high risk category. In sum, NERA concluded that crude delivery was a most competitive market except for refineries in the inland market.

Finally, the DOJ study found 42 high risk and 23 low risk markets or 58 percent of crude delivery markets to be high risk.

Results of Studies on Competition in the Product Origin or Collection Markets

Mitchell finds 13 refining centers in which only a single pipeline collects product. Examining these in detail, he states that in three centers exploitation is not a problem because perfect vertical integration exists. In the remaining 10 refinery centers, Mitchell lists circumstances such as the existence of vertical integration, water competition, local consumption that is larger than refinery capacity, and pipeline collection that represents a small percentage of capacity as factors that would tend to eliminate exploitation. Thus he concluded that product collection markets are, for the most part, competitive.

In contradistinction, NERA found this function to be most uncompetitive. Thirty-three of 44 markets were found by NERA to be in the high risk category. Therefore NERA concluded that 85 percent of national refinery capacity falls within the medium to high risk category, and only 15 percent of capacity--mainly situated near major consuming centers--is unlikely to be subject to the risk of monopoly increases in product pipeline transportation rates if regulation is removed. In contrast, the DOJ data indicated that only 25 of the 50 BEA markets examined fell into the high risk category.

Results of Studies on Competition in the Product Delivery (destination) Markets

The analysis by Mitchell in the product delivery markets finds these markets to be competitive. He states that markets serviced by product pipelines typically have about five competing local entities, and, in addition, potential or actual water competition exists in about 80 percent of the markets. Finally, Mitchell argues that, because by any measure the refinery industry is competitive, this implies that product pipelines are competitive in destination markets. Nine of what he considers the 14 "worst" cases served by a single product pipeline have significant water competition. Mitchell also found instances of potential or actual competition in the remaining markets such as nearness of ports (Flint), large numbers of local refineries (Salt Lake City), high potential for entry (Phoenix), and state regulation that held pipeline rates too low and eliminated water competition (San Diego).

In contrast to Mitchell, NERA found most product destination markets uncompetitive. Of the 50 markets examined, NERA found 17 high risk, 29 medium risk, and four low risk markets. Using the DOJ standard, the NERA study would indicate that 46 percent of the 50 markets were high risk.

The DOJ study used two types of Herfindahl indexes in its product destination market analysis, one unadjusted for surplus capacity and a second adjusted for surplus capacity. Using the unadjusted Herfindahl index as a threshold, DOJ data indicate that 99 of 115 product destination markets fall into the high risk category, thus indicating a markedly uncompetitive environment. When adjusted for surplus capacity, the high risk markets drop to 85. Thus, whether adjusted or unadjusted, the DOJ raw data place a high proportion of product destination pipelines in the high risk category.

Table 2 gives a rough summary of the conclusions of each study. In general, the NERA study conflicts with Mitchell in all but the crude destination markets and seems to be in agreement with the DOJ data in most markets.

TABLE 2 Summary of Competition Studies

	Mitchell	NERA	DOJ
Crude origin	Low risk	High risk	High risk
Crude destination	Low risk	Low risk	Moderate to high risk
Product origin	Low risk	High risk	Moderate to high risk
Product destination	Low risk	High risk	High risk

Reasons for the differences in these studies are numerous, but one significant point is that the DOJ data reported here were interpreted in a mechanical manner. The DOJ itself has advised that numerous other factors should be examined on a market-by-market basis and that a perfunctory examination of these statistics is misleading. Incorporating these other factors will bring the DOJ results much closer to the Mitchell results.

Although several reasons for the divergent results of these studies have previously been discussed, it is imperative to examine other characteristics, suggested by both Mitchell and the DOJ, that could alter substantially the interpretation of the DOJ raw data.

QUALIFYING FACTORS RECOGNIZED BY BOTH MITCHELL AND DOJ

Both Mitchell (unpublished study, October 1983) and the DOJ (4) have argued that a high degree of concentration, as measured by the Herfindahl index, does not necessarily indicate market power. Moreover, DOJ also recognizes that even where market power exists this does not necessarily indicate regulation. The DOJ tends to favor a cost-benefit approach to regulation. For example, if vertical integration conditions exist such that market power could be wielded by the firm whether it were regulated or not, the DOJ would suggest leaving the market unregulated. Among other factors that would mitigate or alter the DOJ statistics would be a situation in which a pipeline had a small market share in an area that had a high degree of competition or one in which the proximity to facilities in other BEAs increased potential or actual competition. The DOJ also recognized surplus capacity in a market as a mitigating factor. As has been mentioned, the DOJ data only recognized this in the product destination markets. Moreover, where ease of entry exists in ports or places where water traffic could be readily expanded, the DOJ would again make allowances. For these factors that qualify market power, the DOJ data can be readily examined for only the smallness of pipeline market shares. A rough examination of these data indicates that relatively few markets that are highly concentrated would be affected by this qualification. In terms of the remaining factors, a detailed examination of each market, along the lines followed by Mitchell, needs to be performed.

In addition to these factors that qualify market power, the DOJ study and Mitchell, to some extent, have recognized that vertical integration and refinery concentration may place sufficient constraints on markets, which would render regulation either ineffective or unnecessary. For example, a monopoly crude line delivering to its own refinery in an area where the refinery faces no competition would render pipeline regulation ineffective, because a low rate for transportation could be compensated for by a high refinery rate and possibly low crude price if the pipeline in addition had monopoly power. The DOJ study provides several other hypothetical examples where vertical integration renders pipeline regulation either ineffective or unnecessary (4). In addition, the DOJ also recognizes the concept of countervailing power between refineries and pipelines that results in a bilateral monopoly equilibrium (5,p.272). The DOJ lists several such examples (4,p.48):

> Accordingly, if one or more refineries form a bottleneck that is no less concentrated than the product pipelines transporting product from the refineries, then the Department will designate the product origin market as non-high-risk for the product pipelines in the market. Furthermore, if the refinery bottleneck is no less concentrated than a product pipeline corridor connecting the refineries to a separate product destination market, then the Department will designate the product destination market as non-high-risk for the product pipelines in the corridor. By the same token, if the refinery bottleneck is no less concentrated than the crude pipelines transporting crude to the refineries, then the Department will designate the crude destination market as non-high-risk for the crude pipelines in the market. Finally, if the refinery bottleneck is no less concentrated than a crude pipeline corridor connecting a separate crude origin market to the refineries, the Department will designate the crude origin market as non-high-risk for the crude pipelines in the corridor.

Thus both DOJ and Mitchell provide for numerous qualifications. Whereas Mitchell does this by his detailed analysis of "worst" cases, DOJ provides room for more investigation.

In summary, the Mitchell and DOJ studies were strongly on the side of deregulation. For example, Mitchell (1983 study, p. 86) concludes:

> Considering the large number of markets we have examined, and that these were ostensibly the "worst" cases, our findings suggest that the opportunity for oil pipelines to exercise monopoly power must be rare.

The DOJ states in the introduction (4,p.2):

> It is nonetheless evident from an application of the methodology described in the report to the market data presented in the appendix that most interstate pipelines should not be regulated. The department recommends that such pipelines be deregulated as soon as practicable: thus, deregulation may well provide significant savings in regulatory costs for society.

However, NERA (3,p.14) is at odds with these conclusions:

> In conclusion, competition is ineffective in many oil pipeline markets. In the absence of regulation, many, if not most, oil pipelines would have substantial market power and would be able to charge high rates and earn substantial monopoly profits.

Thus Mitchell and DOJ agree that oil pipeline markets are sufficiently competitive whereas NERA concludes the opposite. It is clear then that the more detailed analysis along the lines proposed by the DOJ must be awaited before final conclusions can be drawn.

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APPENDIX

The tables in this appendix contain the summary statistics used in this paper to analyze the DOJ preliminary report. All data herein were compiled from that report (4).

TABLE A-1 Market Structure Data in Oil Pipeline Crude Origin Market

BEA	Herfindahl Index	No. of Pipelines	Pipeline Percentage of Market	BEA	Herfindahl Index	No. of Pipelines	Pipeline Percentage Of Market
002	10000	1	100	126	3724	6	100
010	6249	1	77.42	127	2555	7	96.57
046	8719	1	93.37	128	5648	3	100.00
047	3409	1	15.64	130	1290	2	14.05
065	10000	1	22.35	132	1299	9	94.79
066	10000	1	100.00	133	3344	1	20.78
069	4147	2	67.44	134	1882	8	97.08
070	3434	1	25.16	135	3479	1	10.14
071	5952	2	88.98	136	5962	2	87.6
072	8746	1	93.98	137	1953	9	81.92
074	9595	1	100.00	138	1404	10	89.15
080	4174	2	71.77	139	1740	1	4.3
081	9109	2	63.55	140	6773	2	100
083	2855	2	51.98	141	10000	1	100
105	5202	2	100	144	10000	1	100
106	5536	2	100	145	4224	3	100
107	1939	6	83.01	146	3908	3	94.63
108	4375	2	92.07	150	8145	2	100
112	5508	3	90.43	152	2693	4	97.06
113	1885	6	63.12	153	8121	1	89.83
114	5595	1	69.97	155	1684	4	66.00
115	3886	2	79.33	156	2747	3	69.65
116	3584	2	10.8	157	4343	4	76.59
117	3161	4	82.60	158	10000	1	100
118	4451	2	93.90	159	3172	4	94.27
119	3710	2	56.45	160	3572	1	51.22
120	2246	7	67.77	162	4461	2	88.68
121	1365	5	40.23	165	1904	2	16.84
122	1157	6	31.37	169	1940	1	35.29
124	8161	2	100	180	1407	1	2.13
125	4280	5	95.5				

TABLE A-2 Market Structure Data on Oil Pipeline Crude Destination Markets

BEA	Herfindahl Index 1	Herfindahl Index 2	No. of Pipelines	Pipeline Percentage of Market	BEA	Herfindahl Index 1	Herfindahl Index 2	No. of Pipelines	Pipeline Percentage of Market
010	9403	5507		96.97	120	2261	0	4	71.04
012	6741	3332		0	121	2060	2025	5	58.49
015	8202	8403		90.57	122	957	880	5	36.07
016	6285	2261		79.17	124	8629	0	2	99.58
047	3854	3563	3	82.38	125	5716	3816	2	83.13
057	3062	3271	2	100.00	126	6383	0	3	89.07
059	10000	9519	1	100.00	127	1772	0	5	80.047
065	7656	4455	1	100.00	128	1627	0	1	40.34
067	10000	4460	1	10.00	129	625	0	1	25.00
069	4593	3132	3	100	130	557	556	1	7.8
070	4242	2714	3	100	132	834	0	6	52.27
071	8842	5421	2	99.78	133	5116	0	1	71.52
072	8563	7202	2	95	135	3400	0	2	64.25
073	605	1291	1	24.59	136	2209	0	2	62.71
074	9724	0	1	98.61	137	2462	1527	4	75.40
075	10000	0	1	100.00	138	1424	1400	9	96.58
076	10000	3983	1	100	139	3295	1855	5	79.48
079	9937	4745	1	99.68	140	5469	0	1	73.95
080	4180	2975	2	86.13	145	3890	0	4	96.27
081	9823	9114	1	99.11	146	6457	5471	1	80.36
083	1670	1488	7	100.00	150	9398	0	2	100
095	10000	9486	1	100	151	2130	0	1	46.15
096	5052	4895	2	97.28	152	898	0	2	41.61
105	5434	0	3	99.46	153	8499	0	1	9219
106	5360	0	2	100.00	155	1236	0	3	49.85
107	4458	2452	4	98.07	156	1278	1211	6	74.12
108	8348	2607	2	96.96	157	2606	1558	2	70.59
112	560	4795	1	23.66	159	219	0	1	14.81
113	421	412	5	34.06	160	2718	1867	3	84.43
114	2586	3951	4	71.68	165	2383	1950	2	55.7
115	1453	8788	1	38.12	171	3111	2883	1	51.07
116	3659	3571	2	75.75	180	1092	1005	1	10.46
117	4250	3555	2	87.71					

TABLE A-3 Market Structure Data on Oil Pipeline Product Origin Markets

BEA	Herfindahl Index	No. of Pipelines	Pipeline Percentage of Market	BEA	Herfindahl Index	No. of Pipelines	Pipeline Percentage of Market
02	1	344		113	4	1688	66.67
05	1	741	26.98	114	2	5979	92.43
8	1	2884	53.7	115	1	9476	97.35
9	1	1906	43.66	116	2	8400	96.35
12	1	587	23.19	117	1	1276	35.71
18	5	668	52.13	118	1	8573	92.59
28	2	3250	80.06	120	1	1352	36.76
47	1	3239	49.53	121	3	4827	91.22
49	1	858	24.48	122	5	4142	87.39
65	1	85	9.22	125	1	112	10.59
69	1	8559	92.51	133	2	2633	64.34
70	2	5199	89.98	135	3	5548	86.51
71	1	985	31.38	136	1	7499	86.60
76	1	3569	59.74	137	3	1952	63.05
79	1	447	21.15	138	6	2635	94.55
80	1	1255	23.4	139	5	2070	89.60
81	2	7877	95.92	143	1	4571	67.61
83	7	972	61.72	155	2	3245	78.26
85	1	4921	70.15	156	3	2269	75.34
96	1	1302	36.08	165	1	2031	45.07
105	2	4395	82.11	169	1	2500	50.00
107	4	2219	70.96	171	1	2229	47.00
108	2	6287	85.71	172	1	538	22.22
111	1	6335	79.30	176	1	92	8.04
112	2	6205	97.74	180	2	332	24.26

TABLE A-4 Market Structure in Oil Pipeline Product Destination Markets

BEA	No. of Pipelines	Herfindahl Index (HH I)	Pipeline Percentage of Market (PIP %)	Adjusted Herfindahl Index (HH1)	BEA	No. of Pipelines	Herfindahl Index (HH I)	Pipeline Percentage of Market (PIP %)	Adjusted Herfindahl Index (HH1)
001	1	1736	37.93	1317	90	1	10000	100	10000
006	1	531	11.64	531	92	1	10000	100	10000
008	3	7343	98.69	2948	93	1	10000	100	10000
009	3	3604	100	3333	94	1	7379	85.71	6347
010	2	4186	80.77	4186	95	1	4594	47.89	3866
011	4	5145	100	2500	96	1	3600	40.34	3333
012	3	3604	71.89	1187	97	1	10000	100	1000
013	2	7804	100	5000	98	1	8521	92.31	8521
016	5	2372	89.38	1352	99	2	5080	93.28	2824
017	4	4232	100	2670	100	1	10000	100	10000
018	3	2372	59.27	758	101	1	10000	100	10000
019	1	9182	95.81	4442	102	2	5082	100	5000
020	2	7985	99.35	4621	103	3	4634	100	3333
021	2	5001	100	5000	104	1	10000	100	10000
22	2	8059	99.81	4661	105	5	4274	100	2000
23	1	4978	65.38	3096	106	3	5090	99.36	3058
26	1	10000	100	10000	107	5	2031	69.13	1247
27	1	10000	100	1000	108	4	3299	92.47	2000
28	2	6495	100	5000	110	4	10000	100	10000
29	2	6495	100	5000	111	2	5465	89.11	2187
31	2	6495	100	5000	112	4	4937	98.81	1012
35	1	10000	100	10000	114	3	5374	82.64	788
36	2	6485	99.92	4860	115	1	9227	96.02	1301
37	2	5034	100	5000	116	1	5455	8.23	2700
38	2	5669	100	5000	117	1	7025	82.70	2533
40	1	9420	97.06	9246	122	1	1300	17.61	467
48	1	10000	100	1000	125	2	8218	93.57	6683
49	2	6474	99.84	4558	126	2	5445	100	5000
50	1	8264	90.91	8264	137	5	1437	67.25	909
51	2	6834	100	5000	138	2	4572	65.91	3333
53	2	5968	100	5000	139	3	1517	51.49	1111
54	1	8590	92.65	8590	140	1	10000	100	10000
55	2	2033	56.40	945	141	1	10000	500	10000
57	1	2400	45.52	599	142	2	5182	100	5000
63	1	4444	40	4050	143	2	7146	100	5085
64	4	3009	100	2500	144	2	5509	100	5085
65	2	4788	80.07	3463	146	1	5011	47.62	5000
66	2	4930	91.94	4930	147	3	5261	100	3333
67	1	5254	70.85	2236	148	2	5266	100	5000
68	1	10000	100	10000	149	2	5556	100	5000
69	3	3075	57.62	2500	150	1	10000	100	1000
70	4	2521	56.31	2000	156	1	2867	19.67	2500
71	3	2887	85.45	2500	157	3	2143	71.74	2000

TABLE 4 continued

BEA	No. of Pipelines	Herfindahl Index (HH I)	Pipeline Percentage of Market (PIP %)	Adjusted Herfindahl Index (HH1)	BEA	No. of Pipelines	Herfindahl Index (HH I)	Pipeline Percentage of Market (PIP %)	Adjusted Herfindahl Index (HH1)
72	1	4290	50.56	3393	158	2	5895	100	5000
73	2	3520	82.61	3117	160	2	2347	50	2221
74	1	1000	100	1000	161	1	10000	100	10000
75	1	10000	100	1000	162	1	9383	96.82	9041
76	2	4643	89.38	3333	163	1	9065	95.08	8200
78	1	10000	100	10000	164	1	10000	100	10000
79	3	3781	90.18	2500	165	1	1634	19.55	1288
80	1	5129	65.95	2840	166	1	10000	100	10000
81	2	8395	28.8	5000	167	1	10000	100	10000
83	5	1629	46.43	1105	168	2	6543	100	5005
85	1	10000	100	10000	169	1	5057	71.1	0
86	1	6250	75	5000	170	1	10000	100	10000
87	1	2261	45.83	567	172	1	5894	76.19	3793
88	2	5113	100	5000	173	1	8664	93.02	8534
89	1	8950	94.58	7750					