TRANSPORTATION RESEARCH RECORD 920

Trucking and Intermodal Freight Issues

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NATIONAL RESEARCH COUNCIL
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Federal Truck Size and Weight Study

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The report to Congress that has recently been prepared in response to a directive by the Congress to examine the need for, and desirability of, uniformity in maximum truck length and weight limits throughout the United States is summarized. Several alternative changes to federal limits on truck length and weight are investigated, and the impacts that these changes would have on truck productivity, modal diversion, freight costs, pavement and bridge costs, safety, energy, air quality, and noise are estimated. Also estimated was the present value of forecast cumulative changes in transportation and highway system costs. It was found that increases in truck length and weight limits within a substantial range provide sufficient transportation cost savings to pay for damage done to the highway system under changes in the limits. However, if limits are increased without a corresponding increase in highway system expenditures, then the condition of pavements and bridges in the United States would deteriorate, which would, in turn, affect the motor vehicle operating costs, travel speeds, and circuity experienced by highway users.

The federal government has been involved in the regulation of truck size and weight limits on the Interstate system since the passage of the Federal-Aid Highway Act of 1956. In the Federal-Aid Highway Amendments of 1974 the Congress set limits to truck size and weight by providing for 20,000 lb on a single axle, 34,000 lb on a tandem axle, and 80,000 lb for the gross vehicle weight (GVW); these limits are further controlled by a formula that limits the total weight in accordance with axle spacing.

As of January 1, 1981, six Mississippi Valley states (generally called the barrier states) had gross weight limits for the Interstate system at the lower levels provided for in federal legislation before 1974 (i.e., 73,280 lb). Five Mississippi Valley states plus Montana had axle limits less than the current federal limits of 20,000 lb for single axles and 34,000 lb for tandem axles on the Interstate system.

A much greater number of states have limits greater than the current federal Interstate standards under a grandfather clause provision of federal highway law. Most of the northeastern and southeastern states have higher axle limits, which are often even higher off the Interstate system. Higher gross limits are common among western states, particularly off the Interstate system. In addition, only 36 states allow the operation of "doubles" (tractor-semitrailer-trailer or truck-trailer) on some or all of their highways, 4 allow only a 60-ft length, and 2 permit only 55 ft.

This disparity in size and weight limits makes it difficult for truckers engaged in interstate hauling to operate efficiently. A trucker whose operations cross several state borders must either configure his rig to comply with the lightest axle or gross weight limits (and thus reduce payload) or route his trips to avoid states that have lower limits (and thus add time and mileage); either alternative results in higher costs per ton of cargo. A third alternative is to run illegally in states that have lower limits and accept the risks of detection and consequent delays and fines. Some truckers choose this alternative.

In response to these and other related problems, Section 161 of the Surface Transportation Assistance Act of 1978 directed the Secretary of Transportation to examine the need for, and desirability of, uniformity in maximum truck size and weight limits throughout the United States. A summary of the report to Congress (1,2) that was prepared in response to this directive is presented in this paper.

APPROACH

The federal truck size and weight (TS&W) study analyzes the impacts of changes to federal limits on truck length and weight under 10 alternatives, or scenarios, that specify truck size configurations and weight limits to be evaluated, as well as the extent of the highway system to which the limits would apply and the degree of required conformity by the states. These 10 scenarios consist of a base case and 5 categories of changes in current federal truck length and weight limits.

The base case is an extrapolation to 1985 of recent trends in truck activity, with no changes in the federal or state limits that were in effect on January 1, 1981. It serves as a benchmark against which benefits and costs for the various scenarios are compared. The five categories of changes in limits are

1. Grandfather clause elimination,
2. Barrier elimination,
3. Uniformity (eliminate barriers and grandfather clause),
4. Rollback to pre-1974 limits (retain grandfather clause), and
5. Increases in limits (eliminate barriers and retain grandfather clause).

The data in Table 1 describe the scenarios. January 1, 1981, truck width limits are assumed to remain in effect for all scenarios because proposals to increase truck width were not under active consideration when this study was initiated.

All impacts are expressed in terms of changes from the base case. They have been estimated as annual costs for 1985 for all impacts, except for costs for reconstruction of existing bridges, which are one-time costs.

In order to provide a uniform basis for comparing scenarios to the base case the present value of forecast cumulative changes in costs has been calculated for each scenario. These present values have been calculated by summing all projected future impacts (cost changes from the base case for all future years) and discounting them by 10 percent/year in real terms.

Findings are reported at the national level for all impact areas. In addition, regional results are reported for some of the most significant impacts. The regions are mapped and defined by name in Figure 1. The regions have been defined so as to group contiguous states with relatively similar current TS&W limits. This has been done in order to facilitate the analysis and reporting of impacts of possible changes in federal limits, including the impacts of achieving greater uniformity.

The state TS&W limits as of January 1, 1981, can be characterized by region as follows (federal limits apply unless otherwise indicated):

1. Northeast--high axle limits; 65-ft doubles are not permitted (except in Delaware and Maryland);
2. Southeast--high axle limits (except in Virginia and West Virginia); 65-ft doubles are not permitted (except in Florida);
3. Mideast--65-ft doubles are permitted; Michigan has very high GVW limits;

Table 1. Definitions of TS&W scenarios.

Scenario	Short Title	Affected Highway System	Definition
A	Base case		Current federal TS&W limits and current state limits
B	Grandfather clause elimination	Interstate	Elimination of all grandfathered limits on the Interstate system
C	Grandfather clause elimination	Interstate and primary	Elimination of all grandfathered limits on the Interstate and primary systems
D	Barrier (weight only) elimination	Interstate	Elimination of all weight barrier limits on the Interstate system
E	Barrier (weight and length) elimination	Interstate	Same as for D, but also includes elimination of all length limits of less than 65 ft for all combinations permitted by a state on the Interstate system
F	Barrier elimination	Interstate and primary	Strengthens E by extending federal limits to primary system and by eliminating states' power to prohibit doubles of up to 65 ft
G	Uniformity	Interstate and primary	Elimination of all grandfathered limits and all limits below those specified in Section 127 (the barrier limits) on the Interstate and primary systems; also, length limits must be at least 65 ft on all combinations permitted by a state
H	Rollback	Interstate and primary	Reduces all federal limits to pre-1974 levels and extends applicability to primary system
J	Increased weights	Interstate and primary	Increases federal axle weight limits to higher levels prevailing in several states; removes GVW limits, but substitutes higher bridge formula C for current formula B; prohibits barrier limits; and extends applicability to primary system
K	Low axle, formula A	Interstate and primary	Eliminates GVW limit to permit heavier trucks, but limits these trucks by the lower pre-1974 axle limits and bridge formula A; prohibits length limits for combinations of less than 65 ft; prohibits barrier limits; and extends applicability to primary system

Figure 1. Regions used in TS&W study.

4. Southern barrier--lower axle limits and GVW limits (73,280 lb); 65-ft doubles are not permitted;

5. Midwestern barrier--lower GVW limits (73,280 lb) and lower axle limits (except in Illinois); 65-ft doubles are permitted;

6. North Central--65-ft doubles are permitted;

7. West Central--65-ft doubles are permitted; higher GVW limits on other primary highways; Nebraska has low axle limits, low GVW limits on the Interstate, but allows high GVW on the Interstate by permit; Wyoming and Colorado have high axle limits for tandems;

8. Southwest--65-ft doubles are permitted; New Mexico has high axle limits and GVW limits;

9. Northwest--65-ft doubles are permitted; high GVW limits on other primary highways and by permit on Interstate;

10. Alaska--65-ft doubles are permitted; high GVW limit; and

11. Hawaii--65-ft doubles are permitted; high single-axle limit; high GVW limit on other primary highways.

DISCUSSION OF SCENARIOS

Truck Productivity

From the perspective of users of trucks there is great economic value in having the flexibility to choose vehicles and vehicle loadings that will meet their needs effectively and at a lowest cost. Increases in TS&W limits will increase the allowable tonnage and volume of freight (per trip) that can be carried. Under these circumstances fewer trips and vehicle miles of travel (VMT) will be required to carry the same amount of freight. This improvement in truck productivity reduces truck costs. Conversely, decreases in TS&W limits will increase trips and VMT and result in an increase in truck costs. The cost savings or cost increases will accrue to truckers, shippers, receivers, and consumers. The portion of cost savings or increase that each group receives depends primarily on the competitiveness of the affected markets.

The effects of the TS&W scenarios on truck productivity, as measured by the impact on the truck freight cost per ton-mile, are shown in Figure 2.

Elimination of the grandfather clause in scenarios B and C results in a worsening of truck productivity in those states with limits that currently exceed the federal standard.

The elimination of barrier limits in the six Mississippi Valley states with limits lower than the federal standard results in truck productivity improvements for shipments into, within, and through these states. Extending the elimination of barrier limits from just the Interstate system (as in scenarios D and E) to both the Interstate and primary systems (as in scenario F) results in substantially larger improvements in truck productivity.

Scenario G (the establishment of uniform TS&W limits by eliminating both the grandfather clause and barrier limits on both the Interstate and primary systems) results in improved productivity for shipments into, within, and through the barrier states, and worsened productivity for shipments in states with grandfather clause limits. The net effect of these changes is a modest improvement in truck productivity.

Scenario H (the rollback of truck size and weight limits to pre-1974 levels) results in a worsening of truck productivity, primarily because the payloads carried by many trucks would have to be reduced. This decrease in payloads in turn results in more vehicle miles being required to carry the same amount of freight and correspondingly higher truck freight costs.

Scenario J (increased weight limits) results in a substantial decrease in truck cost per ton-mile because it allows carriers to load existing trucks more heavily and, in some cases, to shift to different truck configurations that have higher average payloads. The shaded portion of the bar for scenario J in Figure 2 (and in later figures) represents the range of impacts for two variations of scenario J. These two variations differ only moderately in impacts to truck productivity and transport cost. They differ substantially in terms of pavement costs, however, and are discussed in the section on Pavement Impacts.

Scenario K also assumes the elimination of gross weight limits to permit heavier overall loads. Nevertheless, the lower pre-1974 axle limits and lower bridge formula A would be applied to these heavier trucks in order to reduce their impacts on pavements and bridges. This scenario results in cost savings due to productivity improvements about one-tenth the size of those for scenario J.

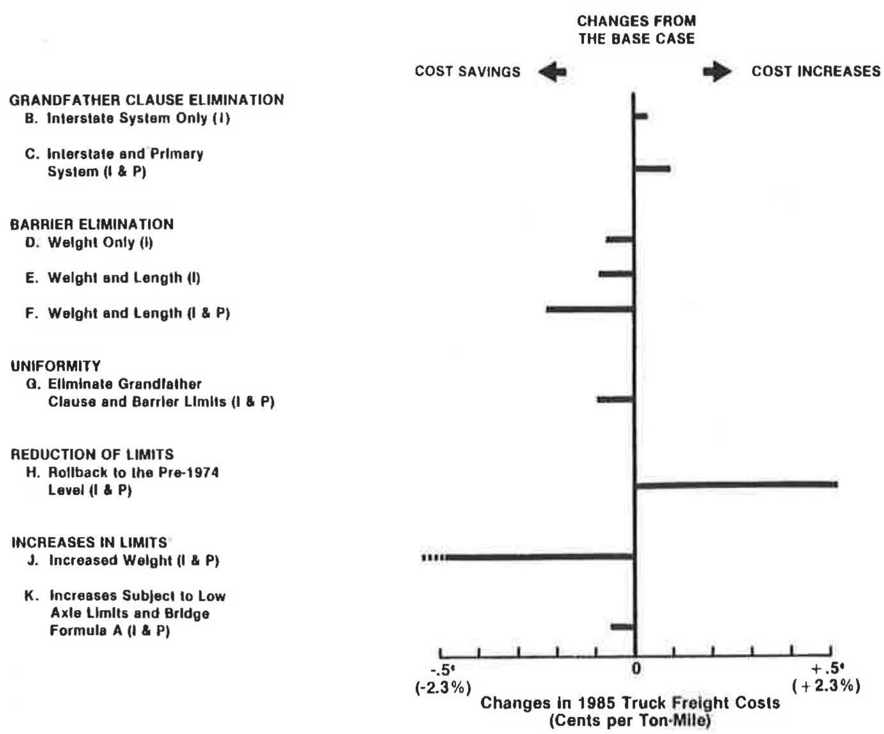
Modal Diversion

Choice of mode is only moderately sensitive to shipping costs and rates compared with other components of overall distribution costs and quality of service (including handling costs, reliability, security, and inventory costs). However, changes in TS&W limits will have little effect on these other components of distribution cost and quality of service because shipping costs and rates are the principal modal-choice factors that would be affected by TS&W limit changes.

Changes in truck costs and rates result in some change in the selection of transport mode for some shipments. The most significant effect would be on competition between rail and truck. Higher truck rates would result in the diversion of some shipments to rail whereas lower truck rates would have the reverse effect. Changes in truck costs and rates could also have some slight effect on barge traffic (by affecting the competitiveness of truck and barge transport with rail transport) and on air traffic, but these effects on modal competition are considered to be minor, and they have not been analyzed in this study.

The effects of the alternative scenarios on rail traffic (billions of short-line ton-miles) are shown in Figure 3. The data in the figure indicate that the six scenarios that would reduce truck transport costs will also result in moderate diversion of traffic from rail to truck. The greatest effect would occur in scenario J, in which it is estimated

Figure 2. Scenario impacts on truck productivity.



that rail traffic would decline by about 27 billion ton-miles, or about 2 percent of 1985 base case rail traffic. Only a small amount of diversion from truck to rail will occur in the case of the grandfather clause elimination scenarios, and a moderate amount of diversion (about 13 billion ton-miles) will occur in the case of reduced weight limits.

Total Freight Costs

The effects of the scenarios studied on total (truck and rail) freight costs are shown in Figure 4. The impacts shown are the net effect of changes in truck productivity and diversion to or from rail.

The scenarios that improve truck productivity (D,

Figure 3. Scenario impacts on modal diversion.

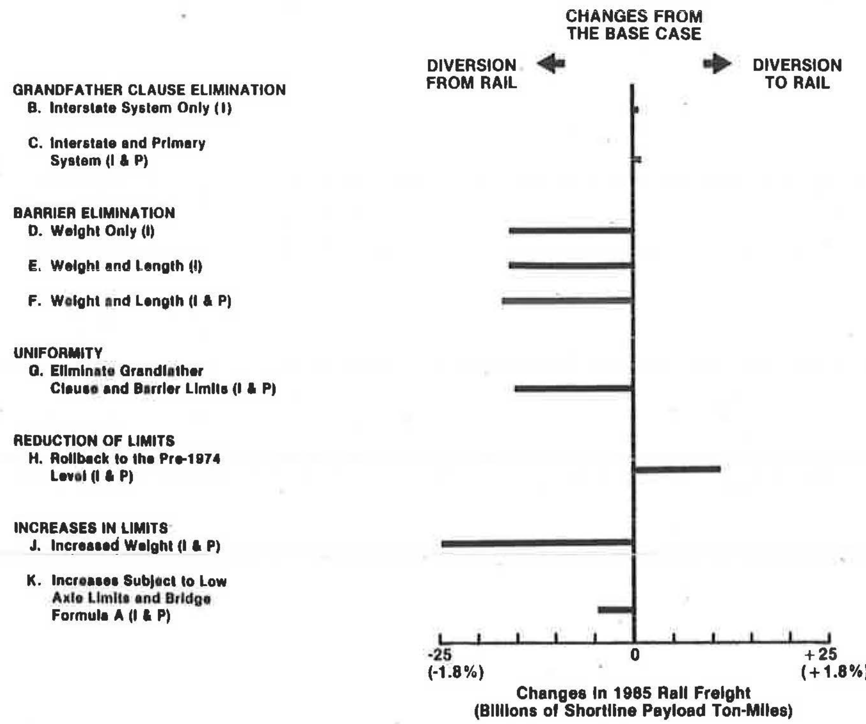
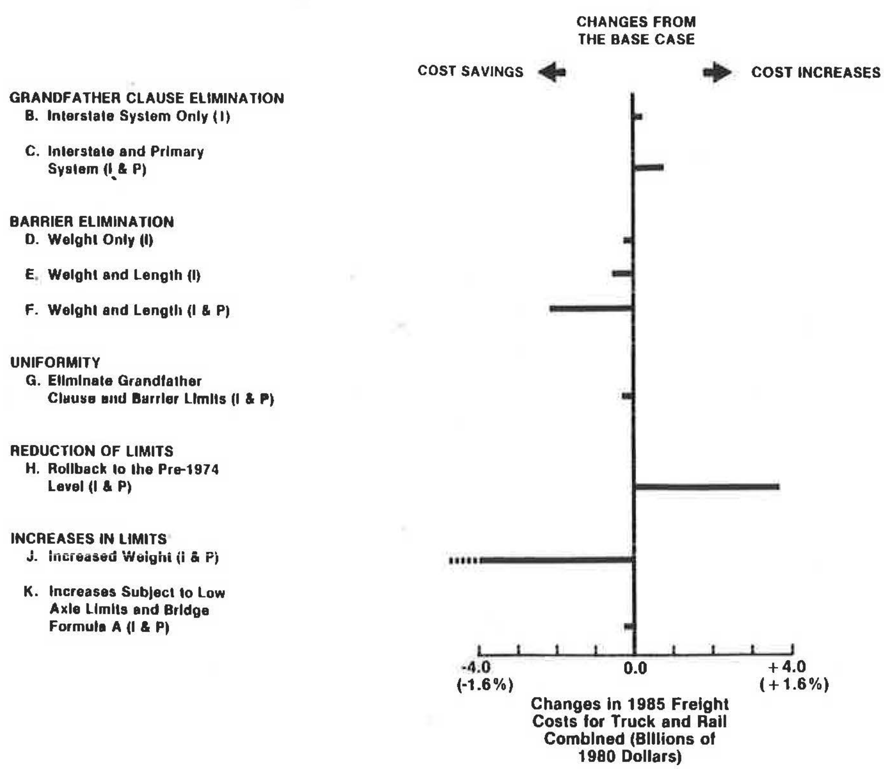


Figure 4. Scenario impacts on total freight costs.



E, F, G, J, and K) result in lower total freight costs for truck and rail combined. The scenarios that worsen truck productivity (B, C, and H) result in higher total freight costs for truck and rail combined. However, in both cases the magnitude of the changes in total freight costs is less than that due to changes in truck productivity alone.

For those scenarios that improve truck productivity, some of the cost savings due to improved productivity will be offset by cost increases due to diversion from rail to truck. Many shippers who shift from rail to truck may do so even though the shift results in increased shipping costs. Many shippers are willing to shift despite increases in their freight costs because truck offers shorter shipment times and more reliable delivery dates than rail. Conversely, for those scenarios that worsen truck productivity, some of the cost increases due to worsened truck productivity are offset by cost savings due to diversion from truck to rail. However, those shippers who shift from truck to rail lose the shorter shipment times and more reliable delivery dates associated with truck transport. In balance, the effect of scenarios B, C, and H on those shippers who shift to rail is negative because they would choose to ship by truck in the base case and would shift to rail only when truck weight limits are decreased. The data in Figure 4 present only the net effects of all these factors.

Pavement Impacts

Highway pavements are affected by changes in the number of trucks and truck axle weights. Pavement wear increases sharply with increases in axle weights. Thus higher axle weight limits tend to accelerate pavement wear, even though they reduce truck miles by allowing higher average payloads.

Accelerated pavement wear affects the expenditure levels required by highway agencies to maintain the condition of the highways, primarily as a result of increased pavement maintenance costs and requirements for more frequent or costly pavement overlays.

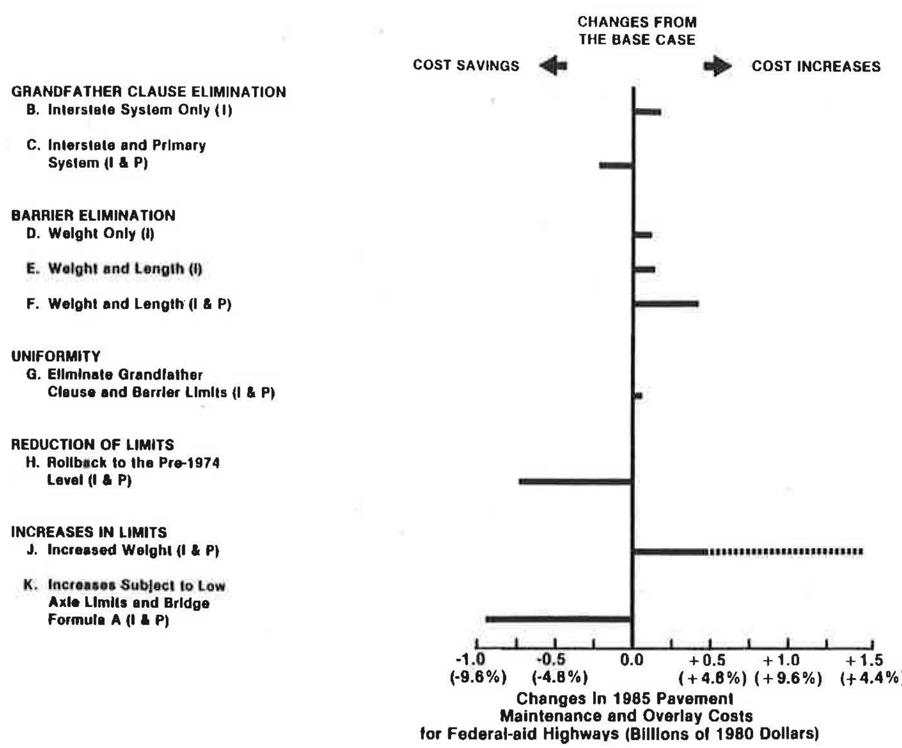
Although relatively little factual data exist regarding recent trends in national average pavement conditions, the general consensus is that states have not been able to meet requirements to hold average conditions constant. For those scenarios that would involve substantial additional requirements, doubt exists as to the ability of the states to respond adequately. Inability to meet these requirements would result in greater long-term pavement resurfacing costs and increased vehicle operating costs.

The impacts of the TS&W scenarios on the pavement maintenance and overlay requirements in 1985 are shown in Figure 5. These estimates are based on the amount of work required to maintain the current conditions of the Federal-Aid highways. No analysis of impacts has been conducted for non-Federal-Aid highways, principally because both data and theory are lacking for many of them. Because non-Federal-Aid highways are typically low-volume roads, the pavements for these highways often reflect standard minimum designs; these pavements usually provide greater load-carrying capacity than the traffic that uses the highway requires. These minimum pavement designs are constructed principally to withstand non-traffic-related damage (e.g., environmental effects), and modest changes in truck traffic should have little effect on most of these highways. Nevertheless, because non-Federal-Aid highways comprise most (80 percent) of the highways in the United States, modest incremental cost changes can amount to significant costs. In a small proportion of these highways that carry high-volume heavy truck traffic (e.g., coal-haul roads), weight increases can cause major pavement cost increases, particularly on routes that have low-quality pavements.

In summary, the overall national effect of limiting pavement impacts to Federal-Aid highways is probably a fairly small underestimate of national costs, but the effects on a small proportion of the routes may be quite significant.

Generally, those scenarios that allow higher axle weights result in more pavement costs. The excep-

Figure 5. Scenario impacts on pavement costs.



tion is the elimination of the grandfather clause on the Interstate system. Under this scenario some trucks would divert from the Interstate system to other Federal-Aid primary highways so that they could continue to take advantage of grandfather clause limits. Thus, although truck weights on the Interstate system would decrease (producing a reduction in Interstate system pavement costs), truck weights on other primary highways would increase, thereby producing an increase in pavement requirements on these highways. The net result is a small increase in pavement costs.

Scenario F, which eliminates barrier limits on both the Interstate and primary systems, produces a large increase in pavement requirements. Under this scenario pavement maintenance and overlay costs would be about 4 percent higher than under the base case. In the barrier states pavement maintenance and overlay requirements would increase by about 14 percent over the base case.

Scenario J, which would allow the largest increases in axle weights, results in the largest increase in pavement requirements. Two variations of scenario J were analyzed: the increase in pavement requirements might be as little as that shown by the solid bar in Figure 5 or as great as that shown by the shaded bar.

In the first variation a substantial amount of freight traffic would shift from tractor-semitrailers to short heavyweight doubles, which have more axles than tractor-semitrailers (doubles with short trailers that have tandem axles). Although a fully loaded short heavyweight double weighs more than a fully loaded tractor-semitrailer, its weight is spread over more axles; therefore, it does less damage to pavements than the tractor-semitrailer. Under this variation pavement cost increases would be about $350 million.

If the projected shift to short heavyweight doubles does not materialize, the impacts of scenario J on pavement requirements could be substantially worse. To quantify this effect, a second variation on scenario J was analyzed for pavement impacts. In this variation there is no shift of freight movement between truck types. The only effects are that trucks run heavier to take advantage of the more permissive weight limits, and some traffic will shift from rail to truck. In this variation, the impact of scenario J on 1985 pavement maintenance and overlay requirements jumps to about $1.5 billion, almost 14 percent higher than would be required to maintain and overlay pavements to the constant average condition in the 1985 base case.

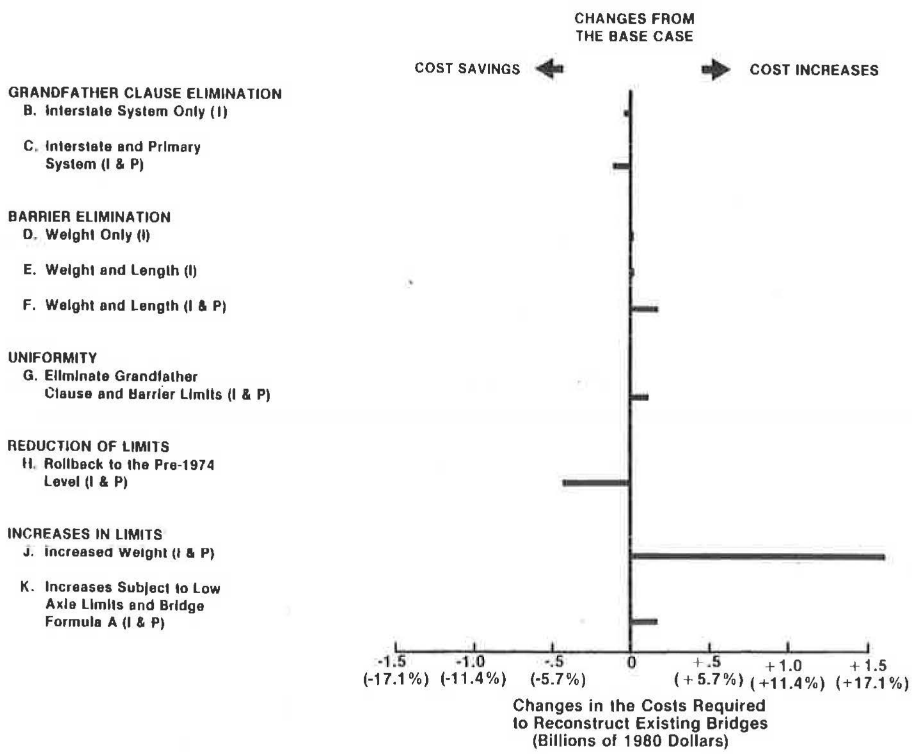
Bridge Impacts

The structural members of bridges are affected by GVW and axle spacings. Bridges are designed to withstand overstresses, but repeated applications of loads beyond those assumed in bridge design will produce adverse cumulative effects that may require that the bridge be rebuilt or posted to prohibit heavier trucks.

The impacts of each TS&W scenario on costs required to reconstruct those existing bridges that would have inadequate load-bearing capacities under each scenario are shown in Figure 6. The cost impacts for existing bridges have been calculated based on the assumption that all bridges that cannot carry legal loads (within permissible overstress criteria) under each scenario would be reconstructed. The costs for reconstruction of existing bridges are one-time costs. However, several years would transpire before the full impacts would be experienced, and several years would be required to finance and obligate these expenditures. Accordingly, it was assumed that these expenditures would be spread evenly over the 5-year period from 1981 to 1985.

The percentages given in Figure 6 indicate the bridge cost impacts as a percentage of projected capital outlay for bridges on state-administered highways over this period. However, note that states may choose to post bridges (or otherwise re-

Figure 6. Scenario impacts on bridge costs.



strict use to lighter vehicles) as an alternative to reconstruction. Through posting, states can save, or at least postpone, bridge reconstruction costs. The disadvantages of posting (as an alternative to reconstruction) are difficulty of enforcement and added circuity of truck travel, which results in higher goods movement costs and higher fuel consumption.

Scenario J results in the largest increase in bridge costs for any of the scenarios analyzed. Bridge costs would increase in all regions under this scenario. The largest increases would occur in barrier states and in those states that currently allow doubles but restrict gross weights to levels at or below the federal limit of 80,000 lb. Under scenario J short heavyweight doubles that weigh about 105,000 lb would become legal. This type of truck would exceed permissible overstress criteria for many long span bridges with low design loads.

The largest savings in bridge costs would occur under scenario H, under which TS&W limits are rolled back to pre-1974 levels. Bridge costs under this scenario would be reduced in all regions except the barrier states, where the GVW limit is currently 73,280 lb, as it was before 1974.

The impacts of TS&W scenarios on costs required to construct new bridges so that they can handle projected traffic loadings have also been estimated. These impacts tend to parallel cost impacts for existing bridges in terms of the relations among scenarios, but they are far smaller in magnitude.

Safety Impacts

Safety impacts of changes in TS&W limits result from changes in the number of truck trips and the types of trucks used. Increases in TS&W limits tend to increase truck payloads and allow a given volume of freight to be moved with fewer trips. This effect tends to decrease the highway users' exposure to truck accidents. However, improvements in truck productivity associated with increases in TS&W limits create the potential for diversion of freight to trucks from other modes. In many cases the amount of freight diverted is of sufficient magnitude to produce a net increase in accidents.

One of the most contested issues in analyzing the safety impacts associated with TS&W limits is whether accident rates for double trailer trucks are higher than the rates for tractor-semitrailers. Recent safety studies produce conflicting results on this issue: some indicate substantially higher accident rates for doubles, and others indicate no appreciable difference in the accident rates of doubles and tractor-semitrailers.

An intensive examination of truck safety conducted by Bio Technology, Inc. (3) has recently provided evidence from selected highway test sections indicating that accident rates for double trailer trucks are appreciably higher than the rates for tractor-semitrailers. This study, and in particular this conclusion, has been highly criticized by the trucking industry, which has alleged that there are a number of flaws in the study methodology and that the results cannot be used to draw general conclusions regarding the comparative rates of different truck configurations.

The changes in total accidents under each scenario are shown in Figure 7. Two sets of impacts are shown because wide disagreement exists regarding the relative safety records of different types of combinations. The most significant difference in the assumptions of the two results shown in Figure 7 is that the first set of results (the striped bars) assumes that doubles have substantially higher accident rates, and the second set of results (the solid bars) assumes that doubles have the same accident rates as tractor-semitrailers. There are studies that support both assumptions.

Energy Impacts

An increase in the size and weight limits would permit trucks to transport more freight with only a slight increase in fuel consumption. Total freight transported per gallon of fuel would thus rise.

Figure 7. Scenario impacts on safety.

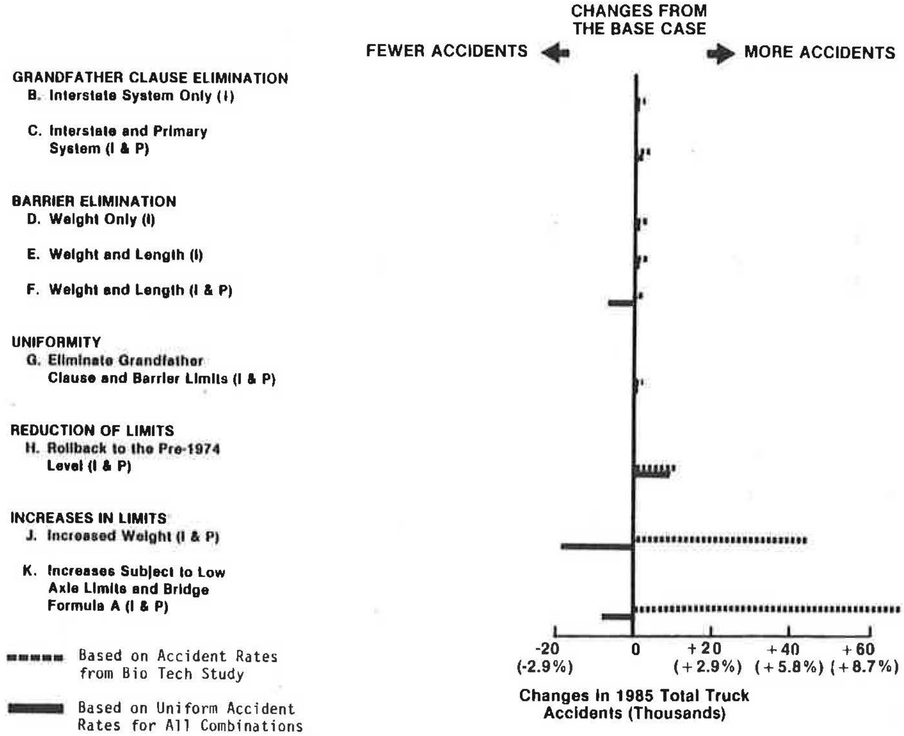


Figure 8. Scenario impacts on energy consumption.

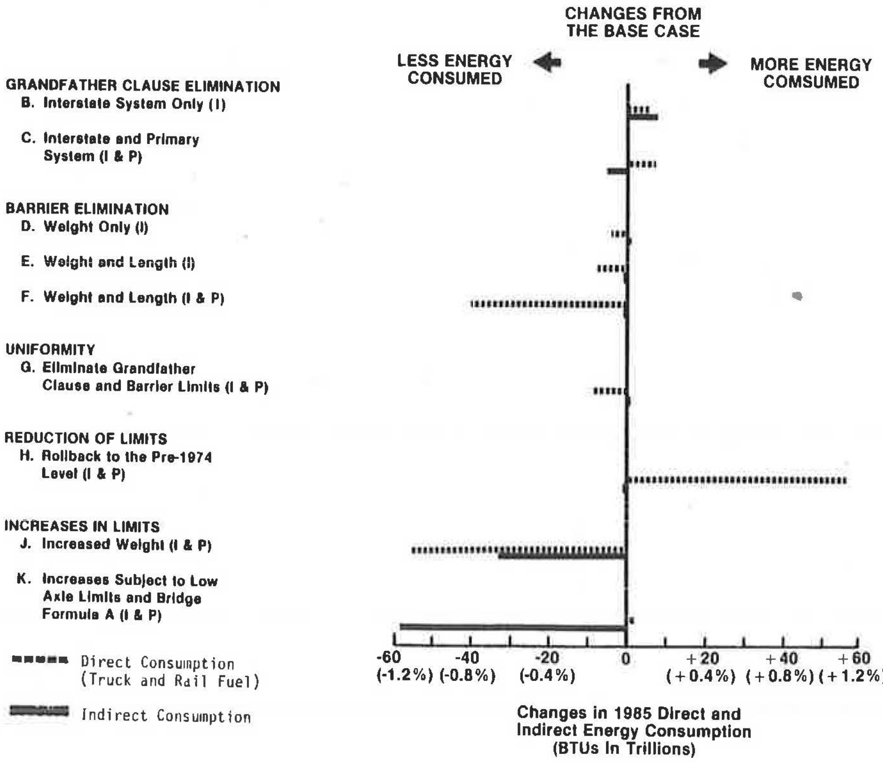


Table 2. Scenario impacts on air quality.

Scenario	Hydrocarbons	Nitrogen Oxides	Carbon Monoxide	Particulates
	Change in Emissions from Heavy-Duty Vehicles and Rail Freight Operations (%)			
B	+0.17	+0.15	+0.17	+0.15
C	+0.34	+0.38	+0.41	+0.37
D	-0.68	-0.32	+0.25	-0.29
E	-0.71	-0.37	+0.13	-0.34
F	-1.27	-1.18	-1.00	-1.13
G	-0.63	-0.39	-0.06	-0.32
H	+1.34	+1.44	+1.56	+1.46
J	-2.30	-2.68	-3.12	-2.62
K	-1.03	-1.23	-1.49	-1.20

This improvement in fuel efficiency, however, would be offset somewhat by diversion of traffic to trucks from the more fuel-efficient rail mode. Higher weight limits may also result in increases in energy consumed in paving and maintaining the highway system.

The impacts of the scenarios analyzed on direct energy consumption (truck and rail fuel) and on indirect energy consumption are shown in Figure 8. Indirect energy is primarily the energy required for pavement overlays, but it also includes energy consumed in road maintenance, bridge construction and repair, and production of fuel, as well as energy embodied in vehicles and parts. (In the case of scenario J the bars shown in Figure 8 represent the impacts expected for the variation involving a major shift of payload to short heavyweight doubles. Each of the two bars would be slightly shorter--perhaps about 10 percent shorter--but in the same direction for the variation that involves no shift of truck payload to short heavyweight doubles.)

The data in Figure 8 indicate that the gains in truck fuel efficiency due to increases in TS&W limits are generally dominant by comparison with the offsetting effects of rail-to-truck loss of fuel efficiency and added pavement requirements.

Air Quality Impacts

The impact of each TS&W scenario on hydrocarbon, nitrogen oxide, carbon monoxide, and particulate emissions from heavy-duty trucks and rail freight operations is given in Table 2. Increases in TS&W limits would generally reduce emissions slightly, and decreases in TS&W limits would increase emissions slightly, because emissions are closely correlated with changes in truck miles.

The largest increases in emissions for heavy-duty vehicles and rail freight operations would result from scenario H (the rollback scenario), ranging from 1.34 percent for hydrocarbons to 1.56 percent for carbon monoxide.

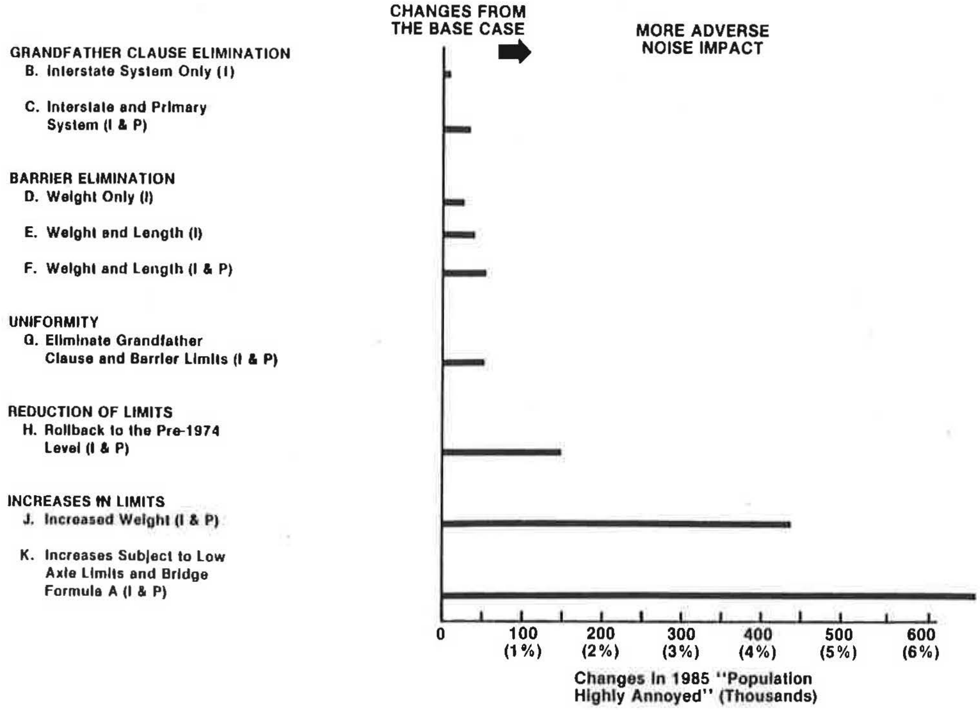
The largest decreases would result from increases in TS&W limits in scenario J, ranging from 2.30 percent for hydrocarbons to 3.12 percent for carbon monoxide.

Noise Impacts

Noise impacts of each TS&W scenario have been estimated based on an analysis of vehicle and traffic conditions for typical road segments and an empirical relation developed by the U.S. Environmental Protection Agency (EPA), which relates noise levels to the fraction of residents who describe their reaction to noise as highly annoyed. Community response to noise is difficult to capture in a single measure, so "population highly annoyed" should be regarded as a somewhat abstract index of the relative community noise impact.

Some adverse noise impacts relative to the base case are expected for all scenarios, as shown in Figure 9. For those scenarios that decrease TS&W

Figure 9. Scenario noise impacts.



limits, the adverse effects would be due to an increase in truck miles. For those scenarios that increase TS&W limits, the adverse effects occur because, even though total truck travel decreases, large increases in average load and number of axles significantly increase noise exposure. Due to the predominance of this effect, scenarios J and K result in more adverse noise impacts than other scenarios.

Economic Impacts of Grandfather Clause Elimination

The grandfather clause is a provision of federal highway law that permits all states to retain any limits above the federal limits if such limits were in force before the effective date of the federal limits (July 1, 1956). As of January 1, 1981, 15 states still had Interstate system single-axle limits greater than 20,000 lb, 17 states had Interstate tandem-axle limits greater than 34,000 lb, and 12 states had Interstate gross limits greater than 80,000 lb.

Elimination of the grandfather clause would result in a worsening of truck productivity (as shown in Figure 2) and an increase in overall transport costs (as shown in Figure 3). These cost impacts, which are small in percentage terms when spread over all commodities and industries, may actually involve substantial impacts on particular industries. For this reason a special investigation was conducted to determine which specific industries would be affected and by how much.

In most instances the increased costs will be small in relation to the value of the goods transported. These increased costs will result in a slight price increase to consumers or a slight decline in receipts of affected producers or shippers. In the case of industries that ship commodities with a low value per ton (e.g., agriculture, logging, construction), increased truck transport costs would represent a higher percentage of commodity value (perhaps 1 or 2 percent, and in a few instances as much as 10 percent).

Discernible economic effects due to reduced weight limits on the Federal-Aid primary system are most likely to be observed in the following areas.

1. In southern Idaho, Montana, and western North Dakota, farmers whose wheat is currently transported to Lewiston, Idaho, in double-bottom trucks (about 10 percent of total production) may have their receipts decline by up to 3 percent. Some additional dislocations might occur due to resulting adjustments in the grain marketing system.
2. In Michigan several commodities will be affected by a reduction of the current 164,000-lb effective GVW limit on designated highways to 80,000 lb. Sugar beets is likely to be the most affected commodity. Among the economically more important commodities, timber and to a lesser extent corn are likely to be the most affected. Increased transport costs for affected shipments of corn (about 10 percent of corn produced in Michigan) will average less than 1 percent of the price of corn.
3. In Nevada and Utah the current limits are 129,000 and 122,000 lb, respectively, and the existing rail network is limited. Reduction of these high limits could affect some mines, particularly those in remote locations.
4. In Alaska only one rail line and no Interstate highways exist; a 109,000-lb GVW limit applies to other roads.
5. In several eastern states particularly high limits exist for three- and four-axle single-unit trucks. In states where the highest of these limits exist overall costs for individual highway construction and maintenance projects that must be accessed by roads to which reduced weight limits apply are likely to increase by about 2 percent. The cost of highway projects that do not require such access will increase by less, if at all. (These changes do not reflect the savings in highway costs due to reduced requirements for pavement construction and maintenance reported for scenario C in Figures 5 and 6.) The cost of other affected construction projects in these states will be increased to a lesser extent.

If reduced weight limits are applied only to the Interstate system, fewer construction projects and minerals movements will be affected, and a number of states that do not have high limits on the Interstate system will be unaffected.

PRESENT VALUE OF CUMULATIVE COST CHANGES

All of the cost impacts discussed in the preceding sections are annual impacts for 1985, with the exception of the costs for existing bridges, which are a one-time cost for reconstruction of existing bridges on Federal-Aid highways.

Cost impacts for years before 1985, as well as future years, will not generally be at the same levels shown for 1985. For example, the increases in pavement costs shown in Figure 5 will not be sustained indefinitely. Once highway pavements have been adequately rehabilitated to accommodate heavier trucks, adverse pavement cost impacts will be reduced to a small fraction of those shown in Figure 5 for 1985.

The present value of forecast cumulative changes in highway costs for each scenario as compared with the base case is shown in Figure 10. The cumulative cost changes reflect pavement and bridge cost impacts in years before 1985 as well as in all future years. Scenario J, which would allow the largest increases in axle weights, results in the largest increase in the present value of highway cost impacts. The increase in highway costs in scenario J may be as little as $2.6 billion if the shift to short heavyweight doubles materializes, or as large as $6.4 billion if it does not.

The cumulative highway cost changes shown in Figure 10 would have to be borne by highway agencies, and presumably should be passed on to trucks through user charges in an equitable manner. These cost changes are calculated as the requirements for highway agency expenditures necessary to maintain current highway condition. If this expenditure does not occur (e.g., if expenditures by highway agencies remain the same under each scenario), then the condition of the pavements and bridges would deteriorate, which would in turn affect the motor vehicle operating costs, travel speeds, and circuity experienced by highway users.

The costs to highway users associated with a worsening of highway conditions can be substantial. For example, if highway agency expenditures for pavement overlays under scenario J are the same as those projected for the base case, then scenario J would produce a worsening of pavement condition. The present value of the cumulative changes in motor vehicle operating costs alone due to this worsening of pavement condition could be on the order of $17 billion. Thus if highway agencies are unable to meet the expenditure levels to maintain highway conditions under each scenario, cumulative cost changes due to highway system damage could be considerably greater than those shown in Figure 10 for those scenarios that result in additional pavement requirements (i.e., B, D, E, F, G, and J). The distribution of these costs among the states are not uniform and vary according to the scenario.

The present value of forecast cumulative cost changes for freight transportation, including changes in expenditures for truck and rail freight transportation and property damage due to accidents is shown in Figure 11.

The present value of forecast cumulative cost changes for highways and transportation combined is shown in Figure 12. Freight transportation costs tend to be the dominant component. Scenarios D, E, F, and G, which would eliminate barrier limits, and scenarios J and K, which would increase limits, all show cost savings relative to the base case for highway and transportation costs combined. The practical implication of this finding is that elimination of barriers or increases in TS&W limits

Figure 10. Present value of highway cost impacts.

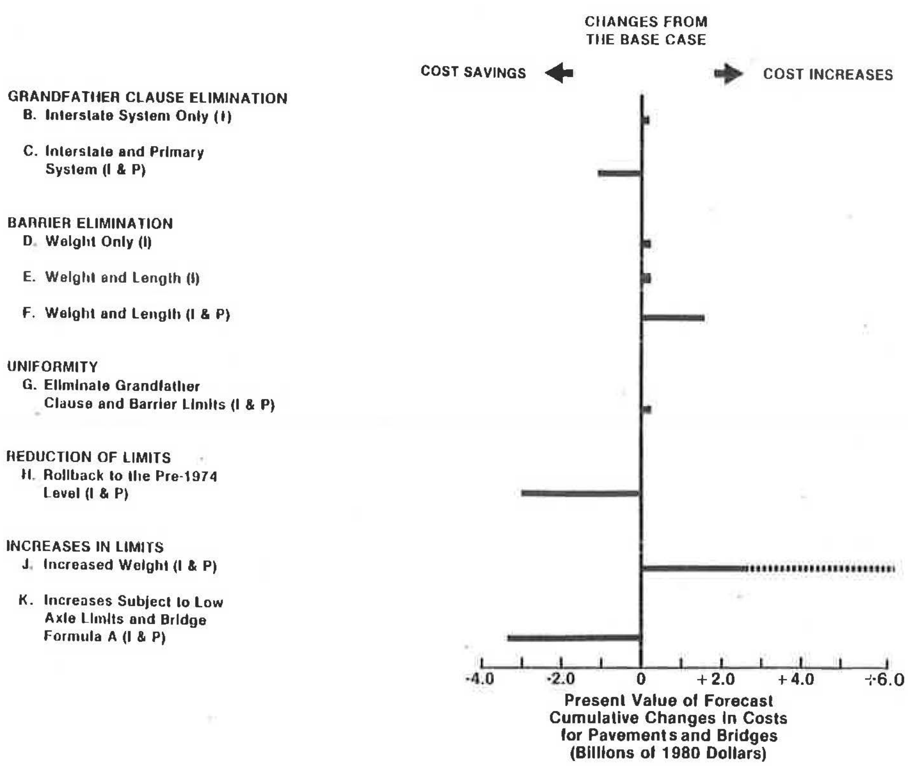


Figure 11. Present value of transportation cost impacts.

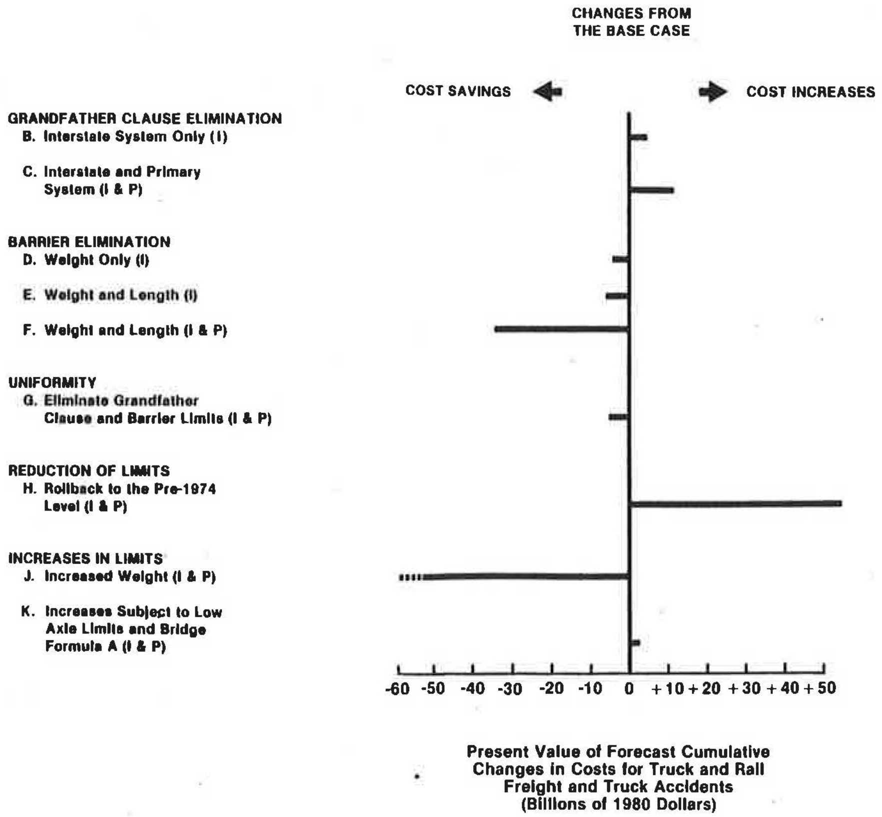
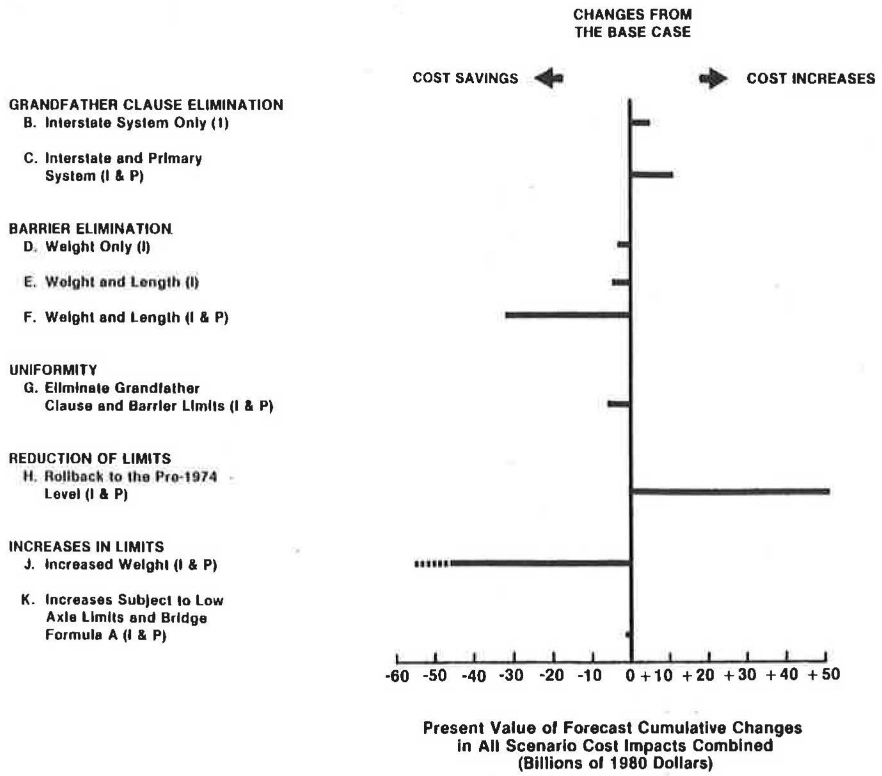


Figure 12. Present value of all scenario cost impacts.



provide sufficient transportation cost savings to pay for damage done to the highway system under these scenarios. However, if barriers are eliminated or limits are increased without a corresponding increase in expenditures to maintain highway conditions, the net impact of these actions could be a much lower decrease, or even an increase, in total cumulative costs.

REFERENCES

1. An Investigation of Truck Size and Weight Limits. Office of the Secretary of Transportation, U.S. Department of Transportation, 1981.
2. An Investigation of Truck Size and Weight Limits: Appendices to the Final Report. Office of the Secretary of Transportation, U.S. Department of Transportation, 1981.
3. G. Vallette, H. McGee, J. Sanders, and D. Enger; Bio Technology, Inc. The Effect of Truck Size and Weight on Accident Experience and Traffic Operations--Volume 3: Accident Experience of Large Trucks. FHWA, 1980.

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Truck Weight Study Sampling Plan in Wisconsin

WILLIAM D. GARDNER

The procedures used by the Wisconsin Department of Transportation for determining the number and locations of sampling stations for its truck weight study are described. The purpose of the program is to collect representative trucking characteristic data for use in pavement design, highway cost allocation, motor carrier enforcement, and other planning and research activities. Previous weight studies have produced data of limited value due to inadequate road type and geographic coverage. In addition, stations are selected without statistical guidelines for sampling. The use of new weighing-in-motion technologies and the emphasis on the collection of basic weight data permit a more random selection of weigh stations and a more comprehensive sample of truck traffic. The sampling plan developed relies heavily on user needs and statistical criteria to help ensure a valid and meaningful sample. By using data from the 1980-1981 highway performance monitoring system Wisconsin truck weight case study, the number of required stations is calculated on the basis of the average variability of truck weights in the state. These stations are distributed across recommended road types in proportion to the size of the total population (truck vehicle miles of travel) on each road type. Stations by road type are assigned to counties by using a weighted random numbers procedure. Criteria are presented for selecting corridors and sites where stations should be established. This type of sampling approach can generate more representative and comprehensive data that better describe the truck population.

Most states, including Wisconsin, determine the number and location of their truck weight study stations on essentially a nonprobability, nonrandom basis. The number of stations operated may be a function of budget constraints. Station locations may be selected for convenience, to minimize travel expenses, or to provide perceived coverage of major truck routes. They may also be limited to certain permanent static scale locations.

The resulting data from the study may be representative, but there is no way of making such a determination. Only with some type of probability sample can definitive statements be made about the statistical validity of the sample. It may well be that cost or technological limitations will be the ultimate determinant of sample design. Within cost and operational constraints, though, it is critical to encourage the greatest possible use of statistical criteria. The flexibility and lower operating costs of new weighing-in-motion technology make such an approach more feasible.

The Division of Planning and Budget of the Wisconsin Department of Transportation (WisDOT) normally conducts a truck weight study every other year. The truck weight study collects a variety of trucking characteristic data by weighing and classifying trucks and interviewing the drivers of trucks on rural Interstate and rural state trunk highways. Wisconsin's truck weight study was suspended in 1981 so that it could be evaluated and restructured as necessary. Concerns about the high cost of the program, the accuracy and statistical reliability of the data collected, and the usefuleness of the data led to this evaluation project.

Several working papers and a final report that contained recommendations for a new truck weight study were developed during the project (1-4). Study phases included identifying and ranking the needs of data users, creating a sampling plan, and exploring options in weighing technology.

The focus of this paper is on the recommended sampling plan for Wisconsin. A methodology that uses statistical criteria in order to determine the number and general locations of sampling stations is described. In addition, some guidelines for selecting precise station sites are presented. The scheduling of operations is not addressed here.

SAMPLING POPULATION

Truck sampling in Wisconsin has been limited to rural Interstate and rural state trunk highways. The data in Table 1 illustrate the lack of adequate coverage by comparing the percentage of trucks sampled by road type in the 1979 truck weight study with the

Table 1. Comparison of Wisconsin truck weight study sample with truck VMT.

Highway Jurisdictional System	Percentage of Vehicles in Truck Weighting Study Sample	Percentage of Truck VMT
Rural		
Interstate	63	12
State trunk highways	37	37
County trunk highways	0	13
Town roads	0	6
Urban[a]		
Interstate	0	5
State trunk highways	0	16
City and village[b]	0	10
Other	0	1

[a]Includes areas inside incorporated municipalities.
[b]Includes urban county trunk highways.

percentage of truck vehicle miles of travel (VMT) on that road type. In addition, sampling was limited to stations in the southern half of the state.

Although data users require different levels of detail (some are interested in site-specific data whereas others are interested in systemwide statistics), the overall objective of the truck weight study is the development of a representative statewide sample of truck weight data. In order to create such a sample, all major road types (including urban roads) and the entire state should be considered as the population from which to sample.

Lower-order roads, such as local and town roads, should be excluded from the regular program, primarily because of the expense involved in obtaining adequate samples. A scarcity of trucks on many of these roads would require extended periods of sampling. Potentially large variations in truck weights across local roads (due to differences in local economic activity) could necessitate many sampling stations to develop a representative sample. Lower-order roads could be sampled on a special study basis.

The statewide sample will include only Interstates and major state and county roads. The road types recommended for sampling along with their percentage of total VMT (rural and urban) are given in the following tables. The table below gives the road types and percentage of total VMT for rural highways:

Rural Jurisdictional Type	Functional Class	Percentage of Total Rural VMT
Interstate	Principal arterial	15.6
State trunk	Principal arterial	32.6
State trunk	Minor arterial	20.3
County trunk	Major collector	10.4
Total		78.9

This next table gives the road types and percentage of total VMT for urban highways:

Urban Jurisdictional Type	Functional Class	Percentage of Total Rural VMT
Interstate	Principal arterial	12.6
State trunk	Principal arterial	32.8
State trunk	Minor arterial	9.7
Total		55.1

The data presented in these tables are from Wisconsin's 1980-1981 highway performance monitoring system (HPMS) truck weight case study, which sampled more road types and more seasons than the regular program. (HPMS data, except where noted, served as the data base used in this project.)

Not surprisingly, average weights of trucks do differ by road type, where higher-order roads generally carry heavier traffic, as indicated in Table 2. (Data on urban Interstates are not available in Wisconsin and cannot be collected with portable scales for safety reasons. Such data will be collected once weighing-in-motion equipment is acquired. The sampling plan may need to be refined to reflect the data.) Stratification by road type should be an effective strategy. Stratification of a sample involves dividing the population into groups or categories (such as road types) and then selecting independent random samples within each group or stratum (5, p. 156). With a stratified sample each stratum should be homogenous with respect to values of the statistic (i.e., mean weights) and different from other strata. Other stratifications could be made, such as stratifying by average daily traffic (ADT) volume group or geographic area. Possible increases in precision from greater stratification, however, must be weighed against the increase in sampling costs (each stratum requires at least one sampling station).

SAMPLING PLAN

Two basic types of trucking characteristic data are of interest to users: (a) weight and classification data and (b) data items obtained through driver interviews such as commodity type carried, origin and destination, and so on.

The primary uses of WisDOT truck weight study data are for pavement design and research, highway cost allocation and planning studies, and motor carrier enforcement. The users of these data require accurate weight and classification data more so than survey data. Survey-type information is requested by these users, but the uses are not as well defined and are generally less critical. The new truck weight study will emphasize the collection of basic weight and classification data, and the sampling plan is designed accordingly.

The sampling plan specifies how many sampling stations are to operate on each road type and locates those stations around the state. The statistical derivation of the number of stations or the sample size is influenced by three factors: the sampling distribution of the statistic, the degree of confidence chosen, and the level of precision desired. The sampling distribution refers to the variability of that characteristic for which WisDOT is interested in obtaining an estimate.

With all other factors held constant, it is the variability of that characteristic in the population that most directly affects the size of the sample. The more variable the characteristic, the larger the sample needed to accurately estimate it. If, for example, the gross operating weights of trucks are highly variable across the state, this suggests the need for a large number of stations for sampling. A

Table 2. Average weight of loaded trucks by truck category and road type.

Truck Size	Avg Weights (lb) by Road Type: Rural Interstate, Principal Arterial	Rural State Trunk: Principal Arterial	Rural State Trunk: Minor Arterial	Urban State Trunk: Principal Arterial	Urban State Trunk: Minor Arterial	Rural County Trunk, Major Collector
2P	6,500	6,500	–	–	–	–
2S	9,000	10,000	–	–	–	–
2D	15,862	16,362	15,820	12,851	13,838	12,990
3+ axles	37,241	39,072	40,887	31,400	38,500	38,310
3-axle combination	30,685	25,593	23,442	21,962	18,930	–
4-axle combination	39,157	36,445	34,108	28,700	27,547	31,415
3-S2	62,237	59,333	64,499	51,893	49,592	48,553
Other 5-axle combinations	51,087	40,715	32,500	–	–	–
6+ axle combination	72,910	71,271	70,156	–	–	–

Note: Data are from 1980-1981 Wisconsin HPMS case study, except 2P and 2S, which are from 1979 Wisconsin HPR truck weight study.

reasonable balance must be drawn between how precise the estimate will be (e.g., ±5 or ±10 percent) and the amount of confidence held in that estimate. The greater the precision or confidence level, the larger the required sample size.

By using operating gross vehicle weight as the controlling variable for the collection of weight and classification data, the calculation of station sample size can be guided by the following formula:

$$n = z^2(k^2)/d^2 \quad (1)$$

where

- n = sample size,
- z = number of standard deviations for the desired confidence interval,
- k = coefficient of variation of the variable (standard deviation divided by the mean), and
- d = degree of relative accuracy desired.

SAMPLING METHODOLOGY

A four-step methodology that uses a random numbers technique was developed to calculate the necessary number of stations on each road type and general locations for those stations. These steps are described below.

Step 1

In step 1 the state is divided into heterogeneous clusters, where counties are used as clusters within which sample stations will be located.

A cluster sampling approach involves dividing the population into heterogeneous subgroups and then choosing a sample of subgroups. In this step a subsample of counties will be selected, and the field stations will be located within those counties.

Counties represent mutually exclusive and exhaustive subsets of the population. They are well defined and well documented and thus easy to use. Because not all counties will be sampled, they should serve as small-scale models of the population, i.e., they should contain a range of variation in truck weights (heterogeneity). Counties appear to contain such a range due to the variety of road types in each county. Not all counties, however, contain all the recommended road types. In addition, counties are unequal with respect to road mileage. The sampling procedure should be sensitive to these conditions (see step 3).

A cluster sampling approach is usually less statistically efficient than other types of surveys primarily due to the error introduced if nonrepresentative or homogeneous subgroups are chosen. With each stage of the sampling process (defining the clusters, selecting subgroups, and then choosing the actual locations within the subgroups), there is risk of sampling error. For a given sample size (trucks weighed), cluster samples produce greater error than a simple random sample or regular stratified samples.

Nevertheless, cluster sampling is probably the most common sampling procedure used for large-scale field surveys (6). Because of the reduction of the universe down to certain counties, the overall costs of the survey will be less. With regard to the truck weight study, travel and equipment installation costs may be significant. It is more economical to sample just within certain counties than to sample more extensively all over the state as other survey types would dictate. In the case of the truck weight study, it is much less expensive to survey many trucks at fewer stations than a few trucks at many stations, particularly if weighing-in-motion equipment is used, because then the cost per observation will be small. This sampling approach, combined with the proper stratification, will document many of the variations in truck operating weights and generate data that are sufficiently representative.

Step 2

In step 2 the total number of stations and their distribution across road types are determined. There are several ways of calculating station sample size on the basis of variation in truck weights. One approach is to determine the number of stations on each road type by using the total variation in truck weights on that road type. Total variation could be defined as the variation in operating weights of all trucks (empty and loaded trucks combined) across all truck categories. The resulting coefficients of variation (COVs) would be large. If this total COV for each road type was applied to the sample size formula, unrealistically large station sample sizes would be specified with, for example, a 90 percent confidence and 10 percent precision level. The data in the table below indicate the required number of stations by using this technique (note that data on urban Interstates are not available):

Road Type	COV	No. of Stations
Rural Interstate	0.39	41
Rural state trunk		
Principal arterial	0.56	85
Minor arterial	0.67	122
Urban state trunk		
Principal arterial	0.75	153
Minor arterial	0.71	137
Rural county trunk, major collector	0.77	161
Total		699

The high COVs in this table are due in part to the bimodal nature of the population, i.e., there is a clustering of weights around an empty truck mean weight and a loaded truck mean weight. In addition, the variation within each truck category is added to that of all other categories. This type of aggregation procedure inflates the sample size, as does calculating the absolute number of stations on each road type separately.

A more useful alternative would be to define variation in a different manner, calculate the total number of stations statewide, and then distribute this total across road types. An averaging, rather than an aggregating, approach to COV derivation can be used. By averaging and weighting the variation in truck weights across truck categories and road types, a single composite average statewide COV can be calculated and in turn used to determine the total station sample size. The steps in this procedure are detailed below.

1. Determine the COV of each truck category on each recommended road type (urban Interstates are excluded from the analysis). The results of this procedure are given in Table 3.
2. Create a weighted average COV for each road type. First multiply the COV of each truck category on a road type by the total number of empty and loaded trucks (sample size) of that category on that road type. Then add these products and divide by the sample size (all loaded and empty trucks of all categories on that road type) to create a single

Table 3. COV and sample size of each truck category by road type.

Vehicle Type	Rural Interstate		Rural State Trunk: Principal Arterial		Rural State Trunk: Minor Arterial		Urban State Trunk: Principal Arterial		Urban State Trunk: Minor Arterial		Rural County Trunk, Major Collector	
	COV	Sample	COV	Sample	COV	Sample	COV	Sample	COV	Sample	COV	Sample
Single unit												
2P and 2S	0.36	881	0.33	1,064	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
2D	0.42	585	0.44	767	0.46	559	0.45	603	0.47	514	0.52	391
3 or more axles	0.40	149	0.51	248	0.45	164	0.50	104	0.48	99	0.58	110
Semis and truck-trailers												
3-axle combination	0.30	101	0.38	76	0.39	33	0.36	65	—[a]	—[a]	—[a]	—[a]
4-axle combination	0.29	468	0.29	263	0.32	77	0.28	99	0.29	40	—[a]	—[a]
3-S2	0.29	5,921	0.30	1,629	0.42	715	0.39	315	0.40	107	0.44	98
Other 5-axle combinations	0.47	60	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
2-S1-2	0.17	213	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
6 axles or more combinations	0.35	68	0.47	36	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]

Note: COV and sample size are from the number of trucks sampled during the 1980-1981 HPMS case study, except for 2P and 2S data, which are from the 1977-1979 HPR truck weight study.

[a]Insufficient data.

road type COV. The results are given in the following table:

Road Type	Weighted Avg COV
Rural Interstate	2,594/8,446 = 0.31
Rural state trunk	
Principal arterial	1,425/4,047 = 0.35
Minor arterial	669/1,548 = 0.43
Urban state trunk	
Principal arterial	497/1,186 = 0.42
Minor arterial	345/760 = 0.45
Rural county trunk, major collector	310/599 = 0.52

3. The same weighted averaging procedure is then used to calculate a statewide composite COV from the individual road type COVs. The resulting COV is 0.35, i.e.,

$$0.31\ (8{,}446) + 0.35\ (4{,}047) + 0.43\ (1{,}548) + 0.42\ (1{,}186) + 0.45\ (760) + 0.52\ (599) = 5{,}850/16{,}586 = 0.35.$$

Once the composite COV has been established, different total station sample sizes can be calculated by using varying confidence and precision levels:

95 percent confidence/5 percent precision level: $[(1.96 \times 0.35)\ 0.05]^2$ = 188 stations.

95 percent confidence/10 percent precision level: $[(1.96 \times 0.35)\ 0.10]^2$ = 47 stations.

90 percent confidence/5 percent precision level: $[(1.65 \times 0.35)\ 0.05]^2$ = 133 stations.

90 percent confidence/10 percent precision level: $[(1.65 \times 0.35)\ 0.10]^2$ = 33 stations.

80 percent confidence/5 percent precision level: $[(1.29 \times 0.35)\ 0.05]^2$ = 82 stations.

80 percent confidence/10 percent precision level: $[(1.29 \times 0.35)\ 0.10]^2$ = 21 stations.

The accuracy level chosen for the truck weight study is largely a function of cost. Generally, a 90 percent/10 percent accuracy level is sufficient for planning data. However, the costs of establishing a truck weighing station are high; the precise amount depends on the type of equipment used. The 80 percent/10 percent level produces the least number of stations, yet it is acceptable for the objectives of the truck weight study.

Thus there are 21 stations to be distributed across 7 road types. There are two ways of distributing this total. One way is to distribute the stations based on the amount of truck travel on each road type. A second method would be to distribute stations according to the relative variability of truck weights on each road type. Both approaches link sample size to the nature of the population.

The first way sets the amount of sampling on each stratum (road type) according to the size of the stratum in the population. Stratum size can be defined as the amount of truck travel or truck VMT. The share of truck VMT on each road type can be calculated by considering only the recommended road types as the population.

The other approach is to use the relative variability in truck weights as the distribution factor. If the weighted average COVs of each road type are added to produce a total, then the share of the total variability accounted for by each road type can be determined. Assuming that 21 stations is the recommended total, distribution of stations across road types on a VMT-share basis or COV-share basis can be computed, as given in Table 4.

The COV-share distribution method results in more stations on lower-order roads. From the standpoint of statistical efficiency this method is superior. However, the analysis of the data from such a sample

Table 4. Distribution of stations across road type.

Road Type	VMT Share: Percent	VMT Share: No. of Stations	COV Share: Percent	COV Share: No. of Stations
Urban Interstate	10	2	11	2[a]
Rural Interstate	19	4	11	2
Rural state trunk				
Principal arterial	23	5	13	3
Minor arterial	17	4	14	3
Urban state trunk				
Principal arterial	13	3	17	4
Minor arterial	6	1	17	3[b]
Rural county trunk, major collector	12	2[c]	18	4
Total		21		21

[a]Because no information exists on the variability of weights on urban Interstates, it is assumed to be equal to that on rural Interstates.
[b]3.57 is rounded off to 3.
[c]2.52 is rounded off to 2.

is more complicated. Special weighting should be conducted to account for the disproportionate sampling (i.e., one road type may account for 40 percent of the total sample size of trucks weighed, but only 25 percent of the population size) when combining data across road types to estimate means and variations.

Users of trucking characteristic data, however, would prefer to have more stations on higher-order roads because those are the major trucking routes and generally are of greater interest. The VMT-share design is proportionate sampling that is self-weighting; thus, no special manipulations of the data would be required. Because of these factors, the proportionate VMT-share distribution method should be employed.

Step 3

In step 3 a subsample of counties is selected and the stations are located by road type in the counties. The procedure used is given below.

First, list each station with its defining road type and number, as shown below:

01. Urban Interstate;
02. Urban Interstate;
03. Rural Interstate;
04. Rural Interstate;
05. Rural Interstate;
06. Rural Interstate;
07. Rural state trunk, principal arterial;
08. Rural state trunk, principal arterial;
09. Rural state trunk, principal arterial;
10. Rural state trunk, principal arterial;
11. Rural state trunk, principal arterial;
12. Rural state trunk, minor arterial;
13. Rural state trunk, minor arterial;
14. Rural state trunk, minor arterial;
15. Rural state trunk, minor arterial;
16. Urban state trunk, principal arterial;
17. Urban state trunk, principal arterial;
18. Urban state trunk, principal arterial;
19. Urban state trunk, minor arterial;
20. Rural county trunk, major collector; and
21. Rural county trunk, major collector.

Second, create a list of counties by arranging all counties in alphabetical order; then number them from 1 to 72.

Third, determine the total state trunk and county trunk mileage of each county and create a code for each (7). (Truck VMT by county would be preferable to use; however, it is not available.) For example, 08-224 would be the eighth county on an alphabetical list that has 224 miles of county and state highways.

Finally, use five-digit random numbers from a random numbers table to select a subsample of counties and assign each station and road type to a county (8); then sample the result with a replacement (i.e., more than one state can be assigned to a county). For example, if the first entry in a random number table is 25350, then the first station should be assigned to county number 25 if it has 350 or more road miles associated with it. If it has fewer than 350 roads miles, if it does not contain any roads of the station 01 type, or if no county 25 exists, this random number should be ignored and the next random number in the table used to identify the next county to be sampled. The results of this procedure are given in Table 5 and shown in Figure 1.

This step of the sampling plan selects the counties and road types in those counties where truck weight study sampling stations will be located. The random selection method will provide a good geographic distribution of stations. The weighting technique based on mileage and sampling with replacement equalizes the chances that any particular location on the recommended road type network will be chosen for any type of station. The actual locations for stations can be determined by using the guidelines set forth in the following section.

Step 4

In step 4 the actual station locations within the selected counties and road types are determined.

The most statistically correct procedure for selecting station locations would be to continue the random selection process down to the road segment level. The relevant road network (e.g., urban state trunk, principal arterial) within a county would be divided into segments, each segment listed and numbered, and then one or more segments randomly selected to serve as truck weight study stations. Ideally, segments would be of equal length, although unequal segments could be weighted. A segment length of 1 mile would provide some flexibility in locating weighing equipment; segment lengths of 5 miles would increase this flexibility and also reduce listing costs.

The advantage of this kind of method is that possible bias introduced by judgmentally selecting sites is minimized. Each segment of a road type in a county theoretically has an equal chance of being selected. The overall probability that any particular road segment would be chosen from the entire state road network would equal the product of the selection probabilities at each stage of the sampling process (9) (that is, when selecting the subsample of clusters, the road type assignment, and ultimately the road segment selection).

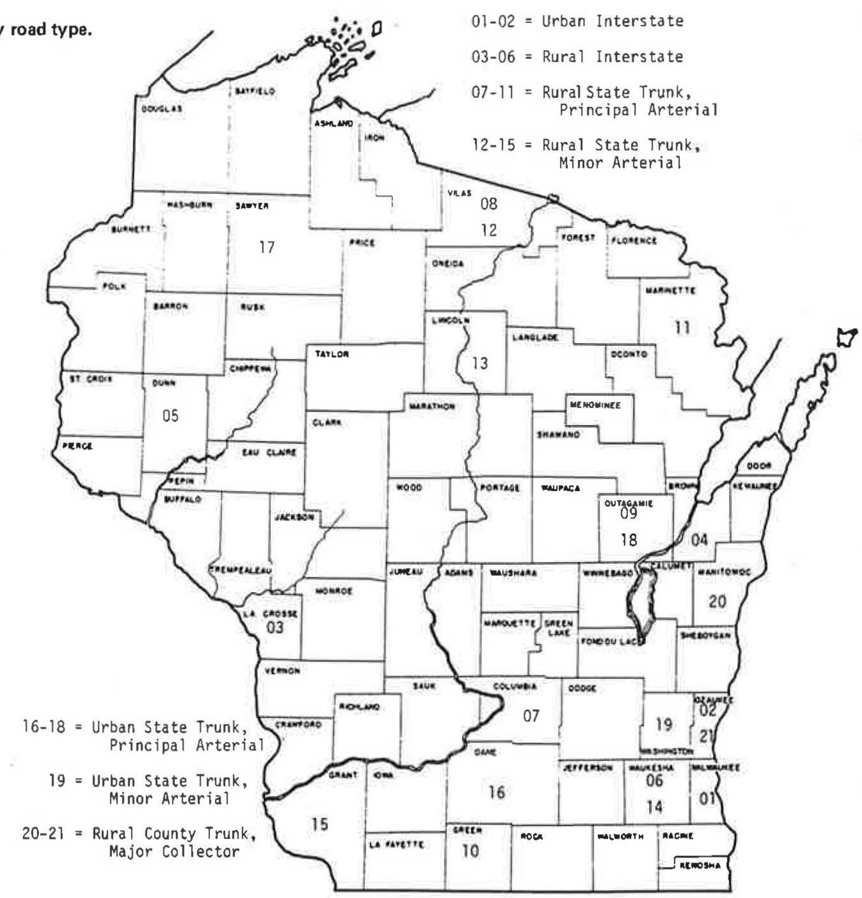
The disadvantages of a random selection of road segments are that listing costs may be significant and the operational limitations of truck weighing are not considered. The listing process would involve either manipulating existing road segment lists into an appropriate format or creating a new list (this would be necessary for county roads). Even with this approach, the selected segment may not be suitable for weighing and classifying trucks.

Many of the restrictions on where weighing can be conducted are related to the type of scale used. If the existing permanent static scales were to be used to the extent possible, then random site selection would not be relevant (new scales could be built at

Table 5. Station types and assigned counties.

Road Type	County
01. Urban Interstate	Milwaukee
02. Urban Interstate	Ozaukee
03. Rural Interstate	La Crosse
04. Rural Interstate	Brown
05. Rural Interstate	Dunn
06. Rural Interstate	Waukesha
07. Rural state trunk, principal arterial	Columbia
08. Rural state trunk, principal arterial	Vilas
09. Rural state trunk, principal arterial	Outagamie
10. Rural state trunk, principal arterial	Green
11. Rural state trunk, principal arterial	Marinette
12. Rural state trunk, principal arterial	Vilas
13. Rural state trunk, minor arterial	Lincoln
14. Rural state trunk, minor arterial	Waukesha
15. Rural state trunk, minor arterial	Grant
16. Urban state trunk, principal arterial	Dane
17. Urban state trunk, principal arterial	Sawyer
18. Urban state trunk, principal arterial	Outagamie
19. Urban state trunk, minor arterial	Washington
20. Rural county trunk, major collector	Manitowoc
21. Rural county trunk, major collector	Ozaukee

Figure 1. Assigned counties by road type.



a randomly selected site but that is probably neither feasible nor likely, given the expense).

Portable static scales can only be used safely where there are turnouts, adequate space for queuing of trucks, level grades, and so forth. High-speed pavement weighing-in-motion scales should not be located near intersections, where severe acceleration or deceleration occurs, where pavement conditions are poor, or on steep slopes. Bridge weighing-in-motion is limited to certain types of bridges.

In addition, a random selection of station sites might produce nonrepresentative stations (for example, adjacent to a major manufacturing facility). Because there are so few stations (out of potentially thousands of locations), it is critical to avoid highly peculiar traffic conditions if the objectives are to obtain representative statewide data and accurate average values.

Because of these restrictions, expanding random selection to this level is not the best approach. Although not statistically pure, it appears that the use of informed judgment at this stage of the sampling process is both reasonable and necessary. Indeed, an FHWA report suggests numerous possible considerations for site selection (10):

1. ADT volume;
2. Percentage of trucks;
3. Percentage of trucks of each type;
4. Variations in the percentages of trucks carrying different types of commodities;
5. Whether there is a seasonable variation in the number of trucks in the ADT and whether within the season there is a variation in the type of commodities carried;
6. Relative amount of interstate and intrastate trips;
7. Land use characteristics, both adjacent to the station site and at origin and destination of the truck traffic;
8. Ease or difficulty of trucks bypassing the station to avoid being weighed; and
9. Nearby alternative routes.

Much of the above information cannot be obtained without first conducting surveys. In addition, precise site requirements cannot be determined without first identifying the weighing technology that will be used. A potentially effective approach is to identify general locations or corridors within which stations can be located once weighing equipment has been selected. Therefore, guidelines should be established for identifying these general locations.

GUIDELINES FOR STATION LOCATIONS

The four guidelines for station location are given below:

1. Where possible, establish stations on routes with high truck volumes. Heavily traveled truck routes should be used because data users (enforcement officials in particular) are interested in documenting the traffic characteristics of major corridors. Almost all Interstates and some state trunks are major truck routes. (The state highway plan identifies major corridors in Wisconsin.)

2. Locate stations on major intercity or interregional routes. The non-Interstate state trunk network serves to connect the various subregions of the state. Where applicable, these routes should be used to monitor regional freight flows.

3. For stations on lower-order roads, special

care should be taken to avoid locations with atypical traffic conditions.

4. Within the above criteria, stations should be located at or near vehicle classification sites, automatic traffic recorder (ATR) sites, or within HPMS sample sections wherever feasible.

This fourth guideline is included to promote a rational and integrated traffic data-collection program. From the perspective of a data user the truck weight study can be thought of as a subfunction of the counting program. For example, in the design of pavements, the critical factor is the projected number of 18-kip equivalent loads. In Wisconsin vehicle classification data from the truck weight study have been used to supplement the vehicle classification and count programs. This practice should continue where possible (not all counties contain these other sites), but the truck weighing sites should be located at the vehicle classification sites or near ATR sites (which are established with their own set of criteria) instead of the opposite approach.

Therefore, where there is an overlap in the criteria of the various programs, station locations should be consolidated. Where possible, HPMS sample sections should be used. In effect, certain "super" traffic data stations could be established that generate data on vehicle weights, classification, counts, and road characteristics. By collecting all data at a single site, more precise and conclusive statements could be made about the relation between vehicle loadings and pavement conditions.

In summary, the county as well as highway jurisdiction and functional class have been selected for each station. Within these strata particular highways should be identified as general station locations that use the above criteria. Once the weighing equipment has been selected, precise station locations can be chosen based on site conditions. This quasi-random approach to selecting the actual station locations introduces an indeterminate amount of error, but it should still produce data sufficiently representative to satisfy the objectives of the program.

SUMMARY

The sampling plan presented in this paper represents one element of a comprehensive planning effort for a new Wisconsin truck weight study. Selecting the number of stations on the basis of variability in the population, distributing stations across road types in proportion to the size of the population (truck VMT) on each road type, and randomly selecting counties for locating stations will help ensure a more representative sample of truck traffic.

Once a new, more representative data base of trucking characteristic data is established, the sampling plan should be evaluated. The number of stations may need to be increased or reduced, or station locations may need to be changed. Although technological and cost constraints necessarily influence any traffic program, they should not be the sole determinants of program structure and scope. User needs and statistical sampling principles must be incorporated to produce valid and meaningful data.

Sampling plans for truck weight studies will vary according to program objectives. In Wisconsin the estimates of the mean weight of trucks by type of highway system are the primary objective. These systemwide estimates are useful in a variety of planning and design applications; i.e., more specialized sampling plans can be created and weight monitoring can be conducted to meet specialized needs to more precisely define truck characteristics in a specific highway corridor.

ACKNOWLEDGMENT

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REFERENCES

1. Truck Weight Study: Data User Needs. Division of Planning and Budget, Wisconsin Department of Transportation, Madison, Working Paper 1, Feb. 1982.
2. Truck Weight Study: Sampling Plan. Division of Planning and Budget, Wisconsin Department of Transportation, Madison, Working Paper 2, June 1982.
3. Truck Weight Study: Weighing Equipment Options. Division of Planning and Budget, Wisconsin Department of Transportation, Madison, Working Paper 3, June 1982.
4. Truck Weight Study: Final Report. Division of Planning and Budget, Wisconsin Department of Transportation, Madison, July 1982.
5. H. Blalock. Social Statistics. McGraw-Hill, New York, 1972
6. G. Churchill. Marketing Research. Dryden Press, Hinsdale, IL, 1979.
7. 1981 Wisconsin Highway Mileage Data. Division of Planning and Budget, Wisconsin Department of Transportation, Madison, 1981.
8. Guide for Estimating Urban Vehicle Classification and Occupancy. FHWA, 1981.
9. L. Kish. Survey Sampling. Wiley, New York, 1965.
10. R. Winfrey, P.D. Howell, and P.M. Kent. Truck Traffic Volume and Weight Data for 1971 and Their Evaluation. FHWA, Dec. 1976.

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Procedure for Assessing Truck Weight Shifts that Result from Changes in Legal Limits

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In recent years, maximum legal truck size and weight limits have become major issues in the United States. The assessment of impacts due to changes in maximum limits is an ongoing, dynamic problem faced by many highway departments and state legislatures. It has been difficult to predict future truck weight distribution patterns as affected by the alternative legislation that governs truck weight. Consequently, it has become implausible to try to forecast precisely the benefits and costs associated with changes in size and weight limits. In the past, various methodologies for projecting truck weight distribution patterns have been developed. Each methodology has made a contribution in the capability of a framework for assessing changes in truck size and weight patterns; however, improvement is needed to enhance the overall precision of these estimates. In June 1977 the Texas State Department of Highways and Public Transportation contracted the Center for Transportation Research to conduct a study on selected aspects of the truck size and weight issue. As a part of this study, a shifting methodology has been developed for the projection of future truck weight distribution patterns. This methodology can be applied either manually or by using a series of computer programs, and it can be used to predict both gross vehicle weight and axle weight distributions. A brief review of available methodologies and a detailed discussion of the Texas Shift are presented. Illustrative applications of predicting gross vehicle weight and axle weight distributions as a result of changes in weight limits are presented. Comparison of the prediction results generated by all the available shifting methodologies is also included.

Given the national trend of increasing truck traffic on U.S. highways and the movement toward minimum size and weight standards for trucks operating on Federal-Aid highways, there has been a need for a methodology to aid highway engineers in assessing the effects of these changes on the highway infrastructure. Legislation has been introduced at the national level and among many states that would allow the "super truck" to operate under a range of provisions and limitations. These trends make the need for a procedure, which would predict future gross vehicle weight (GVW) and axle weight distributions and 18-kip equivalent single-axle load (KESAL) applications that result from changes in the legal size or weight limit, more compelling. An overview of the current methodologies is presented, and a new procedure--the Texas Shift--which is the result of ongoing truck size and weight research investigations in Texas, is described.

Because the prediction of future weight distributions is vital to the evaluation of impacts due to changes in legal weight limits, four major methodologies have been developed in the past:

1. First FHWA procedure,
2. Second FHWA procedure,
3. NCHRP procedure, and
4. Texas State Department of Highways and Public Transportation (TSDHPT) procedure.

Each of these procedures (in descending order) provided an increased level of confidence in their predicted results [for a review of these methodologies, see Larkin (1) and Walton and Yu (2)]; however, further studies indicated that a higher level of confidence may be achievable (3).

AVERAGE GVW FACTOR

From the recent detailed study of the average vehicle weight trends as replicated in the Texas data, the following observations were made:

1. Within the span of the same truck weight laws, changes in the average GVW for each truck type were gradual rather than abrupt.
2. No significant correlation on the average GVW among the four truck types (i.e., 2D, 3A, 3-S2, and 2-S1-2) was observed.
3. The average GVW factor is defined as the ratio between the average GVW and practical maximum GVW for a specific truck type. The variation of this ratio over the years for a specific truck type is insignificant.

The third item is the most significant finding. In this section the derivation and the significance of this average GVW factor are discussed. The data in Table 1 give the average truck weights and the ratios with respect to the practical maximum GVW by using the 3-S2 as an example. The ratio can be expressed mathematically as follows: Average GVW factor = average GVW ÷ practical maximum GVM. For each type of truck, a linear regression analysis was applied:

$$Y = AX$$

where

Y = average GVW,
X = practical maximum GVW, and
A = coefficient.

The statistical package MINITAB was used. The coefficient for each type of truck obtained from the analysis can be used as the recommended average GVW factor. These coefficients are given in Table 2.

T-values computed for the four types of trucks indicated that they are within the limits suggested

Table 1. Relation between average GVW and practical maximum GVW for 3-S2 on Texas Interstate rural highways.

Year	Avg Legal GVW	Practical Maximum GVW	Avg GVW Factor
1960	48.52	72.00	0.67
1961	46.68	72.00	0.65
1962	45.63	72.00	0.63
1963	46.51	72.00	0.65
1964	46.70	72.00	0.65
1965	47.22	72.00	0.66
1966	47.46	72.00	0.66
1967	47.91	72.00	0.67
1968	49.35	72.00	0.69
1969	47.51	72.00	0.66
1970	47.65	72.00	0.66
1971	44.92	72.00	0.62
1972	45.54	72.00	0.63
1973	45.21	72.00	0.63
1974	41.32	72.00	0.57
1975[a]			
1976	59.43	80.00	0.74
1978	53.20	80.00	0.67
1979	54.86	80.00	0.69

Note: 1974 and 1976 data were not included in the following statistics: mean of GVW factor = 0.66; standard deviation = 0.0183; one sample T-test = -1.15 (df = 15); and two-sample T-test = -1.78 (df = 14).

[a]Texas weight limits changed.

Table 2. Recommended average GVW factors for four truck types operating on Texas Interstate rural highways.

Truck Type	Recommended Avg GVW Factor
2D	0.51
3A	0.51
3-S2	0.66
2-S1-2	0.70

Table 3. Practical maximum GVW for trucks in Texas.

	Practical Maximum GVW (kips) by Year		
Truck Type	1951 to 1959	1960 to 1974	1975 to Present
2D	24.6	24.6	27.22
3A	42.26	42.26	44.90
3-S2	58.4	72.0	80.0
2-S1-2	58.4	72.0	80.0

by the student t-distribution; hence, it can be concluded that the average GVW factors may be used to represent the relations between average and maximum GVW for the four truck types.

In the regression of the average GVW and the practical maximum GVW, it was assumed that the relation between these two parameters would not be affected by changes in truck weight limits. In order to validate such an assumption, a two-sample t-test was used to check the significance of variations of the average GVW factor before and after the weight law changes. The changes that occurred as a result of a 1975 weight law change were selected for testing.

The computed t-values for the two sample tests were within the allowable range of the t-distribution. A 95 percent confidence level was chosen for the test, and it was found that the variation of the means of the two samples was not significant at this level. Thus it was concluded that changes in weight laws in 1975 did not have a significant effect on the average GVW factors.

Note that the practical maximum GVW is used in the analysis instead of maximum allowable GVW. The use of the practical maximum GVW allows one to express the changes in both GVW and axle weight limits in a single parameter. If the maximum GVW were used, incorrect predictions would result in cases where weight law changes occurred only in either GVW or in axle weight.

For illustrative purposes, consider the 2D. The total truck weight is bounded by axle weight limits as well as considerations for safety. An increase in maximum GVW limit alone will not affect the weight trend of the 2D because the maximum possible GVW of 2D is controlled by its axle weight. Under both the pre-1975 limit and the current limit, 2D could never attain the 80,000 maximum GVW. Its GVW capacity is limited by the restrictions placed on its axle weight. Hence an erroneous shift would result if maximum GVW (currently 80,000 lb in Texas) is used to develop the average GVW factors.

Due to the operational safety consideration, the steering axles cannot be loaded to the maximum allowable single-axle weight. A review of the trends in steering axle weight distributions for 3A and 3-S2 indicates that there has not been any significant change in past years. The 2D and 2-S1-2 classes were not analyzed due to the difficulty in obtaining the data from FHWA's W-4 tables.

Based on the observation of historical data and review of the pertinent literature, four practical maximum steering axle weights for four types of trucks are recommended for use in the analyses of likely shifts. These weights are summarized in the table below.

Truck Type	Practical Maximum Steering Axle Limits (kip)
2D	7.22
3A	10.90
3-S2	12.00
2-S1-2	13.00

[The practical maximum steering axle limits for 2D and 3A suggested in the table were from Whiteside and others (4). The steering axle limits for 3-S2 and 2-S1-2 were values provided by the Texas Department of Highways and Public Safety.]

These steering axle limits are recommended to arrive at the values for practical maximum GVW limits. A summary of practical maximum GVW for Texas since 1951 is given in Table 3.

With the average GVW factors as a function of practical maximum GVW, engineers and planners may in turn estimate the future practical maximum GVW for any proposed law and by selected truck types. With the available average GVW factor provided in Table 2, the expected average truck weight under any proposed weight limits can be obtained. From the expected average truck weight, a shifted curve can be obtained by using the methodology to be presented.

The average GVW factors provided in Table 2 were derived from Texas weight survey data. Whether such factors are transferable to other states will require further verification.

THE TEXAS SHIFT

Shifting of Truck Weight Distribution Curve

The application of the Texas shift is summarized in Figure 1. The methodology is composed of three major parts:

1. Determining the expected mean and variance of the GVW distribution for a truck type under the proposed legal limit, which involves the analysis of historical data and the application of the average GVW;
2. Constructing a cumulative distribution curve from a set of representative truck weight data provided in the W-5 tables; and
3. Shifting the cumulative distribution curve, whereby the mean and variance of the shifted curve are within the acceptable tolerance of the parameters obtained in the first part of the procedure.

Statistical tests are used to facilitate the decision of whether to accept or reject a shifted curve. Once the tests are satisfied, the shifting procedure is complete and the projected truck weight distribution curve is obtained.

Preparation of a Cumulative Frequency Curve

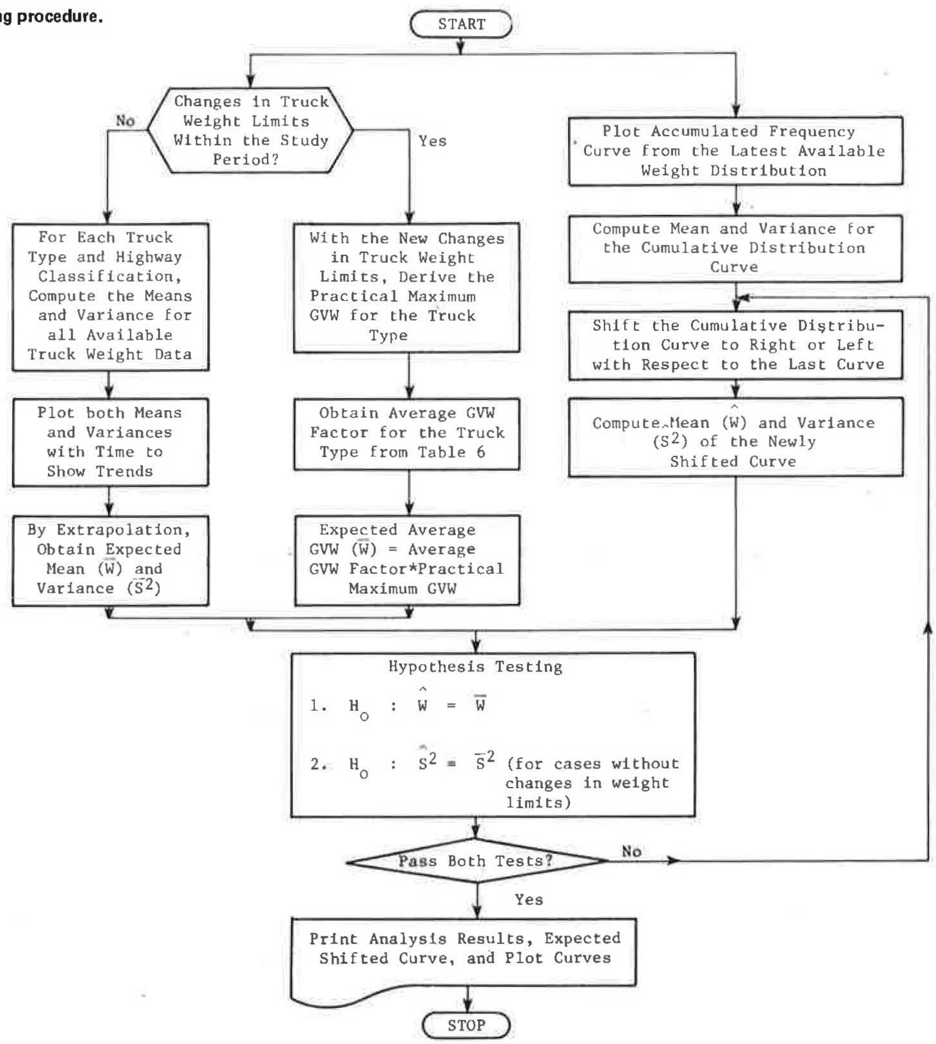
This part of the procedure provides a base curve from which shifting may occur. It is preferable to use statistically significant data from the most recent years.

Step 1: Read data from W-4 or W-5 weight distribution tables. Sum the number of trucks weighed.

Step 2: Calculate the percentage of trucks in each truck weight interval. Obtain the cumulative percentage for each interval.

Step 3: Plot the cumulative percentage for the truck weight intervals.

Figure 1. Manual application of shifting procedure.



<u>Shifting Curve to Obtain Expected Mean and Variance</u>

It has been suggested by Larkin (1) that shifting for 2D and 3A starts at 50 percent and for 3-S2 and 2-S1-2 at 33.3 percent. However, these figures are based on Texas data. In the shifting procedure, users may start at any percentage that would factually or intuitively represent their case.

The shifting procedure is an iterative one. Obviously, the use of a computer to handle the shifting procedure will reduce the time consumed in performing the iterations (3). A manual step-by-step method is provided to illustrate the process.

Step 1: Choose an initial shifting point and start the procedure by shifting the accumulated distribution curve to the right or left from that of the unshifted curve. The amount of shift should be according to the magnitude of the difference of the expected mean weight difference. The shifted curve should resemble the pattern of the unshifted curve (an S curve should be followed by another S curve).

Step 2: Compute the mean of the shifted curve. This can be done by taking the cumulative percentage of each weight interval of the original curve and the percentage for the corresponding interval in the newly shifted curve. The average weight for the shifted curve is the summation of the product of the mean weight for each weight interval with its corresponding percentage.

Step 3: Compute the variance of the shifted curve. Computation of variance is similar to that mentioned in the first part of the procedure. The computation of variance for the example is given in Table 4.

Step 4: To test the acceptability of the estimated curve, two statistical tests are used. The student t-test is used to determine whether the mean is within the 95 percent confidence intervals of the estimated future average truck weight. The chi-square test is used to determine the variance (5). If either the mean or variance of the estimated curve is outside the confidence intervals of the corresponding values, go back to step 1 and repeat the procedure. If both mean and variance are within an accountable limit, go to the next step.

Step 5: Once a distribution curve is accepted, a truck weight distribution table can be constructed.

The computation of mean and variance is given in Table 4. The example demonstrates the prediction for the 3-S2 truck weight curve in 1978. The base year is 1970, which was chosen because of the largeness of its sample size.

In 1975 the weight laws of Texas were changed as follows:

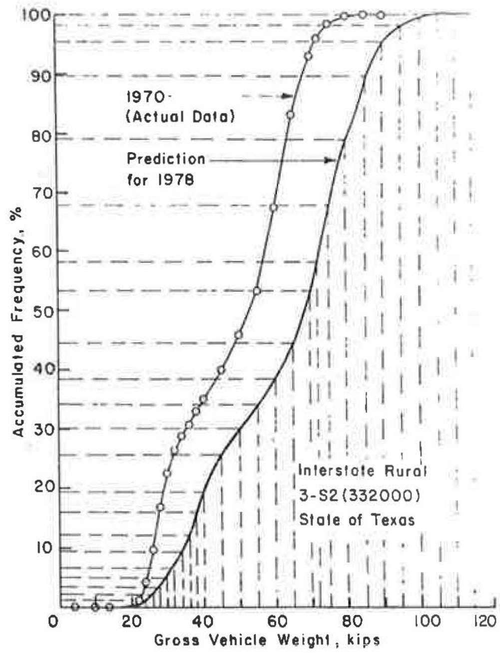
1. GVW = 72 to 80 kips,
2. Tandem-axle weight = 32 to 34 kips, and
3. Single-axle weight = 18 to 20 kips.

Table 4. Computation of mean and variance from an estimated cumulated distribution curve.

GVW Distribution Intervals	(B) Mid-GVW Intervals	(C) No. of Trucks	B x C	B^2 x C
0.0-4.0	2.0	0	0.0	0.00
4.0-10.0	7.0	0	0.0	0.00
10.0-13.5	11.75	0	0.0	0.00
13.5-20.0	16.75	2	33.5	561.13
20.0-22.0	21.0	15	33.5	6,615.00
22.0-24.0	23.0	51	1,173.0	26,979.00
24.0-26.0	25.0	85	2,125.0	53,125.00
26.0-28.0	27.0	117	3,159.0	85,293.00
28.0-30.0	29.0	92	2,668.0	77,372.00
30.0-32.0	31.0	61	1,891.0	58,621.00
32.0-34.0	33.0	37	1,221.0	40,293.00
34.0-36.0	35.0	31	1,085.0	37,975.00
36.0-38.0	37.0	39	1,443.0	53,391.00
38.0-40.0	39.0	32	1,248.0	48,672.00
40.0-45.0	42.5	79	3,357.5	142,693.75
45.0-50.0	47.5	95	4,512.5	214,343.75
50.0-55.0	52.5	117	6,142.5	322,481.25
55.0-60.0	57.5	229	13,167.5	757,131.25
60.0-65.0	62.5	254	15,875.0	992,187.50
65.0-70.0	67.5	157	10,597.5	715,331.25
70.0-72.0	71.0	48	3,408.0	241,968.00
72.0-75.0	73.5	39	2,866.5	210,687.75
75.0-80.0	77.5	20	1,550.0	120,125.00
80.0-85.0	82.5	4	330.0	27,225.00
85.0-90.0	87.5	1	87.5	7,656.25
90.0-95.0	92.5	0	0.0	0.00
Σ		1,605	78,256	4,240,727.88

Notes: Mean = 78,256/1,605 = 48.76.
Variance = $\{4,240,727.88 - [(78,256)^2/1,605]\}$ = 265.06.
Standard deviation = 16.28.

Figure 2. First trial shifting from 1970 data for projection of 1978 GVW distribution.



Based on the 1975 weight laws, the practical maximum GVW was estimated to be 80.0 kips. As noted from the data in Table 2, the average GVW factor for 3-S2 is 0.66. Thus the average GVW after the weight law changes is 52.80 kips.

When the average GVW factors were derived, only legal vehicles were included in the computation of average GVW. Overloaded vehicles can be accounted for by using a violation factor. For example, if the violation population is estimated to be approximately 5 percent of the total population of a particular type of truck, the violation factor is then equal to 1.05. For the above example, the adjusted GVW is 52.8 x 1.05, or 55.44 kips.

As shown in Table 1, the average GVW for 1970 is 47.65 kips. From the 1970 weight distribution curve, a first shifting was attempted (Figure 2). From the shifted curve, an average GVW of 62.5 kips was obtained. A comparison of this figure with the expected average GVW (55.44 kips) indicates that the second curve is too much to the right and should be between the unshifted and the first shifted curve. A new plotting is attempted. From the new shifted curve, a mean of 55.09 and a variance of 352.33 are obtained. The standard deviation of the curve is 18.79. The computation of mean, standard deviation, and variance is given in Table 4.

Because the shifting procedure is based on a logical iteration method, it is difficult and time consuming to find a curve whose mean and variance are exactly the same as those predicted by regression analysis. Hence statistical tests are used to set bounds for the predicted values. The student t-test and chi-squared test are applied to the mean and variance, respectively.

From the example, the parameters of the shifted curve are mean = 55.09, variance = 353.23, and standard deviation = 18.79. The expected mean based on the average GVW factors is, however, 55.44.

The student t-test is applied in order to accept or reject the shifted curve. The t-value for the shifted curve is

$$t = (55.09 - 55.44)/(18.79/\sqrt{30}) = -0.1020$$

It should be pointed out that, in response to weight law changes, only the average truck weight is used to predict a shifted curve.

A chi-sqaure test was conducted by using available 1978 truck weight data. With a confidence level of 0.05 and 29 degrees of freedom, the chi-square value obtained is 42.56 (5). Because the computed chi-square value (1.47) is much lower than 42.56, it indicates that the projection is acceptable.

From the experience gained in the use of this procedure, a few suggestions can be made that should enhance its use by others. Before starting to shift a curve, the mean of the curve should be computed. After the first shift, the mean weight of the shifted curve should also be computed. The next step is to decide whether the next curve should be shifted to the right or left of the first shifted curve. If the mean weight of the first shifted curve is above the expected weight obtained from the average GVW factor, the second shifted curve should be somewhere between the original curve and the first shifted curve. The position of the second shifted curve can be carefully chosen so as to minimize the number of shifts.

PREDICTIONS OF AXLE WEIGHT DISTRIBUTION AND 18-KESAL

In the estimation of highway maintenance and rehabilitation cost, an important input is the prediction of total 18-KESAL. The axle weight distribution directly affects the computation of total 18-KESAL. A method for predicting axle weight distributions for selected vehicle classes was developed.

Estimation of Tandem-Axle Weight Distribution

The procedure was developed in order to focus on two types of trucks: 3A and 3-S2. Axle weight predictions for 2D and 2-S1-2 were eliminated because the available data sources for truck weights (W-4 tables) do not allow distinction between loaded axle distributions (i.e., steering axle versus rear or loaded axles). For 3A and 3-S2, the axle weight distributions given in the W-4 tables allowed separation of the steering axles from the loading axles. An investigation of steering-axle weight distribution facilitated a new approach for the vehicle classes.

For the single-unit truck symbolized by 3A, the single-axle data given in the W-4 tables are the steering-axle data, whereas the tandem-axle data are for loading axles. Therefore, the GVW is

$$GVW = SAW + TAW$$

where SAW is single-axle weight and TAW is tandem-axle weight. For the 3-S2, which has one single axle (steering axle) and two tandem axles, the GVW may be expressed as

$$GVW = SAW + \Sigma(TAW) \quad (1)$$

Attempts were made to relate the GVW, SAW, and TAW weight distribution data for 3A and 3-S2. The approach was to explore the relation among GVW, SAW, and TAW for 3A and 3-S2 so that a TAW distribution could be predicted directly from the GVW distribution.

Therefore, let GVW(i%), SAW(i%), and TAW(i%) be the GVW, SAW, and TAW at i percent along the truck weight cumulated percentage curves for either 3A or 3-S2. For the single-unit trucks represented by 3A, prediction of TAW(i%) was based on

$$TAW_{3A}(i\%) = GVW(i\%) - SAW(i\%) \quad (2)$$

and for 3-S2,

$$TAW_{3-S2}(i\%) = GVW(i\%) - SAW(i\%) \quad (3)$$

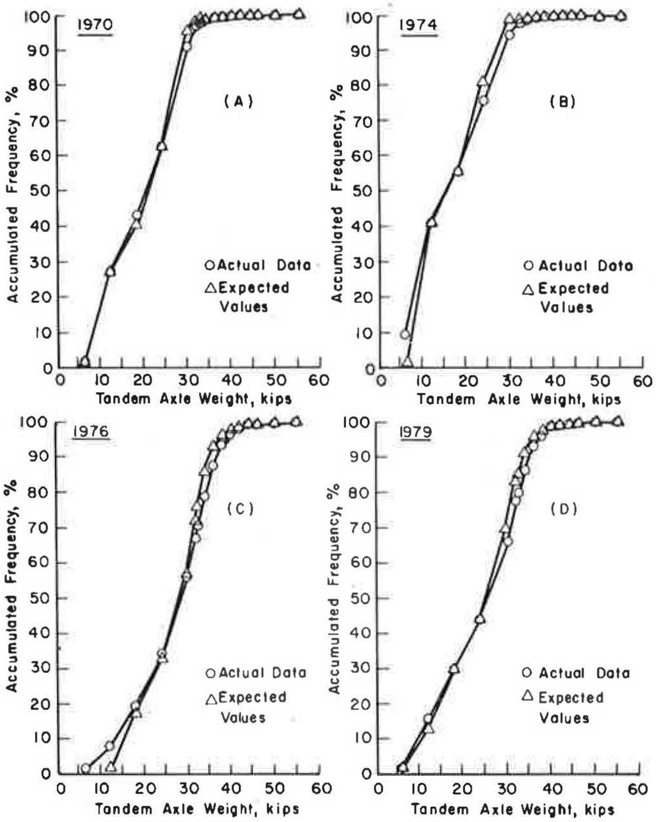
In the analysis, predicted TAW values were compared with data collected in the annual Texas weighing operation. Once the TAW(i%) values were obtained, a predicted cumulative percentage curve was constructed. The predicted TAWs and the actual TAWs were plotted in a graph for comparison. Data collected over a period of several years were used to test the relations stated in Equations 2 and 3. The years selected represent a spectrum of different conditions. Year 1974 was used to reflect the weight distribution before the changes in Texas weight limits. Year 1976 was known as an unusual year in that the weight data reflected a significant increase in truck weights after the 1975 change. Year 1979 was used to reflect the latest trends. The distribution curves for 3-S2 are shown in Figure 3. Along with the distribution curves, the predicted and actual TAW distribution data were also analyzed for the goodness-of-fit with the chi-squared values given in the following tables. The first table gives the chi-squared values for the 3A:

Year	Chi-Squared Value
1970	20.68
1974	75.06
1976	19.58
1979	18.24

The next table gives the chi-squared values for the 3-S2:

Year	Chi-Squared Value
1970	9.08
1974	33.85
1976	12.87
1979	10.35

Figure 3. Comparison of actual and expected tandem-axle distribution for 3-S2 on Texas Interstate rural highways.



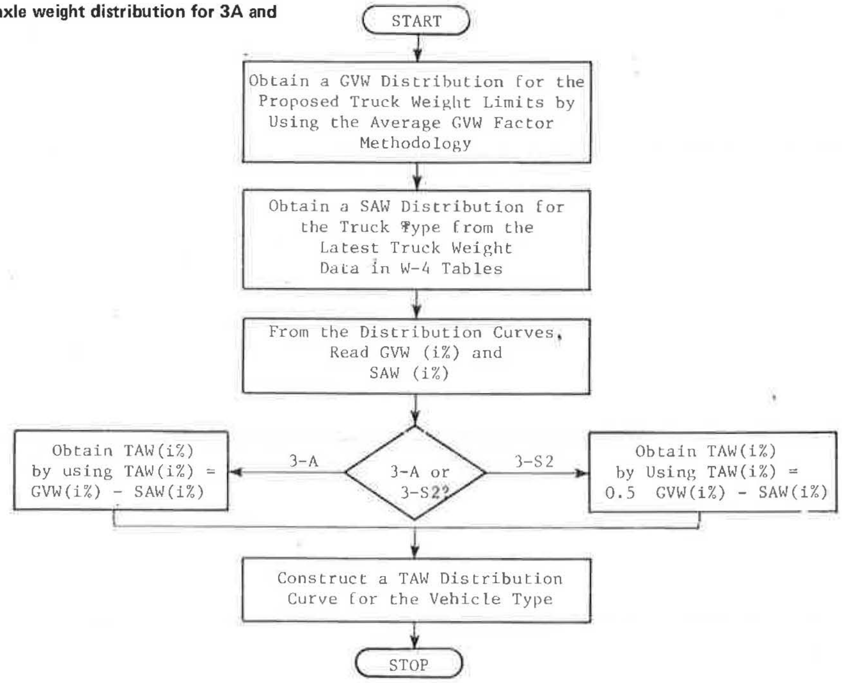
Both the graphics and the chi-squared values indicate that the predicted TAW distribution agrees closely with actual field data.

From the study of GVW and axle weight distributions, it can be concluded that a simple relation of GVW, SAW, and TAW for a single truck is applicable to the weight distribution data. The relations stated in Equations 1 and 2 are valid for 3A and 3-S2 weight distributions, respectively. Thus, for a given year, if GVW and SAW distributions are available, it is possible to obtain the TAW distribution. This finding is essential for predicting TAW distributions and 18-KESAL as a result of a change in the legal truck size or weight limits.

Prediction for Tandem-Axle Weight Distribution Under Proposed Truck Weight Limits

From the extensive study of truck weight distribution patterns, it was observed that the change in axle weight as well as GVW limits in 1975 did not change the distribution of steering-axle weight. This observation is based on the analysis of steering-axle weight distribution curves. Because of practical consideration and concern for operational safety, the steering-axle weight distribution did not change, even though the weight laws changed. Thus, for prediction purposes, it is suggested that the current steering-axle weight distribution be used as an estimate of the future steering-axle weight distribution under the changed legal limits. Similarly, it is possible to predict a tandem-axle weight distribution for both 3A and 3-S2 with the application of the average GVW factor concept mentioned previously. The procedures are shown in Figure 4.

Figure 4. Flowchart for predicting tandem-axle weight distribution for 3A and 3-S2.



The procedures used to predict the tandem-axle weight distribution are as follows:

1. When the previously stated methodology is employed, use the average GVW factor to obtain the GVW distribution curve under a proposed truck weight limit.
2. Obtain the SAW distribution for the truck type from the latest weight data in the W-4 tables.
3. Read the GVW(i%) and SAW(i%) values from the GVW and SAW distribution curves.
4. Use the appropriate equation for each truck type; i.e., for 3-S2,

$$TAW(i\%) = 0.5\ [GVW(i\%) - SAW(i\%)]$$

and for 3A,

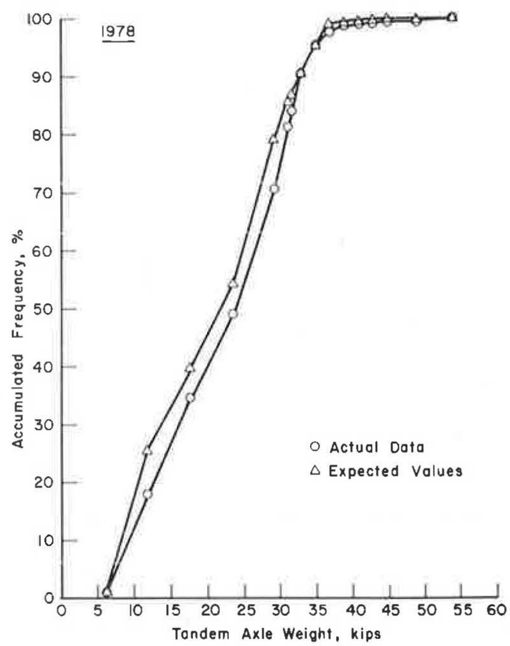
$$TAW(i\%) = GVW(i\%) - SAW(i\%)$$

5. From the TAW(i%) values, plot the distribution curve.

To illustrate the application of the procedure, an example that uses the 3-S2 on Texas Interstate highways is provided in the next section.

An illustration of the actual and predicted values by using TAWEXP, a program that predicts tandem-axle weight for 3A and 3-S2 by using the previously mentioned procedures, is shown in Figure 5. A chi-square test of the actual and predicted curve was performed and found to be acceptable.

Figure 5. Comparison of actual and predicted tandem-axle weight distributions for 3-S2 on Texas Interstate rural highways.



Calculation of 18-KESAL

To assess the pavement impact due to changes in legal weight limits, the 18-KESAL applications have to be computed under the current and proposed weight limits. The data source used in the computation of the total number of 18-KESAL is the W-4 tables. Equivalent factors for both flexible and rigid pavements are provided in the W-4 tables. These factors, when multiplied by the number of axle loads within a given weight interval, give the number of 18-KESAL applications. The summation of the load applications throughout the whole span of weight intervals gives the total loading effect on the pavement by the sample trucks. Equivalent factors for other pavement conditions may be obtained by the equations or nomographs provided in the AASHTO "Interim Guide for Design of Pavement Structures" (6).

The 18-KESAL applications for the proposed weight limits can be computed from the shifted axle weight distribution curve. Both the procedures and the example of shifting GVW and axle weight distribution curves have been presented. In this section, an example is used to illustrate the application of the shifting methodology in arriving at the 18-KESAL applications. The flowchart in Figure 6 summarizes the procedure.

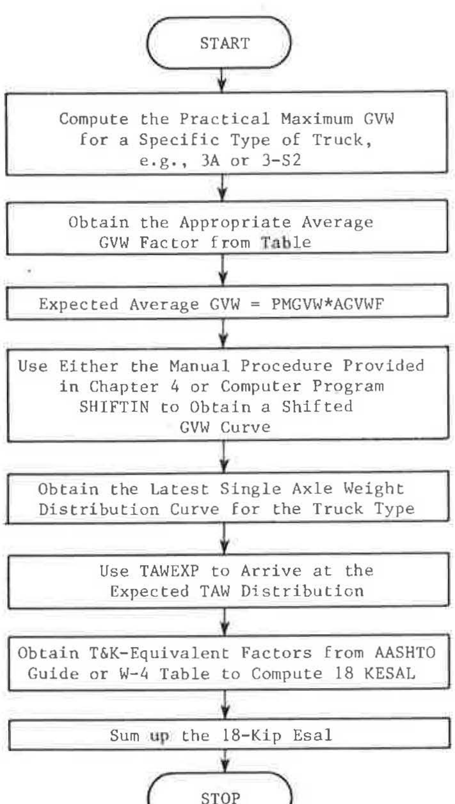
For illustrative purposes, the predicted tandem-axle weight distribution obtained earlier is again used to compute the equivalent 18-kip axle load. Both flexible and rigid pavement 18-KESAL for actual and predicted axle weight distributions are given in Table 5. The differences between the actual and predicted 18-KESAL are less than 1 percent for both the rigid and flexible pavements.

Comment on Shifting Methodology

The shifting procedure for GVW distribution depends on the GVW distribution data. Its accuracy is directly affected by the size and quality of the samples. The shift for TAW distribution depends on both GVW and SAW distributions. Therefore, the accuracy of the prediction of future axle weight distributions depends on the quality of current axle weight distribution data and the sample size.

To remedy the deficiency in sample size, users may combine data of the same truck type from different years. This may be significant for the steering-axle distribution of 3A and 3-S2 because the SAW distribution curves did not shift significantly throughout the years. Hence combining the data will improve the accuracy of prediction.

Figure 6. Shifting procedure and computation of 18-KESAL.



SUMMARY AND RECOMMENDATIONS

The objective of this study was to develop a shifting methodology that could be used to predict future GVW and axle weight distributions and 18-KESAL applications in response to changes in laws governing the size and weight of trucks.

While developing the Texas Shift, the following concepts were introduced to facilitate more precise predictions.

1. Extensive use of historical data in projecting future distribution: Several computer programs were written to facilitate analysis and modeling.
2. Use of statistical methods in analyzing historical data: Statistical tests such as the chi-square test and student t-tests are used extensively in the procedure. Computer statistical packages such as the Statistical Package for the Social Sciences (SPSS) and MINITAB were used in data sorting and analysis.
3. Computer application in conducting the shifting procedure: Due to the large amount of historical data and a large number of required input parameters, use of computers became a necessity.
4. Concept of using mean and variance to predict future distribution: Both the mean and variance for the weight distribution curves usually suggest specific trends over a period of time that can be represented by regression models. By using these models these two parameters may be predicted for future truck weight distributions. The suggested shifting procedure enables one to obtain a future weight distribution curve with acceptable precision.
5. Concept of using an average GVW factor for projecting average GVW under a proposed limit: The average GVW factor is used to relate a known param-

Table 5. Computation of actual and predicted 18-KESAL for flexible pavement for 3-S2 on Texas Interstate highways.

Weight Groups	Observed Sample	Predicted Sample	Flexible Pavement 18-KESAL Equivalence Factor	Observed 18-KESAL Applications	Predicted 18-KESAL Applications
0-5,999	1	25.6	0.010	0.01	0.3
6,000-11,999	848	927.5	0.010	8.48	9.3
12,000-17,999	790	820.7	0.044	34.76	36.1
18,000-23,999	676	586.4	0.1480	100.05	86.8
24,000-29,999	1,019	1,962.2	0.4260	434.09	452.5
30,000-32,000	519	390.4	0.7530	390.81	294.0
32,001-32,500	135	70.2	0.8850	119.48	62.1
32,501-33,999	312	201.6	1.0020	312.62	202.0
34,000-35,999	222	216.8	1.2300	273.06	266.7
36,000-37,999	116	212.1	1.5330	117.83	325.1
38,000-39,999	53	186.9	1.8850	99.91	352.3
40,000-41,999	32	12.3	2.2890	73.25	28.2
42,000-43,999	13	12.3	2.7490	35.74	33.8
44,000-45,999	4	12.8	3.2690	13.08	41.8
46,000-49,999	2	6.2	4.1700	8.34	25.9
50,000-55,000	2	0.0	5.100	10.20	0.0
Σ	4,744	4,744.0		2,092.00	2,217.0

Note: Δ = (2,217 - 2,092)/2,092 = 5.98 percent.

eter to an unknown parameter (for example, the future maximum GVW to the future average GVW). From the proposed truck weight limits, the future maximum practical GVW may be derived for a certain truck type. By multiplying the future maximum practical GVW with a given average GVW factor, the estimated average GVW for that truck type under the proposed limits may be obtained. Once the future average GVW is obtained, a future truck weight distribution may be projected by using the shifting methodology suggested herein.

Although the main data set came from the Texas Interstate system, the shifting procedure can be used for other types of highway systems and is considered applicable to other states. For a long-term investment on the existing federal and state highway systems, it is strongly recommended that truck weighing activities be intensified and operating efficiency be improved.

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This paper reflects our views, and we are responsible for the contents, facts, and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of TSDHPT. This report does not constitute a standard, specification, or regulation.

REFERENCES

1. J.G. Larkin. Modeling Future Truck Weight Patterns as Influenced by Alternative Vehicle Weight Legislature. Graduate School, Univ. of Texas at Austin, M.S. thesis, 1982.
2. C.P. Yu and C.M. Walton. Estimating Vehicle Weight Distribution Shifts Resulting from Changes in Size and Weight Laws. TRB, Transportation Research Record 828, 1982. pp. 16-18.
3. C.M. Walton and others. Truck Weight Shifting Methodology for Predicting Highway Loads. Center for Transportation Research, Univ. of Texas at Austin, Prelim. Res. Rept. 241-5, Sept. 1982.
4. R.E. Whiteside and others. Changes in Legal Vehicle Weights and Dimenions: Some Economic Effects on Highways. NCHRP, Rept. 141, 1973, 184 pp.
5. R.J. Larsen and M.L. Marx. An Introduction to Mathematical Statistics and Its Applications. Prentice-Hall, Englewood Cliffs, NJ, 1981.
6. Interim Guide for Design of Pavement Structures. AASHTO, Washington, DC, 1981.

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Truck Size and Weight Enforcement: A Case Study

C. MICHAEL WALTON AND CHIEN-PEI YU

In this paper the current state regulations affecting motor vehicle sizes and weights, the agencies involved directly or indirectly in the enforcement of these regulations, the characteristics of oversize and overweight vehicle movements within the state (both legal and illegal), and the cost of these vehicle movements to the state are discussed. The characterization of oversize and overweight movements in Texas is emphasized. To study the economic effects to the state, a 100 percent compliance case was set up to compare with the actual case. The case study of Texas showed that, although the current oversize and overweight movements may save the trucking industry up to $1.4 billion over the next 20 years at current conditions, these movements are estimated to cost the state an additional $261 million over the same 20-year period. Similarly, enforcement of the state laws is estimated to result in only $84 million if the current fine and permit fee structure is maintained. It was recommended that the current fine and fee structure be revised to discourage violation.

Due to the growth of truck traffic, interest in the effects of change in motor vehicle size and weights, and the challenge of perpetuating the nation's highway infrastructure, Texas has sponsored a series of truck size and weight investigations. These studies have focused on gaining a better appreciation of these trends and how to best integrate them into a rational decision framework for future highway programs and activities. The issues of legal limits, enforcement, and permitting were combined into a case study of the Texas experience, which may provide information and assistance to other states.

Almost two-thirds of all Texas communities depend entirely on trucks for service, and 98 percent of the fresh fruits and vegetables and 99 percent of the livestock are transported to principal markets by trucks (1). The importance of load limits and highway design practices was recognized early in the history of highway development. This interrelation led directly to limitations on vehicle loads, and laws were enacted in many states to establish maximum allowable motor vehicle sizes and weights (2). The first such law in Texas was enacted in 1929 (3). Since then the law has been modified several times. The most recent major changes of the law occurred in 1975, when the maximum gross vehicle weight was raised to 80,000 lb, the maximum single-axle load to 20,000 lb, and the maximum tandem-axle load to 34,000 lb.

As the highway system in Texas matured and there was a shift in emphasis from construction to maintenance and rehabilitation, the enforcement of motor vehicle size and weight laws became a highlighted issue. Strict enforcement of motor vehicle size and weight laws is a step toward reducing motor vehicle size and weight violations, heavy truck accidents, and, even more, highway maintenance and rehabilitation expenditures.

The various governmental units in Texas that are involved in regulating or enforcing the regulations on motor vehicle sizes and weights include the Department of Public Safety (DPS), the Texas State Department of Highways and Public Transportation (TSDHPT), the Office of the Attorney General (AG), the Texas Railroad Commission (RRC), and the Justices of the Peace (or the county court system). Among these governmental units, the DPS has the most direct role in enforcing size and weight laws.

A study was undertaken to summarize the current size- and weight-related activities in Texas and to present an analysis of current oversize and overweight truck movements within the state based on existing available data. The following major areas are discussed in this paper:

1. A brief overview of the development of size and weight limits in Texas;
2. Characteristics of size and weight violations and legal oversize and overweight permit operations; i.e., characterization of both the size and weight violations and legal permit operations in the state; and
3. The cost of oversize and overweight operations to the state; i.e., an estimate of the costs is prepared with the objective of bounding the significance of this particular aspect of the more global issue.

METHODOLOGY

For evaluation of pavement rehabilitation costs, programs based on AASHO Road Test results were used to calculate equivalent single-axle load (ESAL). The REHAB model from TSDHPT was used to translate ESAL figures into dollar costs. A methodology identical to that used and documented in the first part of the study was used to compute vehicle operating cost and fuel consumption (4).

In order to evaluate the cost of highway rehabilitation due to oversize and overweight trucks, two cases were selected for comparison. Case 1 represents actual conditions as reflected in the 1980 truck weight survey, where oversize and overweight trucks were included in all computations. Case 2 represents an artificial 100 percent compliance condition in which 1980 data were modified so that all vehicles were running at or below the legal maximum. Total payload for both case 1 and case 2 remained the same. These two cases were selected in order to bound the cost of highway rehabilitation due to oversize and overweight trucks and the benefits in terms of truck operating cost differences between violators and nonviolators.

The study was restricted to data for the first 9 months of 1980 because comparable data were not available after September 1980 and prior years' data were not maintained by DPS.

CHARACTERISTICS OF ILLEGAL OVERSIZE AND OVERWEIGHT VEHICLES ON TEXAS HIGHWAYS

There are three types of oversize and overweight vehicles on Texas highways--those operating (a) illegally; (b) with a permit; and (c) under special, separate legislations (e.g., ready-mixed concrete trucks; vehicles transporting cotton seed modules, fertilizer, milk, poles, piling, unrefined timber, electric power transmission poles, and unladen lift equipment; and cotton trucks).

Operation of illegal oversize and overweight trucks was characterized according to the following items: category of violation (oversize, overweight, and so on), monthly, location, highway class, vehicle body type, permit category, carrier type, amount overweight, disposition, vehicle lease status, and fine levied.

Category of Violation

There are four categories of size or weight violations:

1. Single-axle weight in excess of 20,000 lb;
2. Tandem-axle weight in excess of 34,000 lb;
3. Gross vehicle weight (GVW) in excess of the permissible maximum [the permissible maximum for both 3-S2 and 2-S1-2 is 80,000 lb, for 2D it is 40,000 lb, and for 3A it is 54,000 lb, legal maximum GVW for other vehicle types is the sum of all legal axle weights (GVW not to exceed 80,000 lb)]; and
4. Vehicle size in excess of those permitted by law.

Monthly Frequency and Location

Violations were also studied according to the month of occurrence. Figure 1 plots the frequency of violation versus month. It appears that weight violations peak during the months of April, May, June, and July, whereas size violations show relatively the same peak all the way into September.

An effort was made to determine the spatial distribution of size and weight violations by county throughout the state. Violations in each county were analyzed in relation to their major business category. Interviews were also conducted with experienced personnel regarding the causes of violations in different counties. The results suggest that independent grain, gravel, and log transporters are the major recorded violators in Texas. [These data were from an interview with Inspector Haddock, Traffic Law Enforcement Division, DPS, on May 6, 1981.]

Highway Class

The violation data were also arranged according to highway class. The four different types of violations on each class of highway are given in Table 1. Data show that 61.1 percent of the cases filed took place on U.S. and state highways, 27.7 percent on Interstate highways, 9.6 percent on farm-to-market roads, and 1.5 percent on other highways. However, a rather different picture emerges when these violation cases are compared on a per mile or per lane-mile basis. On a per mile basis, the number of violations that occur on Interstate highways is about 6 times that on other state highways. This indicates that, on a mileage or lane-mileage basis, the Interstate highways have the highest rate of recorded violations. The table below gives the violation rate on a per mile basis:

Rural Highway System	Mileage	No. of Violations	Violations per Mile
Interstate	1,395	9,194	6.59
Other main	17,725	20,249	1.14
Farm-to-market	29,674	3,193	0.11

Figure 1. Histogram of violation frequency versus months (by category).

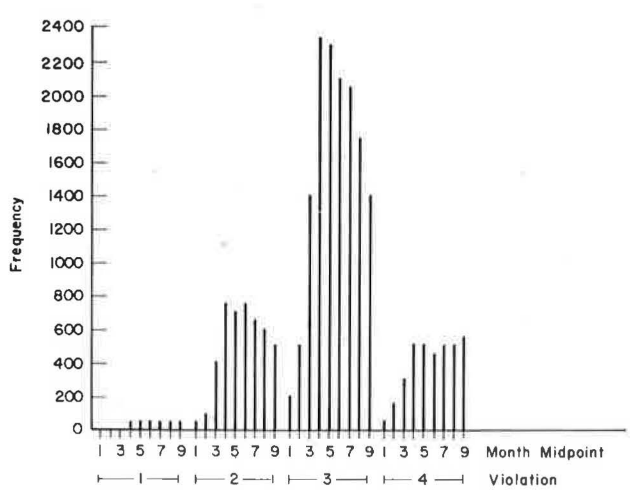


Table 1. Oversize and overweight violation cases by highway class.

Road Class	Overweight Violations: No. by Violation Code 1	2	3	Total	Percent	Oversize Violations: No. by Violation Code 4	Percent	Overweight and Oversize Violations: Total[a]	Percent
Interstate	276	2,752	4,498	7,526	26.9	1,668	32.4	9,194	27.7
Other main	512	3,240	13,468	17,220	61.5	3,029	58.8	20,249	61.1
Farm-to-market	89	481	2,246	2,816	10.1	377	7.3	3,193	9.6
Other	24	100	298	422	1.5	79	1.5	501	1.5

[a]Total of all violations (1-4).

Table 2. Analysis of size and weight violation cases filed by body type.

Vehicle Type	No. of Violations by Code Type 1	2	3	4	Total Violations	Percent of Total
Float	170	1,858	3,831	3,589	9,718	29.1
Pole	22	178	1,470	194	1,864	5.6
Tank	33	827	2,342	20	3,222	9.7
Refrigerator	12	155	198	64	423	1.3
Van	55	369	505	176	1,105	3.3
Livestock	25	139	238	360	762	2.3
Dump	257	2,482	11,060	147	13,946	41.8
Special	31	513	749	783	2,076	6.2
Unknown	4	52	96	64	216	0.6
Passenger car				9	9	0.0

This next table gives the violation rate on a per lane-mile basis:

Rural Highway System	Mileage	No. of Violations	Violations per Lane-Mile
Interstate	9,066	9,194	1.01
Other main	40,131	20,249	0.50
Farm-to-market	59,392	3,193	0.05

[Note that these data are from TSDHPT records as of August 31, 1981.]

Another comparison was made based on truck vehicle miles of travel (VMT) for each highway system. A comparison was made by dividing the number of violation cases filed for each highway system by the total VMT on each respective highway system. The computation indicates that the other main rural highways (U.S. and other state highways) have the highest rate of violation per VMT, followed by Interstate highways and farm-to-market roads.

Body Type

The size and weight violation records released by DPS also give the body types of vehicles found to be oversize or overweight. The results of the body-type analysis are summarized in Table 2. The data indicate that 41.8 percent of all oversize and overweight vehicles are dump trucks and approximately 29.1 percent are float trucks. Dump trucks are the most frequent violators of weight limitations (50 percent), whereas float trucks (a truck combination with a flatbed trailer that has no side boards) violate size limitations most often (66.4 percent).

Permit Category

The DPS size and weight violation data were analyzed according to permit category. The findings revealed that 52.6 percent of the weight violations were committed by private carriers and 42.8 percent by special carriers. Also, 59.3 percent of the size violations were attributed to private carriers and 37.2 percent to special carriers. Common carriers as well as contract carriers have low rates of violation. These data correspond to comments rendered by DPS personnel with respect to their observation that independent trucks are the significant challenge to License and Weight officers (according to interview data from Inspector Haddock).

Lease Status

An analysis of size and weight violation data according to lease status indicated that more than two-thirds of the violations are by unleased vehicles.

Type of Carrier

A review of the violation cases filed according to type of carrier indicated that intrastate carriers committed 83.4 percent of all weight violations and 82.9 percent of all size violations, whereas interstate carriers committed only 10.5 percent. Exempt carriers committed only 6.2 percent of the violations (intrastate, 2.6 percent; and interstate, 3.6 percent).

Amount Overweight

DPS violation records provided the distribution of excess over registered weight each vehicle was carrying. It is observed that most vehicles exceed their registered weight by 4,000 to 8,000 lb, although a few exceed it by as much as 50,000 lb.

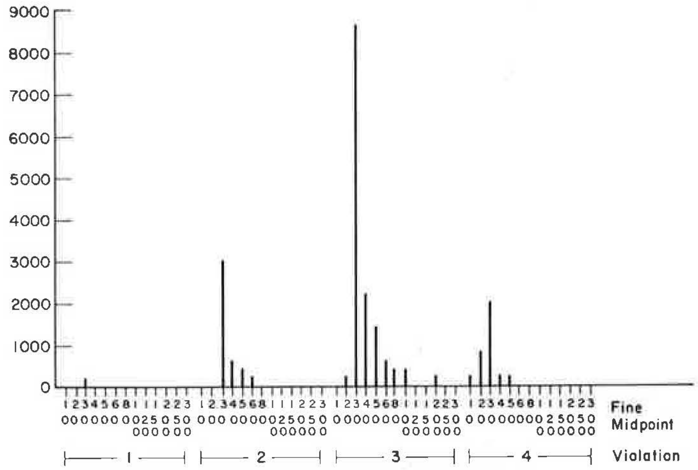
Disposition of Cases

During the first 9 months of 1980 there were 22,833 size and weight violation cases filed by DPS License and Weight officials. Of these cases, 22,502 (98.6 percent) resulted in fines administered in the courts and 323 (1.4 percent) met other dispositions.

Fine Analysis

Section 15(b) of Article 6701d-11 of the Revised Civil Statutes of Texas states, "Any person, corporation or receiver, who violates any provision of this Act shall, upon conviction, be punished by a fine of not more than Two Hundred Dollars ($200.00)." Previous law stipulates a minimum of $25 for a first conviction. The court fee for processing a case is usually $3.50. The data in Figure 2 show the distribution by amount of fine charged. Average fines range from $28.75 to $40.41. Paxson and Glickert (5) discussed the influence of the inadequate fine structure on truckers' tendency to overload. When the amount of fine likely to be charged times the probability of being caught is far below the profit that can be obtained by running overloaded, an incentive exists to run overloaded.

Figure 2. Distribution of fines charged by the court for each category of fine.



CHARACTERISTICS OF OVERSIZE AND OVERWEIGHT PERMIT OPERATIONS

The characteristics of legal oversize and overweight permit operations are discussed according to permit type, time length of permit, location where permit is issued, and historical trend.

Permit Type

As indicated previously, TSDHPT issues five types of permits to applicants for oversize and overweight movement:

1. Permit 598--movement of concrete beams;
2. Senate Bill 290 permit--oil field activities such as oil well drilling, cleaning, and servicing equipment;
3. Permit 591--movement of mobile homes;
4. Permit 438--general oversize and overweight vehicle movement; and
5. Permit 1407--oversize and overweight permit issued through telecommunication.

Detailed permit issuance data from September 1, 1979, to August 31, 1980, were made available to the researchers. Analyses indicate that oversize and overweight permits represent 77.6 percent of the permits issued.

Based on another set of data obtained from TSDHPT, which classified all permits as oversize only, overweight only, or oversize and overweight, the data in the table below give the distribution of permits issued from October 1, 1978, to September 30, 1980:

	Distribution of Permits			
	10/01/78 to 09/30/79		10/01/79 to 09/30/80	
Type of Permit	No. Issued	Percent	No. Issued	Percent
Overweight only	6,518	1.5	6,137	1.3
Oversize only	102,961	24.2	205,924	22.7
Oversize and overweight	315,464	74.2	353,682	75.9
Total	424,943		465,743	

Time Length and Fees

The Revised Civil Statutes of Texas (3) allow four types of permits according to time length: (a) single trip, (b) 30 day, (c) 90 day, and (d) annual. During 1978 and 1979 single-trip permits comprised about 94 percent of all the permits issued. The fees collected from each type of permit and their share of the total are given in the table below:

Permit	Permits Issued		Fees Collected	
Type	No.	Percent	Amount ($)	Percent
598	3,270	0.7	16,350.00	0.4
SB290	4,812	1.0	556,298.52	18.6
591	80,650	17.3	403,255.56	13.5
438	361,368	77.6	1,929,347.06	64.8
1407	15,643	3.4	78,215.00	2.6
Total	465,743		2,993,466.14	

SB290 permits consitute only 1 percent of the total issued, yet fees collected from the sale of this permit constitute 18.6 percent of the total collection. This is explained by the fact that a large number of SB290 permits are 30 day, 90 day, or annual--all of which cost substantially more than single-trip permits.

Over the past few years there has been a steady increase in the issuance of oversize and overweight permits. The data in the table below summarize the number of permits issued over the past 4 years:

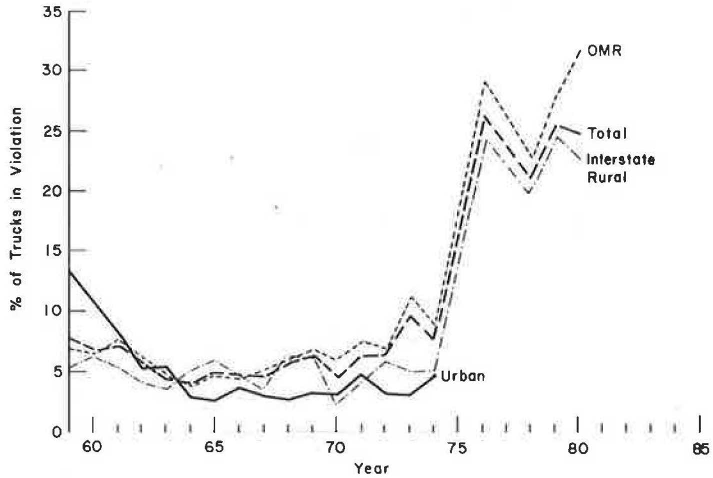
Date	No. of Permits	Increase Over Previous Year (%)
10/76 to 9/77	360,000	12.7
10/77 to 9/78	406,000	4.7
10/78 to 9/79	425,000	4.7
10/79 to 9/80	466,000	9.6

CHARACTERIZATION OF OVERSIZE AND OVERWEIGHT OPERATION FROM ANNUAL TRUCK WEIGHT SURVEY

The annual truck weight survey conducted by the states in cooperation with FHWA is a third source of information on oversize and overweight operations in the state. In Texas the annual truck weight survey is conducted through the weigh-in-motion method in which a truck is weighed through some electronic devices while in motion. Due to the nature of the scheme it is not possible to know if the trucks passing over the weighing equipment possess legal oversize and overweight permits or are overloading illegally. Nevertheless, the results obtained from such data are objective and present the opportunity to gauge actual oversize and overweight operations on the highways.

In Texas truck weight data are collected through five permanent weigh stations, three of which are located on Interstate highways and two on other state highways. Collected data can be checked through a computer program to determine whether or not a truck is overloaded. Results indicate that 3-S2, the most

Figure 3. Historical trend of oversize and overweight movements on Texas highways, 1959-1980.



commonly used truck carrier on Texas highways, is the truck group most often operating overweight. This is followed by 2-S1-2 on Interstate highways and 3A on other main highways. Because of its lesser frequency of operation on other state highways, 2-S1-2 has not been a major contributor to overweight operations on those highways. The 3A, which constitutes a large portion of the traffic on other main highways, has been found to operate overweight in large numbers on those highways.

A summary of the percentage of vehicles overweight on various highway systems from 1959 through 1980 is shown in Figure 3. The data suggest that there has been an upturn in overweight trucks on highways since 1974. Hence in 1980, 22.98 percent of all trucks on Interstate highways and 32.01 percent on other state highways were overweight. This is a significant increase from the 5.08 percent on Interstate and 8.60 percent on other state highways noted from the same data files for 1974.

COST OF OVERSIZE AND OVERWEIGHT OPERATIONS TO THE STATE

In an attempt to gain a perspective of oversize and overweight operations, an assessment of selected economic effects was undertaken, which include

1. Increased pavement maintenance and rehabilitation cost due to increased pavement damage;
2. Increased highway structure (bridges, culverts, and so on) maintenance and rehabilitation cost due to accelerated damage by oversize and overweight trucks;
3. State expenditures to enforce vehicle size and weight laws, which include DPS expenditure for License and Weight Service and TSDHPT expenditure for maintaining permit issuance operations;
4. Savings to the owner-operators of oversize and overweight trucks from reduced vehicle operating cost; and
5. Economic benefits accrued through the issuance of oversize and overweight permits for special truck movements (e.g., concrete beams, mobile homes).

The foregoing list is only a brief and partial summary of the economic effects of oversize and overweight vehicle operations. In order to arrive at an estimated cost of the economic effects of oversize and overweight vehicle operations, two cases were structured. The first case represented the existing condition with respect to the current distribution of sizes and weights of vehicles operating on the highway system. In this case truck weight data from the 1980 truck weight survey were used. The second case represented an artificial 100 percent compliance condition in which all vehicles were running at or below maximum size and weight limits. To represent the second case, data from the 1980 truck weight survey in Texas were modified by removing all overweight vehicles from the truck fleet and reassigning their payloads to a fleet of vehicles that would carry their payloads at the maximum permissible load. This analysis was based on 1980 truck weight survey data and, hence, its results must be qualified by the reliableness and the representativeness of the 1980 truck weight survey.

Data representing case 1 and case 2 were used in conjunction with the computer program "Trucky," which calculates total payload per 100 vehicles, total number of load vehicles, truck operating cost, fuel consumption, and ESAL on rigid or flexible pavement. These figures, together with ton-mileage and truck traffic forecasts, were input into a program called "Twenty," which generates a 20-year forecast for ESAL for rigid and flexible pavements, vehicle operating cost, and fuel consumption (4). The data in Table 3 give program Twenty's computation for both case 1 and case 2. It is clear that in case 2 (the 100 percent compliance condition) pavement damage is lessened and pavement life is extended.

Estimated ESAL figures for each highway type were then input into the REHAB program at TSDHPT. This program generated pavement rehabilitation cost estimates for the next 20 years. Pavement rehabilitation cost figures were based on unit cost data taken from the 12-month moving average of statewide bid prices (January to December 1980). For 1980, estimated extra pavement cost due to oversize and overweight trucks is approximately $9 million. Estimated damage for the next 20 years is approximately $125 million. An estimate was not made for the impact on bridges.

Attempts were also made to estimate government expenditures associated with the enforcement of size and weight laws. Expenditures for permit operations by the License and Weight Service (DPS) and TSDHPT were considered as the two major outlays in this area. The 1980-1981 fiscal year budget for DPS License and Weight Service is $3.845 million. The budget level proposed for 1981-1982 and 1982-1983 reflects substantial increases. To estimate expenditures for the next 20 years at the current enforcement level, an average of the annual budget from 1980-1983 is used. In forecasting 20-year permit operation expenditures for TSDHPT, the 1980 expenditure figure is used. Hence the estimated 20-year expenditure (in constant 1980 dollars) is $96.607 million for the DPS License and Weight Service and

Table 3. Comparison of estimated 18-kip ESAL for cases 1 and 2, 1980-1999.

Item	18-kip ESAL for Next 20 Years: Case 1[a]	Case 2[b]	Ratio of Pavement Life in Case 2 to Case 1
Interstate highways			
Rigid pavement	15,333,025	14,287,704	1.07
Flexible pavement	9,865,324	9,329,357	1.06
Farm-to-market roads			
Rigid pavement	161,797	136,040	1.19
Flexible pavement	101,014	84,770	1.19
Other state highways			
Rigid pavement	1,634,257	1,402,829	1.16
Flexible pavement	1,037,768	899,565	1.15

Note: All figures shown above are per mile figures.
[a]Case 1 is based on actual field data.
[b]Case 2 is an artificial case in which no overloading exists.

$38.857 million for oversize and overweight permits (TSDHPT) for a total of $135.464 million. The state costs (in constant 1980 dollars) from oversize and overweight vehicle movements for 1980 as well as those estimated for the next 20 years are summarized in the table below (note that highway bridge structures are not included in the highway costs):

Category	1980 Base Year Cost ($000,000s)	20-Year Cost Forecast ($000,000s)
Administrative		
DPS	3.667	96.607
TSDHPT	1.943	38.857
Total	5.610	135.464
Highway pavement maintenance and rehabilitation	9.008	125.105
Total	14.618	260.569

Nevertheless, the trucking industry is estimated to derive financial savings from oversize and overweight operations. These financial savings accrue primarily in the form of vehicle operating cost savings, which include savings on fuel, labor costs, and so on. Estimated vehicle operating cost for the next 20 years is given in the table below, which indicates that the cumulative vehicle operating cost savings are estimated to be $1.3 billion, or about 5 times the cost accrued to the state (note that costs are in constant 1980 dollars):

Highway Class	Cost ($000,000s): Case 1	Case 2	Case 2 - Case 1
Interstate	43,015.568	43,427.682	412.144
Farm-to-market	9,294.951	9,437.702	142.751
Other state highways	37,382.574	38,145.109	762.535
Total	89,693.093	91,010.493	1,317.400

Considering these findings, the next question to address is whether the oversize and overweight vehicles have been paying for the damage, if any, to the highways. The operators of oversize and overweight vehicles may reimburse the state in two forms. The first is through fees charged by TSDHPT for oversize and overweight permits, and the second is through fines levied by the courts for size and weight violations. The actual amount of fines levied against violators during the first 9 months of 1980 was $914,716. This figure was multiplied by four-thirds to obtain the estimated fine for the whole year. Receipts from permits issued during the 1979-1980 fiscal year amounted to $2,993,466. Costs and benefits from oversize and overweight operations for cases 1 and 2 over the next 20 years are given in the table below:

Item	Cost ($)
Savings in vehicle operating cost	1,317,710,000
Truckers' payment for oversize and overweight operations	
Fines for size and weight violations	24,392,000
Payment for oversize and overweight permits	59,869,000
Total	84,261,000
Net savings to the trucking industry	1,233,449,000

Enforcement activity at the current level is assumed for the 20-year estimate. Based on these considerations, it is estimated that net savings to the trucking industry from oversize and overweight operations in 1980 was about $42.3 million. If current enforcement activity is assumed constant for the next 20 years, the trucking industry's net savings would be approximately $1.23 billion in constant 1980 dollars. However, it must be emphasized that the above figures, particularly pavement maintenance and rehabilitation cost, are based on 1980 FHWA truck weight survey data, which are a 1-day sample of the truck traffic on Texas highways. Because the data are collected through five permanent weigh stations, and because these stations cover only selected areas in the state, the weight survey data may not be representative of the actual truck weight situation on the Texas highway system. Hence the reader must be cautioned in using or quoting these figures.

Some forms of oversize and overweight operations are necessary for the state's economy, such as the movements of concrete beams and mobile homes, trucks carrying oil well servicing and cleanout equipment, and other oil field-related activities. To prohibit these oversize and overweight movements would slow down the progress of the state's economy. Hence permits are still necessary for certain types of movements. Nevertheless, illegal oversize and overweight movements should be strictly regulated to preserve the highway infrastructure and reduce public nuisance.

CONCLUSIONS

The benefits to and the need for certain currently permitted oversize and overweight movements are readily apparent. Of primary concern, however, are illegal oversize and overweight movements. Highway vehicle loads must be limited in order to avoid rapid deterioration of roadways and the consequent high maintenance and rehabilitation costs that both TSDHPT and, ultimately, the taxpayers must bear.

Hence size and weight laws should be strictly enforced to ensure adequate protection of the state's highway investment. In addition, strict enforcement of size and weight laws leads to a reduction in unfair and illegal competition among the motor carriers.

The findings of this study can be briefly summarized as follows:

1. On a commodity basis, grain, sand, gravel, and log transporters are the major recorded violators in the state.
2. Overall, U.S. and state highways have the highest number of violation cases filed, followed by Interstate and farm-to-market roads. However, on a violation per lane-mile basis, the Interstate system ranks first, followed by U.S. and state highways and farm-to-market roads.

3. On the basis of violation cases filed per VMT, U.S. and state highways have the highest ratio, followed by Interstates and then farm-to-market roads.

4. Through DPS violation files it was discovered that dump trucks are the major violators of weight limitations (50 percent) whereas float trucks are the major violators of size limitations (66.4 percent).

5. Private and special carriers together constituted 95.4 percent of the weight violation cases filed and 96.5 percent of the size violation cases filed. Only 0.3 percent of weight violations are filed on common carriers and 3.1 percent on contract carriers; 1.6 percent of the size violations filed are on common carriers and 0.5 percent on contract carriers.

6. When classified according to lease status, two-thirds of the cases filed come from unleased vehicles and one-third from leased vehicles.

7. Of the weight violation cases filed, 86.3 percent were committed by intrastate carriers and 13.7 percent by interstate carriers. With respect to size violations, 83.6 percent of the cases filed were on intrastate carriers and 16.2 percent were on interstate carriers. The interstate carriers have a higher percentage of violations of size than of weight limitations.

8. In most violation cases vehicles exceed their registered weight by approximately 4,000 to 8,000 lb, although a few exceed it by as much as 50,000 lb.

9. Of the oversize and overweight cases filed by DPS officers, 98.6 percent were fined by the judges.

10. The average fine for a weight violation ranges from approximately $35 to $40 for a GVW violation. The average fine for a size violation is $29. The fine is not set in scale to the amount over the limit each vehicle is charged with carrying; therefore, vehicles slightly overweight and those heavily overweight may be levied identical fines. The fine structure should be such that the incentive to overload is nonexistent or even negative.

The following points relate to oversize and overweight permit operations.

1. During the period from September 1, 1979, to August 31, 1980, 81 percent of the permits issued were for oversize and overweight movement (77.6 percent of these through form 438 and 3.4 percent through telecommunication), 17.3 percent for mobile home transport, 1 percent for oil field-related activities (form SB290), and 0.7 percent for concrete beam movement.

2. Of the permits issued, 93.8 percent were single day, 5.2 percent were 30 day, 0.8 percent were 90 day, and 0.3 percent were annual.

3. Frequency of the type of permits issued in each highway district depends on the types of industries present there. Districts 2, 7, 10, and 12, for example, issued a large number of mobile home permits because of the presence of large mobile home industries in those districts.

By using TSDHPT published data to study the overweight vehicle movements in the state, the following items were noted.

1. Based on the TSDHPT truck weight survey, vehicle types 3-S2 and 2-S1-2 are the most frequent overweight truck types (each with more than 25 percent overweight), whereas on U.S. and other state highways 3A and 3-S2 are the major overweight truck types (each with more than 25 percent).

2. There has been an upsurge in oversize and overweight movement since 1974. In 1980 the percentage of trucks overweight on Interstate highways increased from 5.08 to 22.98 percent, while on U.S. and state highways the increase was even higher, from 8.60 to 32.01 percent.

3. The economic analysis (based on 1980 FHWA truck weight survey data) indicates that, through overloading, the trucking industry has realized a significant savings. Yet this savings by the trucking industry has been at the expense of the state's highway system, which has been damaged by overloaded vehicles. Moreover, the trucking industry has not fully paid for its share of this damage. However, caution must be exercised in quoting these figures due to the shortage of sample data in the truck weight survey.

In an effort to enhance the current enforcement level, several recommendations are made.

1. The current joint program of enforcement by the DPS, AG, and RRC in Texas should be continued. However, because filing suit is currently considered as only an extraordinary measure, a stronger statute is needed to limit the shipping, operating, and receiving of oversize and overweight trucks.

2. Because size and weight violations occur most often in the private independent carrier and special carrier sectors and most often are incurred by the haulers of grain, gravel, sand, and timber, special means should be found to curb violations by these groups.

3. Revision of the current fine structure is advised in order to remove the incentive for truckers to operate oversize and overweight. Fines should be scaled so that persistent violators will be punished to a greater degree than occasional violators.

4. A highway cost-allocation study to determine the relation between highway truck size and weight and the cost incurred is advised. Such a study would aid in the determination of a fairer fine structure for size and weight violations.

5. An increase in the DPS License and Weight Service enforcement force and budget is recommended to allow the establishment of additional checkpoints and the purchase of better detection equipment.

6. Establishment of a more effective truck weight survey program for the state is recommended. Such a program would aid the state in the design, planning, and administration of highway-related facilities and other funding-related questions.

The question of the appropriateness of current size and weight limits was addressed in previous phases of the study (1,6,7). The underlying premise of this study is that the highway users should bear their share of the cost.

ACKNOWLEDGMENT

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This paper reflects out views, and we are responsible for the contents, facts, and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of TSDHPT. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. F. Pass and others. Texas Almanac and State Industrial Guide, 1978-1979. A.H. Belo Corporation, Dallas, 1977.

2. The Truck Weight Problem in Highway Transportation. HRB, Bull. 26, July 1950, 172 pp.
3. Vernon's Annotated Revised Civil Statutes of the State of Texas. West Publishing Company, St. Paul, Vol. 19 1/2, Parts 1 and 2, 1977.
4. J. Brown and others. Effects of Heavy Trucks on Texas Highways. Texas State Department of Highways and Public Transportation, Austin, Sept. 1978.
5. D.S. Paxson and J.P. Glickert. Value of Overweighting to Intercity Truckers. TRB, Transportation Research Record 889, 1982, pp. 33-37.
6. C.M. Walton and D. Burke. Truck Sizes and Weights: A Scenario Analysis. TRB, Transportation Research Record 747, 1980, pp. 78-83.
7. C.M. Walton and O. Gericke. An Assessment of Changes in Truck Dimensions and Highway Geometric Design Principles and Practices. Center for Transportation Research, Univ. of Texas, Austin, Res. Rept. 241-2, June 1981.

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Impact of Oil Field Truck Traffic

JOHN M. MASON, JR.

Oil field truck traffic is identified in this paper as a special highway user, and an estimate of the annual cost associated with reduced pavement serviceability on thin surface-treated pavements is provided. Identification of oil field traffic through site-specific observation provides the basis for the investigation. The study includes a description of traffic during the development of an oil well, an estimate of reduced pavement service under these operating conditions, and an estimate of increased annual pavement cost due to oil well traffic. Three main components of the analysis procedure include a pavement analysis, a traffic analysis, and an estimate of traffic generated by an oil well. The AASHTO concept of pavement serviceability was used to determine a reduction in pavement service life due to this concentrated traffic demand. Photographic documentation of the evolution of an oil well provided both an axle count and a description of the physical characteristics of the vehicles. Axle weights were estimated by using standard state loadometer data. Estimates indicate a 50 percent loss of service life due to this special-use industry (considering only one well) as compared with the expected service life if the road had continued to serve its intended purpose. An increased annual cost of $16,500/km was determined for a low-volume, light-duty pavement section. The increase in annual cost is a separable cost attributable to the concentration of a special-user activity.

Continued interest in determining the effects of truck traffic on highways has prompted individual states to investigate future impacts of vehicle size and weight limits on pavement service life. Such investigations (1-4) have generally addressed statewide needs to justify corresponding increases in revenues required to meet the costs of new construction and rehabilitation. However, there have been limited studies to assess the site-specific impacts created by specialized industrial development.

Walton and Burke (2), in an unrelated study, discuss the lack of commodity information and the nature of economic (industrial) activities in assessing the economic efficiency of large vehicles. Although special-use industries need to be identified in order to differentiate highway costs and corresponding savings in truck operating costs, additional quantitative estimates are also needed. Among the important estimates are the effects on accident rates and severity, geometric and cross-section improvements, load zoning, truck route delineation, and efficient maintenance of traffic in construction and work zones.

SCOPE

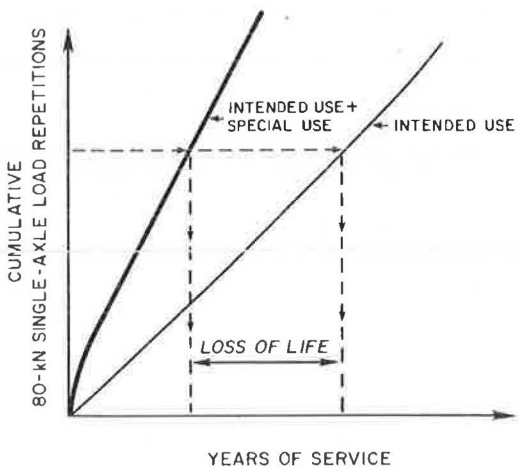
The first phase of a study conducted for the Texas State Department of Highways and Public Transportation (TSDHPT) is presented in this paper. The purpose of the initial research was to characterize oil field truck traffic and develop a preliminary estimate of the potential effects of this traffic on light-duty pavements (Figure 1). This special-use industry can conservatively reduce the expected intended-use service life of a thin pavement by approximately 50 percent or more. Although the successful ventures of oil production efforts have resulted in the benefits of economic growth, the adverse effect of this intense concentrated activity has caused the physical destruction of the pavement surface on the highways that serve the entire oil-producing area (Figure 2).

County roads, state farm-to-market and secondary roads, and city streets in many oil-producing areas were not initially constructed to endure the concentration of intense oil field truck traffic, some of which is well above legal load limits. The responsible road agency (city, county, or state) had not anticipated the resulting persistent rehabilitation under normal (intended-use) operating situations, and a restoration cost was not normally accounted for in the planning of maintenance expenditures. As a result the burden of associated costs has fallen on the public agency that is already obligated with the maintenance responsibilities.

Figure 1. Light-duty pavement section.

Figure 2. Effect of oil field use on light-duty pavement section.

Figure 3. Comparison of intended-use and special-use service life.



EVALUATION CONCEPT

Investigations that compare intended use versus special use are of primary concern to state legislators and highway department administrators, city councils, county administrators, and others who must secure and provide resources for maintaining a safe and concomitant road network. Inherently, roadways throughout the nation carry numerous types of commercial vehicle traffic, and each commodity shares in the cost of providing an acceptable roadway pavement. The design, or intended use, of a particular pavement assumes that the facility will serve its original intent for some period of time.

Figure 3 depicts the argument of the intended-use versus unpredicted special-use concept. Although the highway system can fail due to numerous environmental conditions, it is in serious jeopardy when subjected to traffic conditions well beyond its intended purpose. The acceptance of this contention can assist in justifying a redistribution of available funds to areas affected by industries that have heavy special-use traffic demands. Alternative measures such as general revenue increases or a special-use tax levy can also find support in this evaluation concept.

The fundamental concept of this evaluation technique is the identification of separable cost. This economic concept is most closely aligned with the theory of incremental cost, which seeks to "distribute equitably the cost of a basic road suitable for passenger cars among all classes of users, but to assign the heavier or larger vehicles all costs for which they are solely responsible" (5). The difficulty associated with the application of the incremental cost theory has been the inability to determine various costs due to the incomplete data relative to each of the various groups of users.

Oil field traffic is but one industrial activity that can have an impact on the highway system. Special activities with unique traffic characteristics must be assessed to determine what effects their specific site operations have on existing or intended-use roadways. These activities must be identified, their developmental operations defined, resulting traffic characteristics described, and the consequences analyzed on an equivalent basis with all other roadway users.

All levels in the transportation network hierarchy are similarly affected in every state. Industries that produce high concentrations of special-use trucks include mining, agriculture, timber, energy, gravel production, and others. These site-specific activities pose unique problems to local administrators, design engineers, and maintenance personnel. The consequences span the areas of planning, design, construction, operation, safety, and maintenance of the road and street network. Therefore, a need exists to identify the industries that produce these concentrations of heavy loads and assess their respective contributing impact on the expected life of the road system.

The goal of this study is to provide a basic framework for analyzing other unique traffic demands in pursuit of more complete data that relate vehicle axle repetitions to highway cost under a separable user-cost concept. Although this study does not assess separable costs as an analytic alternative, it does demonstrate the potential utility that such a concept may have in further special-use analyses. Because light-duty pavements were failing rapidly under excessive heavy axle load repetitions, these pavements were the first to be addressed in this project.

OBJECTIVES

Specific objectives of the initial phase included

1. Identification of the primary stages in the evolution of an oil well;
2. Description of the vehicle mix during the development of an oil well; and
3. Estimation of increased annual cost associated with reduced pavement serviceability on a low-volume, light-duty roadway pavement.

STUDY PROCEDURE

The transportation-related activity that occurs during the evolution of an oil well was established through a process of continuous photographic monitoring. Monitoring also included daily site visits to talk with servicing companies and oil field representatives. The developmental stages of an oil well were documented with traffic counts of vehicles entering and leaving a site. Specific information was provided by using a concealed camera to photograph vehicles as they entered or left a site. The camera, actuated by a pneumatic road tube across the entrance, signaled individual frame exposures. This procedure provided a count of the number of axles and an identification of vehicle characteristics.

In addition to the movie camera, a total-count traffic counter was installed at each observation site. The traffic counts were later used to check the reliability of the reduced film counts. A historical evolution of each oil well site was finally determined based on the filmed data, conversations held at the sites with operating personnel, and supplemental photographs taken for the duration of the project.

Study Sites

Five general activities typically comprise the sequential development of an oil well. These include site preparation, rigging-up, drilling, completion (rigging-down), and production. Each fundamental stage of oil well activity develops unique traffic. Specifically, the vehicle mix includes a disproportionate frequency of large vehicles as compared to typical operating conditions on most low-volume, light-duty, farm-to-market (FM) roads, and city streets.

Three oil well sites were secured within an 8-km radius of each other. Each study site was virtually access controlled. Entrance to the drilling platforms could only occur at the points where the monitoring equipment had been installed.

The well sites are situated in a rural area (Figure 4) on open pasture; no other commercial or industrial activity existed in the general vicinity.

Figure 4. Typical rural oil well site.

Table 1. Vehicles defined according to axle combination and corresponding vehicle type code.

Axle Combinations	Vehicle Type Code for Axle Combination
Single-unit vehicles	
Passenger car	PC
2 axles, 4 tires (pickup truck)	PU-1
2 axles, 6 tires (pickup truck)	PU-2
2 axles, 6 tires	SU-1
3 axles	SU-2
Multiunit vehicles	
2-axle tractor, 1-axle semitrailer	2-S1
2-axle tractor, 2-axle semitrailer	2-S2
3-axle tractor, 1-axle semitrailer	3-S1
3-axle tractor, 2-axle semitrailer	3-S2
2-axle tractor, 3-axle semitrailer	2-S3
3-axle tractor, 3-axle semitrailer	3-S3
2-axle truck, 1-axle balance trailer	2-1
2-axle truck, 2-axle full trailer	2-2
2-axle truck, 3-axle full trailer	2-3
3-axle truck, 2-axle full trailer	3-2
3-axle truck, 3-axle full trailer	3-3
3-axle truck, 1-axle balance trailer	3-1
2-axle tractor, 1-axle semitrailer, 2-axle full trailer	2-S1-2
3-axle full trailer, 1-axle semitrailer, 2-axle full trailer	3-S1-2

Filming was maintained for approximately 2 months at well sites 1 and 2. A photographic record was available for only 28 days at well site 3 due to theft of equipment. The depth of drilling governs duration of activity and was found to be similar at each site. Production generally occurred after 2590 m of drilling. Traffic count monitoring is continuing and has been in operation for 18 months.

Data Reduction

Because a single frame was exposed on each axle application, a valid count of axles was possible and a daily record of vehicles was established. The vehicles observed entering and leaving the site were classified according to axle combination. The data in Table 1 give the vehicles defined by axle combination and corresponding vehicle type code. The vehicle code type generally follows the AASHTO classification for axle combinations; the code type was eventually used to assist in assigning vehicle load weights to various axle configurations. Samples of the unique truck traffic serving a well site are shown in Figure 5.

ANALYSIS

The effect of oil field truck traffic was evaluated based on pavement seviceability. After the traffic characteristics associated with an oil well were determined, a comparison of annual costs to provide a suitable pavement surface was made. The comparison was between an intended-use design traffic volume and the observed oil field demand volume. The conceptual framework of the analysis is shown in Figure 6. The three main components include a pavement

Figure 5. Special-use trucks serving oil well sites.

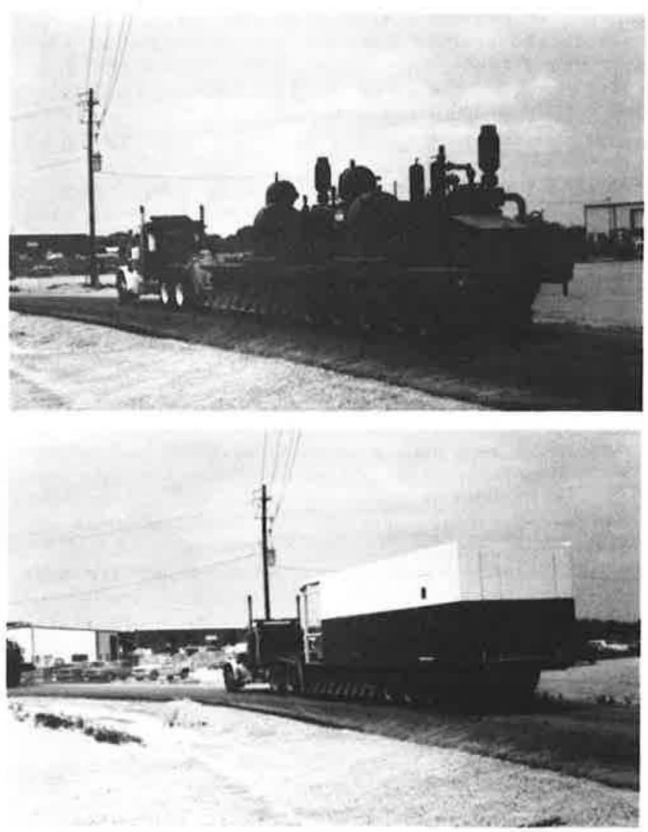
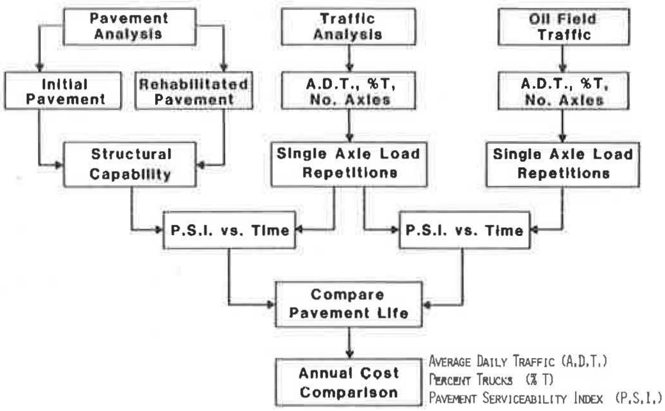


Figure 6. Flowchart of analysis procedure.



analysis, a traffic analysis, and an estimate of traffic generated by an oil well.

Basically, the structural capabilities of a bituminous surface-treated pavement were determined for an intended-use situation. A projected traffic demand was then estimated for a typical low-volume, light-duty pavement. Respective 80-kN single-axle load (SAL) repetitions were calculated for each analysis. A rehabilitation interval was established for a bituminous surface-treated pavement. This was done by comparing the estimated cumulative traffic demand with the terminal pavement serviceability of the intended-use pavement section.

The traffic characteristics of an oil well served as the basis for defining the anticipated traffic attracted to a new well. These characteristics were used to estimate the associated axle load repetitions. An estimate of 80-kN SAL repetitions was calculated for an oil well. Cumulative 80-kN SAL values were established for a light-duty pavement serving an oil well site over the analysis period. Because the roadway pavement must continue to serve both the intended-use traffic and the attracted oil field traffic, the 80-kN SAL intended-use repetitions were combined with the oil field traffic repetitions to represent the total 80-kN SAL applications on the assumed pavement section.

Comparison of the resurfacing intervals over an expected design period indicated a reduction in pavement life. A further comparison was made of the respective total annual costs. The difference between the estimated total annual costs constituted a unit capital loss due to increased traffic, namely, oil field truck traffic. This loss of value represents a consumption, or expenditure, of capital that must be borne by a public agency. These costs considered only the cost of an initial pavement structure and seal coat resurfacing and did not include costs associated with a complete pavement reconstruction, vehicle damage, or accidents.

Pavement Analysis: Intended Use

Light pavements built for an intended use are characterized by low traffic volumes and lightweight vehicles. These pavements are typically constructed as a bituminous surface-treated pavement. This analysis assumed a 12.7-mm crushed stone bituminous surface course (seal coat) on a 152.4-mm foundation base course as a representative initial pavement structure. A seal coat then served as the intended rehabilitation.

One traditional procedure for defining a pavement's ability to serve traffic is the calculation of a serviceability index (6); the serviceability-performance concept is the basic philosophy of the AASHTO guide for the design of pavement structures. Under this concept pavements are designed for the level of serviceability desired at the end of a selected analysis period or after exposure to a specific total traffic volume.

By using the AASHTO equation, 1,420 80-kN SAL repetitions were determined for the initial pavement structure. An additional 2,180 80-kN SAL repetitions were calculated considering a seal coat rehabilitation. An estimated total of 3,600 80-kN SAL repetitions was considered the anticipated capacity of a typical FM road under intended-use conditions.

Traffic Analysis: Intended Use

The traffic analysis assumed a low traffic volume condition. An average daily traffic (ADT) of 250 was selected and considered representative of a low-volume, intended-use traffic condition. Additional specific assumptions included 1 percent heavy trucks, 3 percent annual growth rate, and a 50/50 traffic split on the two-way roadway. These assumptions resulted in 456 trucks in the design lane per year.

The intended-use 456 trucks were distributed across approximate axle load ranges developed from the Department's loadometer data. Converting these truck axle repetitions to SAL equivalents indicated that an estimated 445 80-kN SAL repetitions can be assumed during the first year of service. Cumulative 80-kN SAL repetitions for an 8-year period are shown in Figure 7. Given the assumptions of the traffic analysis, 1,420 80-kN SAL are accumulated after approximately 3.2 years, and 3,600 80-kN SAL are accumulated after 7.5 years. These values correspond to the respective initial life and first rehabilitation life of a typical low-volume, light-duty pavement serving its intended-use condition.

Oil Field Traffic: Specific Use

Traffic characteristics at the three well sites were found to be similar in distribution. Average values were used in the initial analysis. A total of 10,353 vehicles were recorded by the camera. The ADT was approximately 150 vehicles, with peak volumes of 325 vehicles/day. Traffic counts of up to 200 vehicles/day were recorded during the actual drilling process of a single well. Note that these volumes are generally considered as the typical ADT of a low-volume roadway serving only its intended-use traffic.

Distribution of vehicles by code type classification is shown in Figure 8. Passenger cars and pickup trucks comprised approximately 86 percent of the

Figure 7. Intended-use service life.

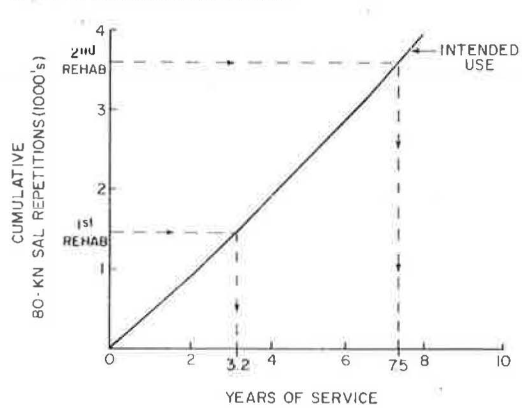


Figure 8. Percentage of vehicles by code type classification.

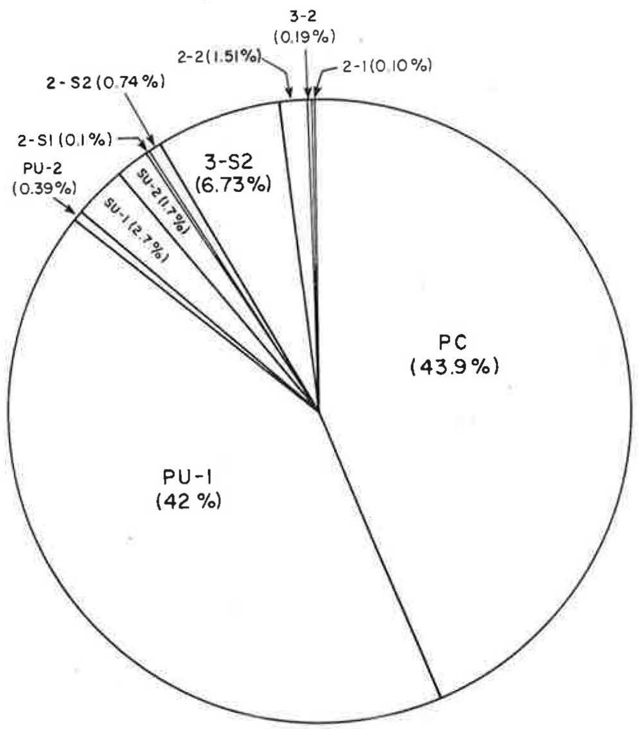
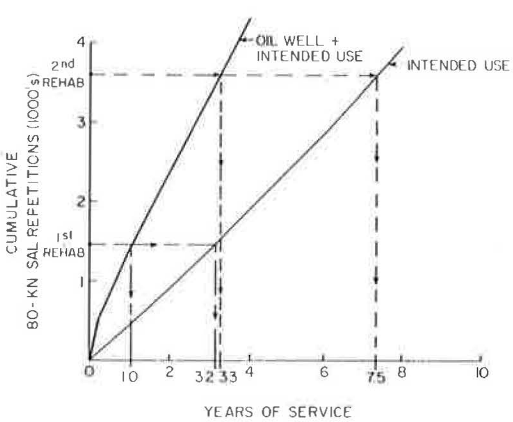


Figure 9. Reduction in service life.



total vehicle mix; truck combinations comprised approximately 14 percent, with almost 7 percent consisting of the 3-S2 (semitrailer) type. The total truck percentage is almost 3 times the anticipated truck percentage on low-volume rural roadways. A total of 1,327 trucks were observed during the drilling phase, and 876 trucks were calculated for oil well production activity during the first year. The total--2,203 heavy trucks--is approximately 5 times the estimated annual truck combinations of the intended-use traffic condition.

The total truck counts were distributed across axle load ranges that corresponded to statewide loadometer data. This approach prevented biasing the oil field truck traffic because actual axle weights were not taken. The method was considered conservative because it assumed the axle weight distribution of oil trucks was typical of all other truck combinations operating on the Texas highway system. Comparison and interpretation of the findings are therefore not biased.

Oil well traffic for one well results in 945 80-kN SAL during the first year of development. Extending production beyond the first year increases axle repetitions by approximately 500 80-kN SAL/year for one well. The loss in pavement use from such traffic is shown in Figure 9. If no additional wells are drilled during the expected service life (7.5 years), the net effect of the drilling and producing of one well is a reduced service life of 4.2 years. In another manner the first rehabilitation is required in year 1.0 rather than year 3.2, and a second rehabilitation is needed in 3.3 years instead of 7.5 years.

Annual Cost Comparison

This reduction in service life was further examined by estimating the annual cost of providing a suitable light-duty pavement surface. This cost considers only the investment cost of the roadway pavement structure and does not include costs associated with vehicle wear, accidents, or other related adverse consequences of a vehicle operating on an unsuitable pavement surface.

The annual cost formula selected for analyzing the pavement service life is given as (7)

$$C = CRF_n[I + (R_1 \times PWF_{n1})] \qquad (1)$$

where

- C = annual cost for pavement per kilometer,
- n = analysis period, i.e., time between initial construction and second resurfacing (years),
- CRF = uniform capital recovery factor,
- I = initial cost of pavement per kilometer ($37,965/km),
- R_1 = first resurfacing cost per kilometer ($5,344/km),
- n_1 = number of years between initial construction and first resurfacing, and
- PWF_{n1} = single pavement present worth factor.

An interest rate of 12 percent was used in all calculations. (Note that the costs for I and R_1 are from 1981 TSDHPT data for unit costs for a typical surface-treated cross section.)

The estimated annual cost for a 250 ADT light-duty pavement roadway is $8,700/km. For a 250 ADT FM roadway that also serves one oil well, the annual cost is $16,500/km, a doubling of the intended-use investment. The difference results in an increase in annual pavement cost of $7,800/km. This cost reflects the impact of one oil well on a low-volume, light-duty pavement section.

Although this increase in annual cost demonstrates the effect of one oil well, the practical impact must also be addressed. It is unrealistic to consider restoring a pavement to its intended-use condition. Once a "find" is made, an oil field is vigorously developed and the demand traffic volumes simultaneously increase as ultimate development is pursued. If the axle repetitions are simply considered multiplicative, the end result is a losing battle when using minimal maintenance techniques.

In reality, it becomes necessary to determine what pavement structure is required in a design situation so as to provide an acceptable level of service for future demand. The future demand must consider both the growth in intended-use traffic as well as ultimate development of a particular field.

These considerations are the primary objectives of the ongoing research effort.

The next phase of the research project is examining the effects of multiple wells by using pavement distress equations for bituminous surface-treated pavements. Specific investigations are being performed on roadways with varying ADT ranges, percentages of trucks, and pavement thicknesses in the intended-use condition. These efforts will provide data to assist in the planning, design, and maintenance of the roadways that exist in the region of this special-use industry. Expected information includes developing impact contours that delineate the radius or zone of special-use influence and projections of drilling and production activity for several levels of development. Anticipating this concentration of unique truck traffic is beneficial in scheduling resurfacing, restoration, and rehabilitation strategies on primary, secondary, and local roads.

CONCLUSIONS AND RECOMMENDATIONS

Roadway networks throughout the nation carry numerous types of industrial traffic, and each activity shares in the cost of providing an acceptable roadway pavement. The design, or intended-use, of a particular pavement assumes that the facility will serve its original intent for some period of time. Although the system can fail due to numerous environmental conditions, it is in serious jeopardy when subjected to a traffic condition well beyond its intended purpose.

Attempts at predicting and anticipating needed financial resources and expenditures will aid in the planning and distribution of allocated funds. Although the estimates developed in this study provide site-specific information to assess the impact of oil field traffic on low-volume, light-duty pavements, the analysis procedure can be applied to other special-use industrial concentrations.

Practical applications of the results of this research are possible at various agency levels. In counties and cities where construction and maintenance capabilities may be limited or near impossible with current budget restraints, this technique can be used to respond to unexpected special-use demands. Administrative, maintenance, and design engineers can each use the approach or findings reported in this research to anticipate the consequences of an increased concentration in traffic demand. Implementation is possible when planners, designers, and administrators use the best estimates available.

Although a reduction in pavement life is inevitable on any road, the effects of increased cost attributable to a special user should not be ignored in times of financial austerity. If rational analysis is coupled with convincing evidence, public agencies will be able to justify additional allocations to maintain their existing system.

ACKNOWLEDGMENT

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The views, interpretations, analysis, and conclusions expressed or implied in this report are mine. They are not necessarily those of TSDHPT.

REFERENCES

1. Mississippi State Highway Commission. A Special Report on the Highway Weight Limit. Mississippi Legislature, Jackson, Senate Resolution 31, Nov. 1976.
2. C.M. Walton and D. Burke. Highway Economic Effects of Increased Truck Size and Weight. Compendium of Technical Papers, ITE, Washington, D.C., 1980.
3. R.F. Carmichael III, F.L. Roberts, P.R. Jordahl, H.J. Treybig, and F.N. Finn. Effects of Changes in Legal Load Limits on Pavement Costs--Volume 1: Development of Evaluation Procedure. FHWA, Rept. FHWA-RD-78-98, Sept. 1978.
4. J.L. Brown, D. Burke, F.L. Roberts, and C.M. Walton. The Effects of Heavy Trucks on Texas Highways. Texas State Department of Highways and Public Transportation, Austin, Res. Rept. 231, Sept. 1978.
5. C.H. Oglesby. Highway Engineering, 3rd ed. Wiley, New York, 1975.
6. Interim Guide for Design of Pavement Structures, 2nd ed. AASHTO, Washington, D.C., 1974.
7. L.J. Pignataro. Traffic Engineering, Theory and Practice. Prentice-Hall, Englewood Cliffs, NJ, 1973.

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Twin Cities Metropolitan Area Heavy Truck Study

MORRIS FREIER

Due to the growing significance of goods movement by heavy trucks in recent years, the Minnesota Twin Cities metropolitan area heavy truck study was conducted to update the Minnesota Department of Transportation data on heavy trucks. These data are needed for pavement design, heavy truck routing, and policy formulation. Similar data were obtained from a 1970 travel behavior inventory (TBI). The 1970 study surveyed 2 percent of all truck trips, but less than 1 percent of the trips were by heavy trucks. The results were of limited use in forecasting because of the small sample. This resulted in a poor distribution of trips when the sample was expanded. From the outset, the current study was constrained due to limited funding. Although the budget was enough for a survey of heavy commercial truck movements, innovative methods were needed to obtain data on the movement of heavy tax-exempt trucks and grain trucks. These data were produced through a combination of limited surveying and simulation. In addition to financial problems, two other constraints had to be overcome: (a) Minnesota's vehicle registration of tax-exempt trucks does not list vehicle weight; therefore, it was necessary to inventory heavy trucks; and (b) because of financial, personnel, and administrative problems, there was no external cordon-line survey conducted in conjunction with the heavy truck study; therefore, the data needed on external and through trips had to be developed by other means; i.e., they were simulated by applying growth factors to the 1970 data and then using 1980 truck counts at the external cordon lines as control totals. A comparison of the results of this study with the 1970 TBI reveals a substantial increase in external and through trips by heavy trucks and a substantial decrease in internal trips. The decrease in internal trips is probably due to the depressed economy, whereas the increase in external and through trips can be attributed to 1,560 miles of railroad track abandoned in Minnesota between 1971 and 1981. Final results of the study reveal that in 1981 there were 116,800 heavy truck trips per day in the metropolitan area, and in the year 2000 there are expected to be 265,300 trips/day.

In 1970 the former Minnesota Highway Department [today the Minnesota Department of Transportation (MnDOT)] conducted a travel behavior inventory (TBI) of the seven-county metropolitan area of the Twin Cities of Minneapolis and St. Paul. The purpose of this study was to collect and analyze travel data, such as vehicle occupancy rate, trips per person per day, transit ridership rate, that would be useful for future trip forecasting. As part of this study a 2 percent survey was conducted of all trucks in the metropolitan area. The results of the truck survey were of limited use in forecasting because of the small sample size and the unsatisfactory distribution of trips that resulted when the sample was expanded.

By 1980 the amount of rail abandonment and its impact on goods movement, and the rapid increase in Minnesota grain exports, made it mandatory to update the 1970 data, particularly as it applied to heavy trucks. This update was necessary because of the following reasons:

1. The 1970 survey had included all types of trucks and assumed that travel patterns for all trucks were similar. By 1980 travel patterns for heavy trucks had changed substantially, whereas travel patterns for pickups and vans had shown relatively little change.
2. Although the 1970 survey had a 2 percent sample, the sampling procedure and low trip rate of heavy trucks resulted in less than 1 percent of the heavy truck trips being sampled.
3. With the recent shifts in goods movement by heavy trucks there is need for more and better information for pavement design, heavy truck routings, and policy formulation.

(Note that for transportation planning purposes, the definition used for a heavy truck is a truck with at least dual rear wheels and a gross weight of more than 15,000 lb.)

In 1981 a new truck trip inventory was conducted as a joint effort of the MnDOT and the Metropolitan Council of the Twin Cities. This study focused exclusively on heavy truck forecasting needs.

The 1981 heavy truck study included three separate surveys: heavy commercial trucks, heavy tax-exempt trucks, and heavy grain trucks. The 1981 survey of commercial trucks differed from the 1970 survey in the following respects:

1. Only heavy trucks were included in the sample. In the 1970 survey all trucks were subject to sampling, including pickups, vans, recreational vehicles, and smaller units not essential to the analysis of freight movements and permissible routings.
2. The interview sample was about 7 percent of all heavy trucks in 1981 as opposed to less than 1 percent in 1970.
3. A decision was made to use a Fratar distribution model instead of the gravity model applied to truck trips in 1970. The reason for the change is the assumption that zonal accessibility is not a major factor in predicting heavy truck travel between zones. Instead, truck travel is related more to the established and forecast types of land use and the basic pattern of truck movements observed during the survey year.
4. The 1970 survey used an areawide expansion factor to expand the sample results. More precision was desired in the expansion of the interview samples to the population of trucks by subarea of the region. For the 1981 survey, the metropolitan area was stratified into 60 factoring areas. These factoring areas were created by analyzing heavy truck registrations and land use within postal zip code areas and then combining abutting and homogeneous zip codes where land use was similar; it was assumed that truck trip generation would be similar. Separate expansion factors were developed for each of the 60 factoring areas.
5. In 1970 the external growth factors were applied to cars and all types of trucks. In 1981 external travel was estimated by using different growth factors for heavy trucks than for cars. The external cordon of 31 stations was divided into 9 corridors. The growth factor developed for each corridor was applied to all external stations included within that corridor.
6. Control totals were imposed on 1980 heavy truck trips within the metropolitan area, although they were not imposed in 1970.

CONSTRAINTS

Although planners were committed to a heavy truck study, there were severe limitations on budget and available personnel. There was enough money available to have a consultant survey heavy commercial trucks, but other means were necessary to collect and use data on tax-exempt heavy truck movements and grain truck movements. Also, due to administrative, personnel, and budgetary limitations, it was impossible to conduct an external cordon-line survey. It was therefore necessary to develop innovative methods to inventory the external and through trips by heavy trucks.

SAMPLING PLAN FOR HEAVY COMMERCIAL TRUCKS

The sampling plan had the Department of Public Safety provide a listing of every tenth truck in its registration file. However, in order to ensure uniform sampling, the truck registrations were first divided into two weight classes and then stratified by county and zip code in the seven-county metropolitan area for each weight class; tax-exempt and farm trucks were excluded. These registration totals by zip code represented the total population of heavy trucks registered in the metropolitan area in 1981 to which the sample would be expanded; i.e., 14,830 vehicles in the 15,001- to 49,999-lb class, and 10,564 vehicles in the greater than 50,000-lb class, for a total of 25,394 vehicles.

It was decided that a sample of 5 to 7 percent would provide sufficient accuracy in compiling the necessary data. The survey was set up, however, so that a larger sample could be used if staff and funds were available. The 10 percent list of registrations in each weight class was selected in order to make up two 5 percent lists, i.e., a working list and a backup list created by putting every other registration on the backup list. Any unusable interview could be replaced by a registration with the same zip code from the backup list. In addition, where more sampling was deemed necessary, the truck could be selected from the backup list.

There are 161 zip codes in the metropolitan area. Some have many heavy truck registrations whereas others have few or none. Because the sampling was stratified within zip code areas, it was decided to expand the sample in a similar manner. The large number of zip code areas with a large variance in truck registrations was too unwieldly to work with and would not produce sufficiently accurate trip-predicting equations.

Therefore, abutting zip code areas of similar land use were combined, which resulted in 60 factoring areas. The division of heavy trucks into two weight classes had been done solely to obtain uniform sampling and not to obtain separate trip expansion factors for each weight class. The registrations of both weight classes were combined to produce total heavy truck registrations for each of the 60 factoring areas. Dividing the number of heavy truck registrations by the number of interviews produced trip expansion factors for each of the 60 factoring areas. The resultant trip expansion factors were used to factor heavy truck trips sampled to a factoring area total. The total of all expanded trips from all of the 60 factoring areas represented an average day of travel for heavy trucks registered in the metropolitan area.

Basis for Identifying Factoring Areas

Many zip code zones did not have enough trucks registered to provide an adequate basis for trip expansion. As a result, zip code zones were combined so that at least 60 vehicles weighing more than 50,000-lb gross weight or 100 vehicles between 15,000- and 50,000-lb gross weight were registered within each trip expansion factoring area.

Homogenous abutting zip code zones were grouped on the basis of the type of land use (and probable truck use) being similar. The basic premise was that the rate of truck trip generation for all zip code zones within a factoring area was similar.

Sample Selection Problems

After the initial truck samples had been selected (a 10 percent sample from each zip code zone), it was discovered that the Department of Public Safety registration lists were not current, as was initially thought. The lists had not been purged of expired registrations.

Because the registration lists are used primarily for law enforcement purposes, the Department does not purge the list of unregistered vehicles. The lists are necessary so that police may check on the owners of expired licenses to determine theft, illegal transfers, and trucks that were abandoned.

The unpurged registration lists wasted time and expense in the early stages of the survey. This problem was overcome by reproducing the same sample list with the registration expiration date inserted for each vehicle, which enabled interviewers to immediately see if a registration was valid.

In early 1981 the state and national economy was such that unemployment in the trucking industry, especially for the large carriers, was high. This probably increased the number of expired registrations compared to normal years (i.e., there was no need to register a truck not being used). In order to make a correction for the decline in truck registrations, the registration file was purged of expired registrations. This reduced the registration total by about 12 percent and was accepted as being more representative of current economic conditions.

Sampling Technique for Heavy Commercial Trucks

During a 1979 examination of the goods movement problems in the metropolitan area, a consultant recommended that a heavy truck survey be conducted. He also designed a survey plan (1) that was used to sample heavy commercial trucks. Every truck listed on the working list was contacted for surveying. In order to be included in the sample, it had to meet one of three criteria:

1. The truck was in service and had trips on the interview day,
2. The truck was in service but had no trips on the interview day, or
3. The truck was temporarily out of service on the interview day.

Any interview that met any of the three criteria was accepted in the sample. If it did not meet the criteria, a replacement with the same zip code was selected from the backup list.

All trips for 1 day by each heavy truck were recorded by an interviewer. The sample of trips was then expanded to represent the total population of trips made by heavy trucks registered within each factoring area. The expansion factor for a factoring area was assigned to each traffic analysis zone (TAZ) within the factoring area. The metropolitan area is divided into 1,058 TAZs. Each zone produces and attracts trip generation. The ultimate goal of the heavy truck survey was to create a table of heavy truck trips between TAZs. It would have been impractical to survey at the TAZ level because the registration addresses of the entire heavy truck population in the metropolitan area would have to be converted to a TAZ of registration in order to properly expand the sample. Instead, surveying was done at the factoring-area level and converted to the TAZ level by assigning the expansion factor from a factoring area to each TAZ located within the factoring area. By converting all trip data from factoring areas to TAZs and then expanding it to the population, it was possible to build a heavy truck trip table and distribute the trips properly.

Integration of Data Obtained from Supplementary Truck Sampling

There were many locations in the seven-county metropolitan area in which there were concentrations of truck fleets. Additional data on freight truck movements could be collected at little additional cost by referring to the trip sheet logs for extra trucks while the interviewer was at the fleet terminal to collect data on specific sample trucks. These supplemental data could be useful, if properly added to the sample data, in providing a more accurate distribution of interzonal truck trips; i.e., trips from the sample zone to more destination zones were reported. The expanded trip total for the zonal trucks remained the same but, by touching more destination zones, the data base for the Fratar expansion was improved. It was apparent that, when supplemental interviews were added, they represented additional truck travel; therefore, the trip expansion factors for these respective zones of truck registration were reduced accordingly. Therefore, after the trip expansion factors had been calculated, they were recalculated for only the TAZs that had supplemental interviews. The formula used was

$$X = (a)(c)/(a + b) \quad (1)$$

where

- X = final trip expansion factor for the TAZ,
- a = number of primary survey samples in the TAZ,
- b = number of supplementary survey samples in the TAZ, and
- c = preliminary expansion factor for the TAZ.

The final expansion factor replaced the preliminary expansion in all TAZs that had supplementary samples. Where there was no supplementary sampling, the preliminary expansion factor for a TAZ automatically became the final one. The supplementary trip data were then merged with the survey trip data. When the combined trip data were multiplied by the respective TAZ trip expansion factors, the resulting trip table represented 1 day of truck travel. The data in Table 1 summarize the results of the interviews attempted. The 10 interview codes used in the table are listed below:

1. Completed interview with trips.
2. No trips, but otherwise complete.
3. Truck is garaged outside of the metropolitan area.
4. Truck is temporarily out of service for repair.
5. Truck has been sold.
6. Truck has been scrapped.
7. No contact made with truck owner.
8. Unable to locate or out of business.
9. Refused interview.
0. Other (farm use, nonroad hauler use, nonrenewal of license, and so on).

Although there were a total of 2,214 interviews for purposes of this study, only those with an interview code of 1, 2, or 4 were used. Therefore, 1,307 primary and 377 supplementary interviews were found usable--a total of 1,684 interviews.

Table 1. Interviews grouped by interview code.

Interview Code	No. of Interviews Primary	Supplementary	Total
1	622	377	999
2	645	0	645
3	165	0	165
4	40	0	40
5	82	0	82
6	10	1	11
7	85	0	85
8	108	0	108
9	53	2	55
0	24	0	24
Total	1,834	380	2,214

Table 2. Distribution of heavy trucks by county.

County	No. of Heavy Trucks by Weight 15,001 to 49,999 lb	≥15,000 lb	Total
Anoka	1,078	618	1,696
Carver	344	125	469
Dakota	1,505	1,049	2,554
Hennepin	7,246	4,895	12,141
Ramsey	3,470	3,062	6,532
Scott	536	320	856
Washington	651	495	1,146
Total	14,830	10,564	25,394

Summary of Major Findings of Heavy Commercial Truck Survey

1. There were 25,394 heavy commercial trucks as of July 31, 1981, that had current year (1981) registration in the seven-county metropolitan area. This figure did not include the 2,677 heavy farm trucks currently registered that were excluded from the sample to be modeled separately.

2. Heavy trucks were registered by county, as shown by the data given in Table 2.

3. The average number of trips per heavy truck, including those that had no travel on the survey day, was 4.02 trips/truck, whereas the trucks that traveled on that day had averaged 6.77 trips. Fifty-nine percent of the sampled heavy trucks were in use on the day of the survey.

4. Although 2,214 truck owners were surveyed for an initial sampling percentage of 8.72, only 1,684 were legitimate interviews because they had trucks garaged in the metropolitan area and they also had a current registration; therefore, the final usable sampling percentage was 6.63.

HEAVY TAX-EXEMPT TRUCKS

Tax-exempt heavy trucks comprise 6.55 percent of all heavy trucks registered and garaged in the seven-county metropolitan area. Tax-exempt trucks were found to average fewer trips per truck per day. They accounted for about 5 percent of all heavy truck trips in the metropolitan area; therefore, the number of internal heavy truck trips would be underreported without their inclusion. Data on tax-exempt trucks were collected through a combination of surveying and simulation. This combination accounted for an estimated 64 percent of heavy tax-exempt trucks in the metropolitan area and nearly all of the heavy tax-exempt truck trips in the metropolitan area.

The procedure adopted was to inventory all of the tax-exempt heavy trucks registered to Minneapolis, St. Paul, Hennepin County, and Ramsey County. Analysis of the data obtained from these surveys produced patterns of the ratio of heavy trucks to total

Table 3. Distribution of heavy trucks and trips per truck in sample of tax-exempt heavy trucks.

Agency	Total No. of Trucks	No. of Heavy Trucks	No. of Trips	No. of Trips per Truck	No. of Heavy Trucks per All Trips
County					
Hennepin	171	82	375	4.57	0.48
Ramsey	78	18	68	3.78	0.23
Total	249	100	443	4.43	0.40
City					
Minneapolis	353	236	690	2.92	0.67
St. Paul	297	62	171	2.76	0.21
Total	650	298	861	2.89	0.46

trucks, and also trips per truck per day, which were used to simulate heavy truck trips for cities and counties in the metropolitan area that were not inventoried.

In addition to the inventory previously mentioned, an inventory was also done for heavy trucks registered to the post offices of Minneapolis and St. Paul and for heavy trucks registered to metropolitan districts of MnDOT. Due to the unique nature of the trips involved, these trips could not be simulated and data obtained from their trips could not be used to simulate trips by heavy trucks from other agencies. However, these separate surveys were used in reporting final totals for all trucks. The distribution of trucks and heavy truck trips in the cities and counties that were surveyed is given in Table 3.

In analyzing the data in Table 3, two patterns emerged that were useful in estimating heavy trucks registered to other metropolitan area cities and counties and in simulating trips made by these trucks:

1. Forty percent of the county-registered trucks and 46 percent of the city-registered truck were heavy trucks, for a combined weighted average of 44 percent; and
2. The average number of trips per day was 4.43 per registered heavy truck for the counties whereas it was 2.89 for the cities.

A high correlation was discovered between the number of trucks registered to a city or county and the number of TAZs within the city or county. This is because in defining TAZs, the original aim was to have the population size of all TAZs as uniform as possible. Therefore, if the population of an area is more dense, the TAZ is smaller and more TAZs are required to make up a city or county. The concentration of population indicates more travel on roads and, in general, more need for public services; therefore, more trucks are required. Conversely, in the more sparsely populated areas the TAZs tend to be larger; thus there are fewer of them in a city or county. With less population there is less need for public service, thus fewer trucks are required.

This relation between number of TAZs and number of trucks in a city or county was used in the simulation and distribution of heavy truck trips. By using the data in Table 1, it is revealed that a reasonable estimate of heavy trucks is 44 percent of the total trucks owned by a city or county; thus the relation between number of TAZs and number of trucks would also hold true for heavy trucks. The data in Table 3 also reveal that there are 4.43 trips/day for each county-registered heavy truck, and 2.89 trips/day for each city-registered heavy truck. Analysis has indicated that the total heavy truck trips estimated could be simulated with approximately the same accuracy by assuming, for the counties, one round trip from the TAZ where the truck is garaged to each other TAZ in the city. The advantage of this method of reproducing trips is that they are uniformly distributed, as one might expect them to be, throughout the course of a year. The results of this analysis are given in Table 4.

There are an estimated 1,780 heavy tax-exempt trucks in the metropolitan area. The data in Table 5 reveal that 1,141 (64 percent) of the estimated 1,780 tax-exempt heavy trucks are accounted for. The rest of the heavy trucks in the metropolitan area belong to agencies such as the Department of Natural Resources or the University of Minnesota, which do little highway travel, or else they belong to small cities and towns where they are used for local street repair and snow plowing; i.e., they make short trips and rarely leave the municipal boundaries. It is reasonable to assume that 64 percent of the heavy tax-exempt trucks account for most of the heavy tax-exempt truck trips in the metropolitan area.

Table 4. Estimates of truck trips by using truck counts and zones.

Agency	No. of Trucks	Estimated Heavy Trucks	No. of TAZs	Estimate of Truck Trips: Rate per Truck	Estimate of Truck Trips: Rate per Zone
County					
Anoka	70	31	69	137	136
Carver	36	16	25	71	48
Dakota	75	33	96	146	186
Scott	34	15	24	66	46
Washington	62	27	61	120	120
Total	277	122	275	540	536
City					
Anoka	39	17	9	49	32
Bloomington	83	37	27	107	104
Brooklyn Center	27	12	11	35	40
Brooklyn Park	21	9	10	26	36
Columbia Heights	52	23	7	66	24
Coon Rapids	25	11	8	32	28
Eden Prairie	27	12	10	35	36
Edina	29	13	20	38	76
Fridley	25	11	9	32	32
Golden Valley	27	12	10	35	36
Hopkins	15	7	6	20	20
Inver Grove Heights	19	8	8	23	28
Maplewood	58	26	18	75	68
Minnetonka	32	14	19	40	72
Rosemount	36	16	5	46	16
Roseville	35	15	20	43	76
St. Louis Park	29	13	15	38	56
South St. Paul	19	8	8	23	28
West St. Paul	20	9	8	26	28
White Bear Lake	50	22	11	64	40
Total	668	295	239	853	876

Table 5. Distribution of tax-exempt heavy trucks.

Agency	No. of Heavy Trucks	Analysis
Minneapolis	275[a]	Survey
St. Paul	62	Survey
Hennepin County	82	Survey
Ramsey County	18	Survey
MnDOT District 5	145	Survey
MnDOT District 9	87	Survey
Minneapolis post office	35	Survey
St. Paul post office	20	Survey
Five other metropolitan counties	122	Estimate
Twenty other metropolitan cities	295	Estimate
Total	1,141	

[a]Includes 39 fire trucks.

HEAVY GRAIN TRUCKS

Although there are few heavy grain trucks registered in the metropolitan area, they account for about 14 percent of the heavy trucks entering the metropolitan area between mid-March and mid-November because this is the season for shipping grain by barge. During the other four months they average less than half this amount. In anticipation of the Mississippi and Minnesota rivers opening to barge traffic, out-of-state grain elevators increase their grain truck shipments to the metropolitan area grain elevators starting in mid-March. Because grain shipping is not as seasonal as it was 10 years ago, grain is shipped to the metropolitan area in large volumes consistently throughout the barge season. During the other four months of the year, grain truck shipments to the metropolitan area are cut in half because barge traffic is closed and grain is either shipped out of the metropolitan area by train or is stored for shipment during the barge season.

In order to simulate a summer day of grain truck travel in the metropolitan area and create a trip table to represent this travel, several assumptions had to be made that pertain to metropolitan area grain elevators and grain trucks:

1. Only grain elevators that receive grain by truck were considered;
2. Because grain elevators would not release data on the amount of grain each one processed per year, elevator capacity was used for determining how to prorate the destinations of grain trucks entering the metropolitan area;
3. It was assumed that, regardless of where grain trucks entered the metropolitan area, their trips to grain elevators could be prorated based on the capacity of the elevators; and
4. It was assumed that each grain truck trip from the cordon station to a grain elevator had a return trip to the same cordon station.

The data obtained from the Minneapolis Grain Exchange are given in Table 6; the data reveal the monthly distribution of 278,000 grain trucks that entered the metropolitan area in 1978.

The heaviest trucking season for grain in 1978 was mid-May to mid-November, when approximately 190,000 truck loads (approximately 68 percent of the grain trucks) entered the metropolitan area. This means that from mid-May to mid-November there were 1.33 times as many grain trucks per day entering the metropolitan area as there would be if they were uniformly distributed throughout the year. Because there are 256 working days in a year, a uniform distribution would produce 1,086 grain trucks/day, but in 1978 it produced 1,450 grain trucks/day from mid-May to mid-November. Because of the emphasis on barge shipping of grain, it is expected that the trend will continue, where a summer work day will have 1.33 times as many grain trucks entering the metropolitan area as on an average work day.

Table 6. Monthly distribution of grain trucks entering the metropolitan area in 1978.

Month	No. of Grain Trucks	Month	No. of Grain Trucks
January	9,800	August	35,700
February	9,800	September	27,000
March	13,600	October	39,000
April	16,500	November	27,000
May	25,500	December	12,600
June	32,100	Total	278,000
July	29,400		

A 1979 grain movement study by the University of Minnesota revealed that in 1979 approximately 328,000 grain trucks entered the metropolitan area, where more than 1,700 grain trucks entered on an average summer day. This number is at least 250 higher than the 1978 estimate, but is a better estimate for current conditions, even though 1979 was a banner year for crop productions. (Note that all data for this study were collected at the elevators, and there was no longer the Russian grain embargo that had existed in 1978.)

In order to allocate the grain trucks to the proper routes at the cordon line, seasonally adjusted heavy truck counts from 1980 were used in conjunction with class counts to determine how many grain trucks were at each cordon station. The class counts were 16-hr counts taken in the summer and were not seasonlly adjusted. The class counts gave an estimate of grain trucks at each cordon station as a percentage of heavy trucks. The percentages were then multiplied by the heavy truck counts at each cordon station to produce an estimate of 1980 grain trucks at each cordon station.

EXTERNAL AND THROUGH TRIPS FOR HEAVY COMMERCIAL TRUCKS

Although the 1970 internal truck survey produced unfavorable results, the 1970 cordon-line survey of external and through trips by trucks produced excellent results. More than 50 percent of the heavy trucks were surveyed, and when the data were processed the results gave a valid distribution of heavy truck trips. Therefore, it was not crucial to have a 1981 survey to update the 1970 cordon-line survey. The areas that generated trips for heavy trucks changed little over a 10-year span, so the 1970 distribution pattern could be used with some confidence to distribute 1980 cordon-line heavy truck trips.

In order to expand the 1970 cordon-line survey data to 1980, growth factors were developed for each of the 31 external stations to represent the 10-year growth in heavy truck volume. Heavy truck counts at each station for a 30-year period (1948 to 1978) were used as input data to develop linear regression predicting equations. When each equation was solved for the 1980 prediction and the predicted number of heavy trucks was divided by the 1970 TBI heavy truck count at that station, the result was a 1970 to 1980 growth factor for heavy trucks at each external station. The correlation coefficient for the regression equations was improved by grouping the 31 external stations into 9 districts on the basis of traffic corridors. Regression equations were developed for each district, and the same growth factor was applied to all external stations included within a district.

To verify the accuracy of the growth factors, the factored 1970 counts at the external stations were compared with 1980 counts. Results revealed that the accuracy of the factored 1970 counts were within 6 percent of the 1980 counts for the total cordon line. The 1980 cordon line of all 31 external stations had a total of 24,434 heavy trucks whereas the factored 1970 counts had a total of 22,991 heavy trucks.

AGGREGATION OF TRIPS AND NETWORK ASSIGNMENT

The calculation of the distribution of all heavy truck trips at the cordon line resulted in the creation of a 1980 trip table of external and through trips for heavy trucks. This was the final trip table needed to complete the trip distribution. A 1980 heavy truck network (alternate 3TC) was created by deleting from the 1980 traffic network (alternate

3C) all links that represented routes on which heavy truck travel was barred. To make the heavy truck traffic assignment, the following trip tables were added together and assigned to alternate 3TC:

1. Heavy commercial truck, internal trips;
2. Heavy commercial trucks, external and through trips;
3. Heavy tax-exempt trucks, internal trips; and
4. Heavy grain trucks, external trips.

The 1980 assignment to the heavy truck network was compared with 1980 ground counts of heavy trucks to assess the probable validity of the assignment. When this was done, necessary corrections were made to validate the network. The major step left to complete the heavy truck study was to expand the trip tables to the year 2000 and assign them to a year-2000 network.

YEAR-2000 FORECAST: EXPANDING 1980 TRIP TABLES FOR HEAVY TRUCKS TO YEAR 2000

The 1980 heavy truck distribution was expanded to a year-2000 distribution by using growth factors for each of the 1,058 internal TAZs and 31 external TAZs. Previous analysis had shown that better future trip predictions through the use of regression models could be made if the internal TAZs were grouped into 108 districts, whose larger size reduced sampling errors. The external TAZs were similarly grouped into 9 districts based on traffic corridors. Thus the confidence level on predictions was much higher with regression analysis applied at the district level instead of the TAZ level.

A regression model was used to develop trip-predicting equations for internal trips by heavy commercial trucks at the district level:

$$\text{Productions} = 85.89938 + 0.22575(X) + 0.05168(Y) + 0.21246(Z) \quad (2)$$

$$\text{Attractions} = 78.75956 + 0.22618(X) + 0.05179(Y) + 0.21964(Z) \quad (3)$$

where

X = manufacturing and wholesale employment,
Y = total population, and
Z = transportation, communication, and utility employment.

When the trip-predicting equations were developed, the forecast year-2000 socioeconomic data were added into the equations. The result was year-2000 district forecasts of heavy commercial truck trips for the 108 internal districts. The predicted year-2000 trips for each district were used as control totals. The year-2000 forecast of trip generation for each district was prorated to the TAZs within the district according to the distribution of the 1980 internal trip table. Each TAZ now had a year-2000 forecast of trip generation. To get a year-2000 trip table of internal trips by heavy commercial trucks, the 1980 trip table matrix was multiplied by the growth factor at each end of every trip. It was then redistributed by means of a Fratar model. The resultant trip table had an estimated 260,000 internal trips for the year 2000.

Another regression model based on the predicted number of heavy trucks in the year 2000 and the trip rate per truck produced an independent estimate of 192,000 trips/day by heavy commercial trucks. This number would normally be used as a control total, but because it was extrapolated from a depressed 1981 economy, it was decided to use the midpoint of the two estimates as a control total. Therefore, the year-2000 trip table of internal trips by heavy commercial trucks was factored down from 260,000 trips to 226,000.

Obtaining a year-2000 trip table of internal trips by heavy tax-exempt trucks was simpler. The 1980 distribution of these trucks was the best estimate of how the trips would be distributed in the year 2000; therefore, the use of growth factors was not applicable. A regression model revealed that there would be 1.888 times as many heavy tax-exempt trucks registered in the metropolitan area in the year 2000 as in 1980. Therefore, the 1980 trip table of heavy tax-exempt truck trips was multiplied by 1.888 to produce the year-2000 trip table.

External and Through Heavy Truck Trips

The 31 external TAZs had been grouped into 9 districts on the basis of traffic corridors in order to develop growth factors. A regression model that used 30 years of heavy truck counts for the districts as independent variables was used to predict 1980 and year-2000 heavy truck counts for each district. The growth factors developed by this model were applied to the 9 districts and resulted in control totals at the 31 external stations for external and through trips by heavy commercial trucks.

The expansion of the 1980 trip table of heavy grain trucks to the year 2000 assumed there would be no growth in the number of grain trucks and only a slight redistribution due to the construction of a large new terminal grain elevator in Savage. Therefore, no external or internal growth factors were applied to the 1980 grain truck trip table. Any growth in grain truck movements would be dependent on unpredictable future variables such as weather conditions, changes in land use, future government farm policy, future foreign demand for grain, effect of new user fees on barge traffic, and the amount of rail abandonment.

The number of trips in each heavy truck trip table for years 1980 and 2000 is given in Table 7.

Assignment to Year-2000 Traffic Network

After all heavy truck trip tables for the year 2000 had been built and internal trips had been calibrated to the control totals, they were added together and assigned to a year-2000 heavy truck traffic network (alternate 3TE). This network was identical to the region's policy plan approved year-2000 network (alternate 3E), except that approximately 1,800 links, which represented routes where heavy trucks are banned, had been deleted. The traffic assignment was analyzed for logical routings and general validity. Because the minimum time paths for the trees

Table 7. Heavy truck trip table totals for years 1980 and 2000.

	Heavy Truck Trip Table Totals by Year	
Heavy Truck Trips	1980	2000
Internal		
Commercial	89,114	226,034
Tax exempt	4,632	8,801
Total	93,746	234,835
External		
Commercial	18,113	24,933
Grain	3,502	3,502
Tax exempt	28	57
Total	21,643	28,492
Through–commercial	1,402	1,954
Total	116,791	265,281

had been built on the heavy truck network, any errors in routing resulted in corrections to the network, not the assignment.

SUMMARY

With the development of new heavy truck trip tables for the year 2000, the old year-2000 forecast trip tables were discarded. The old forecasts had been developed from data from the 1970 TBI. Because of the small sample of heavy trucks in the 1970 internal trip survey, the old year-2000 forecast of distribution was considered unreliable. Furthermore, the old trip tables of heavy truck trips had been distributed by a gravity model, whereas the new trip tables were distributed by a Fratar model, which was more realistic because heavy truck trips are not a function of zonal accessibility.

For the total year-2000 assignment (with the discarding of the old heavy truck trip tables), the gravity model will have to be recalibrated to distribute the trips by automobiles and light trucks on the policy plan network. The next step is a combined total assignment of automobiles, light trucks, and heavy trucks on the network. This can be done even though minimum time paths for heavy trucks were built on the heavy truck network and time paths for automobiles and light trucks were built on the policy plan network. This is because both networks are similar in every detail except for the deleted links on the heavy truck network. For heavy trucks, the deleted links from the heavy truck network do not exist; therefore, heavy trucks do not use these links on the policy plan network after being assigned to it. Automobiles and light trucks, which have had minimum time paths built on the policy plan network, are free to use any link. To combine all of the trip tables for the total assignment, use is made of an FHWA PLANPAC computer battery program called WTLOAD.

An advantage of this type of assignment is that it reveals a more accurate picture of the total traffic, which is useful in analyses such as volume/capacity ratios. However, note that the assignment is built from two combined path building files. If a selected link is needed, it cannot be traced from this combined file. One of the original path building files would have to be used; either the one built for automobiles and light trucks or the one built for heavy trucks.

It is especially useful to use a combined automobile and heavy truck assignment, where heavy trucks use only allowable heavy truck routings, to analyze alternatives of the construction of I-35E through St. Paul. The Minnesota Legislature has mandated I-35E to be a parkway with no heavy trucks allowed. A bypass route of the central business district (CBD) for heavy trucks has been planned for construction in the future, but not until after 1990. This route will run from Warner Road, southeast of the CBD, to north of the CBD where it will join I-35E at the Pennsylvania Avenue intersection. This route is in the year-2000 network. Assignments of year-2000 traffic can be made to the year-2000 network with the CBD bypass in place or with it removed from the network. Analysis of these assignments will then show where the heavy truck travel will go until the bypass is built, and what capacity problems may be created for streets in and near the CBD. Also, a comparison of these assignments with the 1980 assignment would be useful in developing a trend to indicate how soon the CBD bypass would be a necessity.

REFERENCE

1. Design for a Freight Truck Study, Final Report. Roger Creighton Associates, Inc., New York, 1979.

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Abridgment

Strategic Motor Freight Planning for Chicago in the Year 2000

FRANK SOUTHWORTH, YONG JAE LEE, CYNTHIA S. GRIFFIN, AND DAVID ZAVATTERO

The major components of a motor freight planning model that was recently developed to help the Chicago Area Transportation Study evaluate alternative year-2000 physical planning policies are described. The current model allows the planner to evaluate alternative terminal clustering and primary truck route designation plans, both as they affect terminal accessibility to service demands, and as the greater separation of person and goods traffic movements affects highway volumes, speeds, fuel use, and emissions.

Although the daily operating characteristics of carriers are their own concern, serious consideration has to be given to the cumulative impacts of current daily urban goods movement (UGM) practices. Therefore, roadway maintenance costs (both financial and resource based), mixed person-goods traffic interaction, and appropriate land use mixes are the major policy issues discussed in the paper.

The only way to properly appreciate and measure such cumulative impacts is by means of a system's approach to UGM planning, i.e., start with a properly integrated strategic plan. Such an approach is being considered by the Chicago Area Transportation Study (1) based on a simulation model developed by Southworth and others (2). This model was built to allow the testing (through simulation) of a range of UGM systems based on the following three-component plan:

1. The clustering of for-hire freight terminals with zones of high accessibility to truck service demands;
2. The channelization of daily heavy freight vehicle flows along a designated truck route network; and

3. The expansion of the Chicago motor carrier commercial zone to define the most functionally advantageous and economically deregulated UGM region.

This type of plan offers the potential to reduce roadway infrastructure investment and resource costs by focusing urban freight activity on those highways

Figure 1. UGM process model.

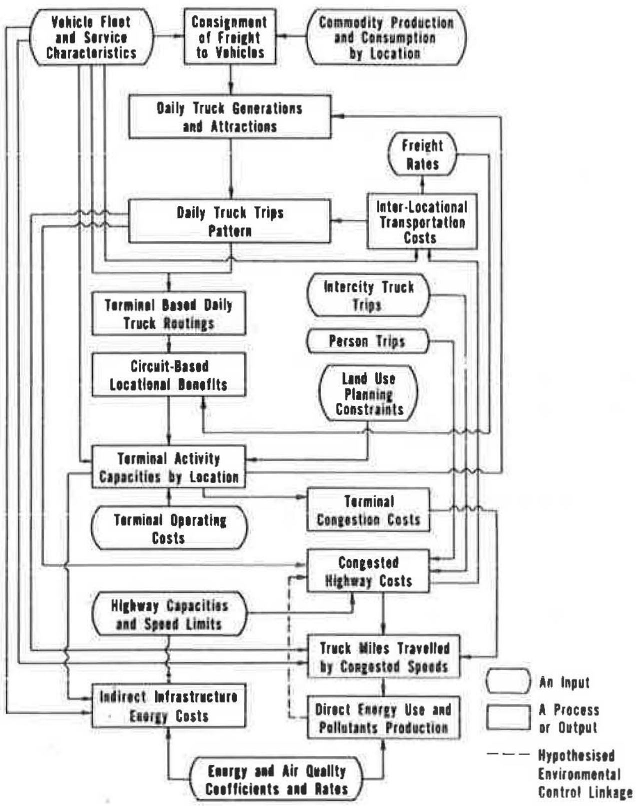
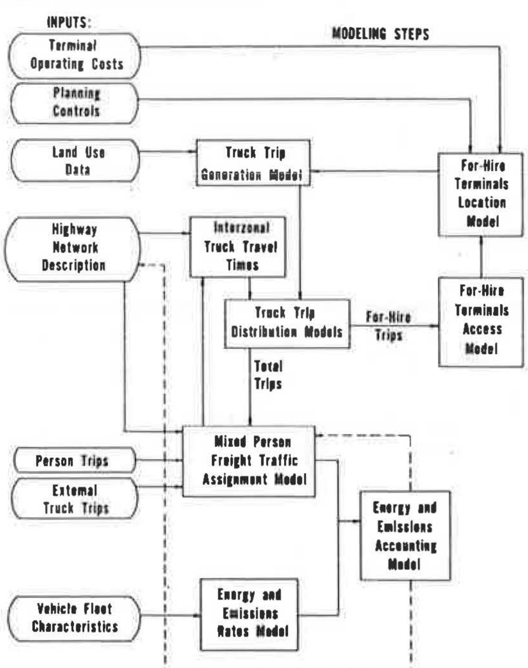


Figure 2. Mathematical model.



best suited to the wear and tear such use creates, while at the same time producing an environmental benefit through the greater separation of person and goods movements. The success of the plan relys on the selection of suitable locations for the terminal clusters. Such terminals act as the centers for nearly all daily, urban for-hire carrier activity; as the hubs of such circuit-based activity, they must serve as the major nodes in the designated truck route system (because nondesignation means truck exclusion).

Because for-hire carriers must locate their terminals within the economically deregulated Chicago commercial zone (CCZ), unless they hold a special intrastate or interstate license, the outer boundary of such a zone must not be allowed to restrict the efficient liaison between terminal-based carriers and potential (and service-needy) shippers. But a CCZ that is too extensive may serve to encourage less-efficient forms of competition between carriers seeking new customers anywhere within the CCZ's area. (This latter possibility is made more likely given the highly circuitous, multidestination daily truck routing options available within large cities.) The Chicago region's current terminals location pattern,due in part to an overly restrictive CCZ, exhibits two important features:

1. The overwhelming dominance of the central area (Cook County) as the site for most of the region's for-hire terminals, and
2. The considerable dispersion of such terminal sites within this central area.

Together, these features create a major source of traffic congestion and an inefficient use of road space. To gauge the extent of these current inefficiencies and to suggest the best directions to follow over the longer term, particularly with respect to infrastructure use, the Chicago motor freight planning model was built. A brief description of this terminal zone location and truck route assignment model is given in the next section. Technical details of the mathematical model and its computer program are given in detail elsewhere (2).

OVERVIEW OF MOTOR FREIGHT PLANNING MODEL

A schematic of the urban motor freight process is shown in Figure 1. The schematic shows a number of inputs, which are identified by the rounded boxes. Such components refer to factors that are susceptible in either the short or long term to clearly exogenous impacts. Also shown as an input in Figure 1 are intercity truck trip volumes. In this instance such flows constitute a spatially semi-exogenous component of the system.

The major purpose behind this process model is structural, i.e., the need to identify the major functional linkages between system components. For example, freight consignment to vehicles (top of Figure 1) produces a set of daily truck trip generations that in turn leads to a spatial truck trip pattern. This pattern will make use of terminal-based multitrip routings, the relative benefits from which will determine the level of terminal-based routing activity at any given urban location. This activity level is subjected to any prevailing land use laws, and may also be a function of nonlinearities in terminal operating costs, which are caused by many trucks wanting to use the same road or loading spaces. Such costs are added to the mixed person-freight highway costs to determine truck miles by speeds and their associated fuel use and emission impacts.

The daily truck trips pattern so produced will itself be a function (in terms of highway routings and distances hauled) of suitable operating costs (notably driver time). Such costs will do much to determine carrier freight rates where for-hire operation is being studied. The interaction of this intraurban trip pattern with external truck and all-person travel often produces serious highway congestion, notably during the peak work trip periods. This in turn causes a rise in vehicle movement costs, which cycle through the system and subsequently affect the daily consumption of direct energy and the production of vehicle emissions.

Over a suitable period of time some trucks may have their terminal base of operations relocated to take better advantage of existing or expected goods production and consumption patterns. Subsequent adjustments in daily routings and trip patterns may also induce a change in vehicle fleet makeup and hence in load-to-vehicle consignments. Then a new set of cycles begins.

By starting with other boxes in Figure 1, this set of relations can be traced from a different initial perspective. For example, by starting with the existing or projected vehicle energy and emissions technology, the impacts from this perspective can be traced through the system.

The mathematical model developed to allow quantitative expression of the process model is shown in flowchart form in Figure 2. The current mathematical model represents only a partial realization of the process model due to the current data and time resources allowed. For example, no reliable and sufficiently comprehensive carrier freight rate data were available. Also, the current model does not deal with the assignment of freight to the vehicle component discussed above because this component is viewed as one entirely within the purview of individual carriers, shippers, and freight forwarders and is of no immediate concern to a tactical or strategic planning study.

The generation, distribution, assignment, location, and evaluation procedure is cyclic in nature and has the following two major feedback loops (or multistep iterations):

1. A for-hire carrier trip generation, distribution, and terminal circuit-based access and location cycle; and
2. A total trip generation, distribution, congested traffic assignment, and highway environmental costs and energy use cycle.

These two cycles are linked through the truck distribution model that uses average, mixed-traffic, congested interzonal travel times to allocate trucks to their next destination. It is possible within the process to calibrate a number of commodity type or industrial sector specific trip distribution models that may be suitably reaggregated to give total truck trip volumes for use in the traffic route congestion (assignment) cycle or to give for-hire multicommodity trip flows. The model is built to handle either daily or peak-period vehicular flows and concentrates on the region's intraurban truck trips. That is, external truck trip volumes require a separate intercity freight modeling step; they are therefore shown as an input in Figure 2. This is one of sevenexogenous inputs to the model shown. By systematically changing one or more of these model inputs to represent a different future scenario, it is currently possible to simulate the resulting circuit-based terminal zone accessibility pattern, plus all primary highway mixed-traffic volumes and speeds and associated traffic energy use and emissions productions.

NOTE ON NEW COMPONENTS OF THE MODEL

The mathematical model has two new components not found in current passenger transportation models or in any past UGM system planning models. The first component is an iterative use of the urban transportation planning program's equilibrium traffic assignment model UROAD to balance nontruck traffic on the region's primary highway system in response to alternative intraregional and interregional truck route designations. Such designations serve to limit all trucks (of a chosen size) to selected portions of the region's Interstate and primary arterials highway network. Local roadway restrictions are assumed left to local jurisdictions and are assumed to support the purpose of the primary route designations.

The second new component of the planning model is an original approach to measuring the locational accessibility of urban truck terminals. By using a synthesis of the graph theoretic and spatial interaction modeling approaches to accessibility measurement, the terminal accessibility module shown in Figure 2 offers a multidestination, multicircuit-based approach to terminal activity locations. [Technical details of these two components are given by Southworth and others (2, Chapter 2).]

EXAMPLE PLAN

An empirical analysis of the system's 1970 daily UGM pattern revealed that once the many highly localized truck trips had been removed from the system, a clear spatial pattern emerges for the remaining nonlocal trips. An idealization of this pattern is shown in Figure 3. The shaded areas refer here to all daily goods vehicle circuit starts, whether by private or for-hire carriers. The connections show the major nonlocal (i.e., short-distance) pickup and delivery place linkages covered by the daily travel circuits of the region. The vast majority of for-hire carriers locate their terminal(s) in the single shaded central area labeled Cook (County).

To encourage both a wider regionwide distribution of such terminals, and at the same time consolidate

Figure 3. High-volume, nonlocal circuit connectivity pattern.

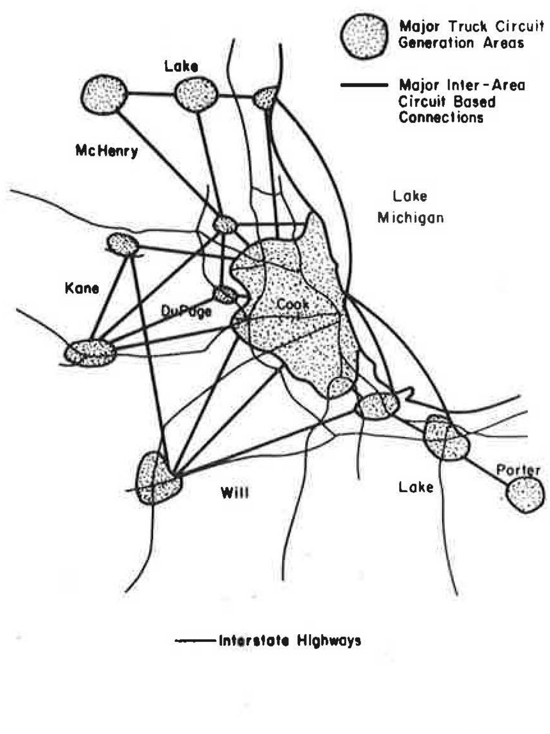
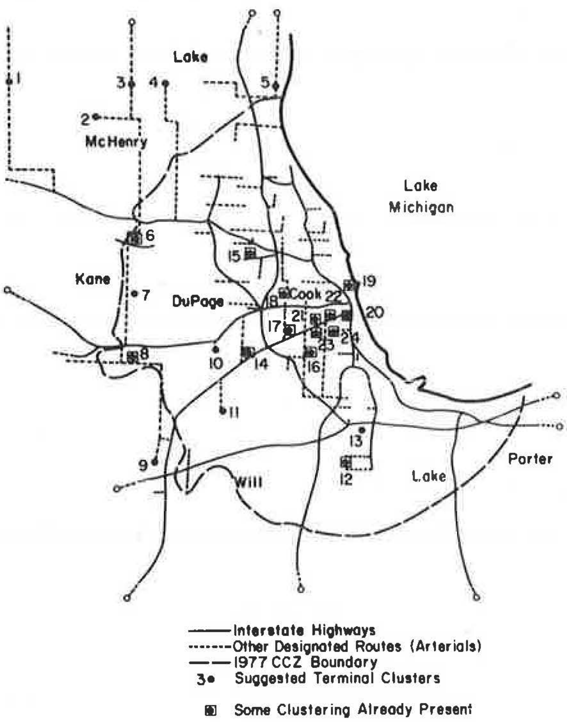


Figure 4. UGM system plan.



those centrally located terminals within fewer clusters, one possible year-2000 terminal clustering and route designation plan is shown in Figure 4. This (tentative) plan, for example, suggests that, if current conditions hold, congestion might be reduced and carrier access to shippers maintained if 24 such clusters are developed that are linked by a primary designated route system of some 1,550 miles of in- traurban highways.

Alternate plans need be generated, however, to account for changes in person traffic volumes, industrial relocations, and any new primary highway building by the turn of the century. Emphasis needs to be placed in all such plans on generating highway infrastructure and terminal zoning plans that will avoid the disruption of current carrier and shipper interactions, while at the same time encouraging the person-freight system separation being sought.

It is hoped that the current modeling effort will help the planner to manage this by paying more attention to the urban freight component of the regional plan than has been done previously. Urban trucking activity should no longer be treated as simply a negative environmental component in traffic congestion studies. The dependence of all large urban systems on daily UGM patterns requires that the potential impacts of any public planning schemes be considered, even longer-term ones, as to their effects on the continued well-being of the carrier industry.

It must also be emphasized that, although this analysis does support the encouragement of terminal clustering in particular, the selection of appropriate sites for such clusters is also a case for local planning of correct land use mixes. Therefore, final site selections must treat this strategic approach as only the first stage in a systematic analysis of UGM operations from the public perspective. Finally, emphasis should be given to different strategic plans that need to be generated in order to cover a range of possible future scenarios (3). The above plan is only a demonstration of the scope and applicability of the model.

ACKNOWLEDGMENT

This research was funded by the Illinois Department of Energy and Natural Resources, Springfield and Chicago. The cooperation of the staff of the Chicago Area Transportation Study is also gratefully acknowledged.

REFERENCES

1. Year 2000 Transportation System Development Plan. Chicago Area Transportation Study, Chicago, 1980.
2. F. Southworth, Y.J. Lee, C.S. Griffin, and D. Zavattero. A Motor Freight Planning Model for Chicago. Illinois Department of Energy and Natural Resources, Springfield, IL, 1983.
3. F. Southworth. A Scenario-Based Approach to Assessment of Requirements for Freight Transportation; Map 2000 Project. Metropolitan Housing and Planning Council, Chicago, Rept. 16, 1982.

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Urban Goods Movement in the 1980s

GORDON P. FISHER AND ARNIM H. MEYBURG

Urban goods movement (UGM), an activity of considerable size and complexity that accounts for perhaps a quarter of national transportation expenditures, has received increased awareness and study over the past 10 years. A significant portion of this increased attention is due to a series of Engineering Foundation conferences on Goods Transportation in Urban Areas; the fourth and most recent one was held in 1981. The background that led to this last conference is described. The major findings and recommendations from the conference focused on (a) planning guideline development and dissemination, (b) dissemination of case histories of UGM activities, (c) development of a measure of UGM activity, (d) evaluation of data requirements and availability, and (e) dialogue between the public and private sectors. On the basis of conference discussions and workshop reports, the outlook for UGM activities for the 1980s is projected, with emphasis on the effects of deregulation, the economic environment, and the role of metropolitan planning organizations.

Urban goods movement (UGM) has not received much attention in urban passenger transportation planning. This lack of attention is because urban freight collection and distribution systems already function efficiently and hence do not generate the interest and special attention of transportation planners. It is suggested also that freight movement is so deeply embedded in the private sector of the economy that government planners and policymakers ought not to intrude, and that the public concern is best met by free market operation. Of course, it has been suggested that the lack of control, understanding, and information for this sector makes it an unlikely candidate for systematic analysis.

The truth probably lies somewhere in between these views. It is true that data about UGM are hard to find because the privately operated UGM industry is highly diverse, fragmented, and proprietary. It is equally true that the system appears to accomplish its goal of commodity collection and distribution within urban areas. Yet a more careful view discloses that the UGM system is not performing satisfactorily.

UGM contributes a disproportionate amount to urban congestion; air, noise, and visual pollution; road surface deterioration; and fuel consumption, which are issues of public concern. It is clear that, although the UGM system functions, it probably does not operate in the most efficient manner, particularly in regard to public concerns. The fragmented and competitive nature of this private industry leads to corporate rather than industrywide (and thus suboptimal) solutions, whereby system capacity, fuel, and manpower are used inefficiently. These deficiencies are detrimental to the public sector in terms of (a) higher transportation costs imposed on consumer products and (b) the externalities generated by the UGM system.

The recent changes in the economic and regulatory environment in which the transportation industry operates provide reasons for a new look at the UGM sector. Although the changed economic climate produces significant consequences for the UGM community (e.g., increased fuel, labor, equipment, capital, and maintenance costs; and decreased economic activity, which results in reduced volumes for commodity collection and distribution within urban areas), deregulation of the interstate trucking industry does not appear to have a detectable impact on the already unregulated UGM industry. Nevertheless, a closer look reveals that many interstate and intercity carriers also perform extensive pickup and delivery functions in urban areas. Hence the tremendous change in the size, composition, and routing structure for the interstate trucking industry (1) that has taken place since deregulation also affects the collection and distribution operations in urban areas. Ease of entry into the trucking business undoubtedly will continue to change the picture of urban goods movement and hence its impacts.

A perspective of the historical evolution of UGM concerns is reviewed as they are reflected in the subject matter of a series of conferences entitled Goods Transportation in Urban Areas (GTUA), which have been held since the early 1970s when the operations of urban freight pickup and delivery began to attract the attention of transportation planners, economists, and public policy analysts. In particular, the fourth and most recent conference held in 1981 (GTUA IV) is discussed. These conferences and their published proceedings (2-5) have increased the knowledge about UGM and generated support from federal, state, and local agencies in order that intelligent solutions to specific and general goods movement problems can be pursued. The development of a reference guide for UGM (6) is only one example of the beneficial impact that these conferences have had in paving the way for increased understanding and concrete actions. Also, several studies have been funded concerning various aspects of UGM (7-10), and many study recommendations have been implemented.

These conferences have increased the awareness of and the appreciation for UGM issues both by the general public and politicians. Moreover, cooperation between the private and the public sectors has evolved where little existed before, with clear advantages to the industry and public alike.

Finally, a valuable by-product of the conferences has been the establishment of nationwide interest among professionals who have responsibilities for UGM.

PURPOSES AND AIMS OF CONFERENCES

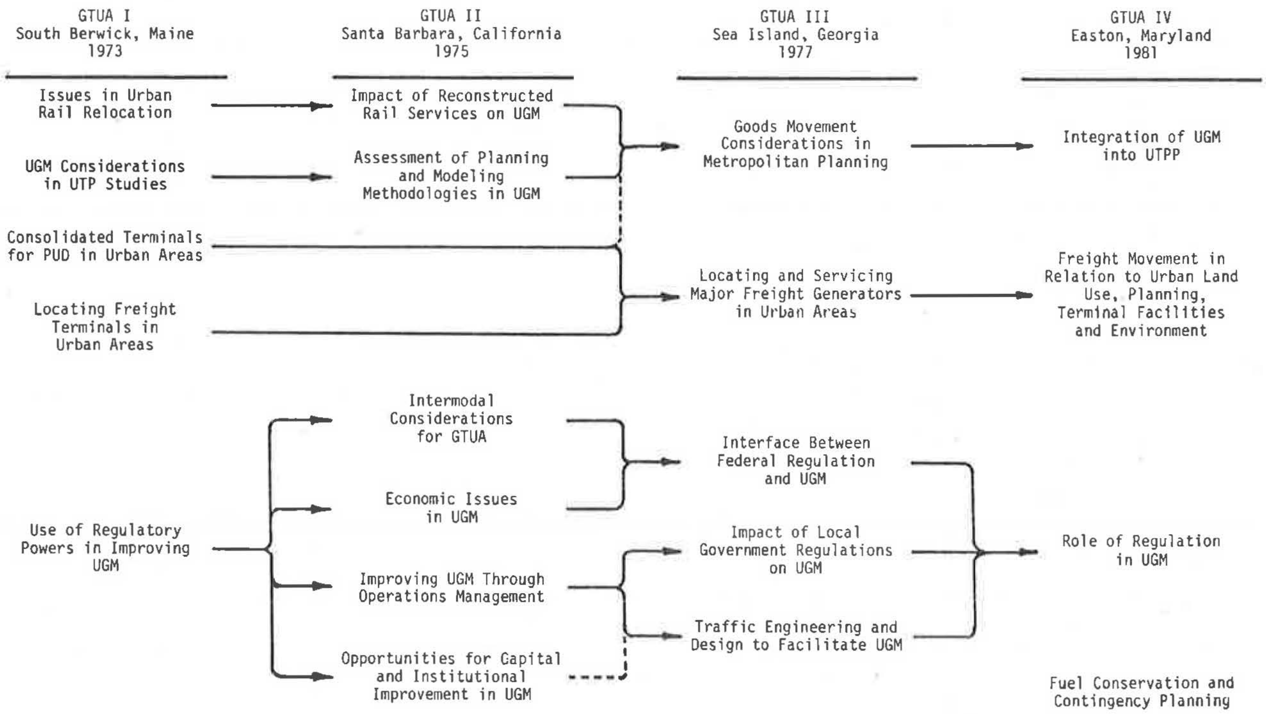
Against the backdrop of the political and technological developments described above, the fourth conference (GTUA IV) was planned with the principal purpose of assessing what effects certain shifts of emphasis might have on urban goods transportation activities. Particular stress was to be given to detailed problem definition, implementation strategies, policy and planning priorities, and research directions.

The conference was constructed around several workshop teams called probe groups, each of which was to develop and report on a particular subject area; i.e.,

1. Integration of UGM into the transportation planning process;
2. Freight movement in relation to land use, planning, terminal facilities, and environment;
3. Role of regulation in UGM; and
4. Fuel conservation and contingency planning.

A fifth group, composed of representatives from each of these four groups, was asked to produce a coherent set of research issues concerning UGM in ex-

Figure 1. Interrelations among probe group subject areas at the four GTUA conferences.



pectation that many of these issues were concerns common to all or most of the other groups.

From a historical perspective (see Figure 1), these themes were not too different from the themes of the previous three conferences. However, the thrust and content of the discussions differed substantially from the earlier ones because of the significant shifts of emphasis that were and are occurring in the political and technological milieu. Moreover, the conclusions have become more explicit and have focused more on practical implementation.

The first theme, for example, is found in all four conferences, but has progressed from the initial focus on long-range planning as embodied in the large metropolitan transportation studies of the 1960s, then to short-range planning typified by transportation system management (TSM), and now on the functions of the metropolitan planning organization (MPO).

Similarly, the second theme grew out of earlier concerns about locating freight terminals in urban areas, locating and servicing of major freight generators, and consolidated terminals for local pickup and delivery. The insights developed over the years allowed the GTUA IV conference to take a more comprehensive approach to this general subject.

Regulation, of course, has been a perennial topic, but this too has shifted dramatically. Whereas the earlier concern was the effects of regulatory constraints on the free operation of market forces and their influence on private and public decision making in goods movement, the dynamic changes stemming from unexpectedly massive deregulation has presented a whole new set of issues.

Many of the old problems, in spite of their changed context, do not go away and must be continually refreshed. It is also not surprising that new problems appear. Thus the topic of fuel conservation, out of fresh memories of the 1979 fuel crisis and vastly inflated fuel prices, warranted special attention.

The spectrum of talents and professional backgrounds among the conference participants may be of interest. Of the more than 50 conferees, 42 percent represented government organizations--almost precisely the same proportion as for the GTUA III conference--but now more heavily weighted toward state, regional, and local government and less federal. About 13 percent were private consultants, which was much lower than usual. The number of academic people was virtually unchanged at about 29 percent. As expected, representation from the industry (four carriers and four shippers) was lower than desirable.

FINDINGS AND RECOMMENDATIONS

The details of the findings and recommendations of the GTUA IV probe groups can be found in the published proceedings (5). Although each group looked at UGM from a different perspective, several areas of concern are similar across the spectrum of group themes:

1. Development and dissemination of planning guidelines,
2. Dissemination of case histories of successful UGM activities,
3. Development of a measure of UGM activity,
4. Evaluation of data requirements and availability, and
5. Initiation or continuation of dialogue between the public and private sectors.

Each of these areas of concern has a different emphasis, depending on which of the probe group themes is considered. For example, the issue of guideline development is an immediately obvious prerequisite for energy contingency planning to ensure adequate distribution of essential consumer products in urban areas during times of fuel shortage. The benefits of efficient logistical operating strategies during emergency situations are apparent to both the public and private sectors.

With a smaller degree of urgency, yet with no less importance, the need for guideline development and dissemination was also among the conclusions of the other probe groups. For example, probe group V concluded that (5)

> A "how to" planning guide would be an important and invaluable addition to the transportation planner's tools. The major problems involving urban goods movement that might confront the public sector would be identified, would be broad in range, and would include diverse topics, such as curb loading space needs, hazardous commodity routing, environmental concerns, redevelopment of land as intermodal facilities, impacts of fuel shortage on trucking, and numerous other planning concerns.

These two examples, which illustrate a common thread running through a range of separate themes, could be expanded to cover all of the groups and to include other equally related examples. It is obvious that UGM problems and research needs, in what appear to be separable problem areas, emerge as being closely related.

The recurrent themes of the need for better understanding, better measurement, and better documentation and dissemination became evident during the conference. It was also concluded that information gathering and measurement of UGM activities are going on all the time. A principal problem, however, is that personnel in the UGM community, who represent independent groups in the public and private sectors, seldom talk to each other. During the conference deliberations it was made clear that it is in the best interest of both sides to coordinate their activities and to cooperate in a constructive framework of information and data exchange.

From a societal point of view, the broader planning and policy approach of planners, regulators, and policymakers, which does not take into account the specific concerns of the private sector, can be as equally shortsighted and inefficient as a narrow, suboptimizing approach of individual goods movement firms that ignore the broader social and economic environment in which they operate. Only in a few urban areas has a constructive dialogue been established, and it clearly has benefited both sides. In such instances private-sector data become available for public-sector planning for UGM within the broader range of the metropolitan transportation system. At the same time private-sector problems and private perceptions about public-sector actions find their way to policymakers and planners. These persons are then in a better position to design their policies, plans, and actions on the basis of improved information about activity types and levels and about problem identification among those people who are affected by their actions. The creation of a proper and effective interface between the two sides clearly is the secret to productive UGM activities that are in harmony with the rest of the urban infrastructure and operations.

It is appropriate to sound a cautionary note concerning the repeated plea for more information and data gathering in the UGM area. There appears to be a tendency among the advocates of more data collection to be vague in the specification of the specific problems that are supposed to be analyzed by means of such information. The question arises whether the demand for data is an excuse for not knowing how to specify and solve the problems, with the hope that the answers will be revealed in the data. Fortunately, the probe groups avoided this particular pitfall.

Related to the issue of data needs is the recurrent question as to whether there really is a UGM problem. The answer is that there is not one overriding problem, but rather a wide range of problems that need solutions.

A further issue is related to the local character of UGM activities and problems. Although there is some merit to the argument that local street networks, land use patterns, and regulations define the major parameters for goods movement in any specific area, the lessons learned in one locale might be useful for consideration in another area. The recommendation by the conference was to assemble a case study report on successful solutions to local goods movement problems with the aim of making these experiences available to the public and private sectors for possible application in other areas. On the other hand, it should not be overlooked that urban goods problems, beyond their generalities, and particularly the solutions to those problems, may be site specific and not easily transferable among communities. Needs and options may be markedly different. Such a caveat, however, does not diminish the value of understanding how others have tried to solve their problems.

The following resolution reached at the end of GTUA IV conference provides a summary about some practical and productive steps to be taken as a consequence of this conference. It was resolved that one or more master guides be prepared and published to cover the following UGM subjects:

1. Zoning and terminal location;
2. Planning guidelines, especially for problem identification, appropriate data, and analytical techniques;
3. Cooperation between the public and private sectors, including guidelines for public relations and mechanisms for citizen participation; and
4. Listing of private and public agencies where data, advice, and guidance may be sought.

It was not indicated how or by which agencies this recommendation might be implemented, although there were suggestions that the U.S. Department of Transportation (DOT) might assume the leadership role.

PUBLIC- AND PRIVATE-SECTOR VIEWPOINTS

A troublesome question that always crops up after such a conference as this is: Who, other than the conferees, is listening? The private side of the goods movement business--the carriers, shippers, receivers, and terminal operators (i.e., those who make the day-to-day economic decisions)--characteristically is not interested or attentive. Optimizing its operations firm by firm, and seldom extending its interest to broad segments of the industry, this private side of goods movement is a formidable force over which little control can be exerted. No one denies that the role of the private sector is to ensure financial viability and to support an environment to facilitate it, but there must be something profitable to be gained from objective studies of goods movement and from sustained dialogue between the private and public sectors. At this point, however, it must be admitted that the series of GTUA conferences has not been useful to the private sector.

On the other hand, the public sector--planners, policymakers, and private consultants--has a more natural affinity with the broad approach followed by the conference. Conference determinations are increasingly useful to successively lower levels of government; i.e., helpful to state, regional, and local officials who ultimately have to face freight transportation problems. However, with limited opportunities for implementing plans and mainly restricted to traffic engineering and regulatory ordinances, government officials have to rely on persuasion and cooperation in dealing with the private sector, a process that is inhibited by the lack of dialogue among affected parties. Such dialogue does not occur naturally, and specific procedures to facilitate and foster it on a sustained basis ought to be established. It is suggested that the MPO may be a proper and primary instrument for assuring that an organized dialogue occurs.

In view of the current federal reluctance to intrude on the private sector or into the business of state, regional, and local governments, it is not to be expected that much, if any, activity in urban goods transportation will come from that quarter. Urban freight simply is not a pressing congressional issue. It is frequently heard from representatives of DOT and Congress that what is done for the improvement of passenger traffic or traffic flow in general (e.g., the Interstate highway system) benefits goods movement as well. This attitude not only ignores the special problems of urban freight, but it requires a good deal of stretching to make current programs fit goods movement without any direct commitment to it. Even if the proposition were true, such an approach is entirely serendipitous, undeliberate, and out of focus.

THE VIEW AHEAD

A conference such as GTUA IV begs the question of where UGM is likely to move in the future. Three issues, among others, merit further comment because of their special importance and breadth: deregulation, the economic environment, and the role of the transportation planner with respect to UGM.

Deregulation

Deregulation will continue to pose problems and new opportunities for UGM during the 1980s. After the massive deregulatory moves of the Motor Carrier Act of 1980, further extensive changes are not expected, although there may be corrective legislation aimed at restricting ease of entry and at predatory pricing in trucking. These matters are under consideration by the Interstate Commerce Commission (ICC), but no policy changes appear imminent.

In general, the impacts of deregulation are not entirely clear, especially in urban area trucking, which has never been subject to much regulation. Interstate truckers have already been affected by competition and overcapacity from newly certificated carriers, although unrestricted routing and other freedoms have given firms more control over management of their business. On the one hand, the pressures of competition have led to shrewder marketing practices by truckers, but on the other hand it has also led to price-pinching by shippers. No one yet knows how the situation will settle. It may be safe to predict, however, that no responsible shipper, out of self-interest, will engage in or encourage predatory practices that may destroy the viability of his carrier sources. A more likely outcome is close shipper-carrier cooperation for mutual benefit.

Since 1980, when the Motor Carrier Act was implemented, approximately 5,000 new carrier entry applications have been granted by the ICC (11), and more than 19,000 carriers have filed new route applications (1). Over the same period, approximately 150 carriers have gone out of business and perhaps 50 more are facing financial difficulties (12). The disturbingly high number of recent trucking business failures is commonly attributed to deregulation, but the inflation and economic recession of the early 1980s are the more likely culprits. There is no reason why a well-managed carrier should not survive and prosper in the new deregulation environment.

The main impact of deregulation appears to fall on interstate rather than urban carriers. However, interstate shipments have their ends in urban areas and are likely to affect local haul and pickup and delivery operations. What the effects will be is difficult to perceive at this stage. The ability of interstate carriers to deliver to a final destination allows the bypassing of local haulers and, if shipments continue to be interlined with local carriers, should cause some modification of pricing strategies toward overall lower rates. Local carriage is not likely to diminish, although some marginal carriers may disappear, with the result being more efficient UGM. Some interstate carriers will continue to interline with local carriers rather than deliver directly because their long-haul equipment is not efficient on city streets. Note, however, that the 27-ft trailer commonly used in tandem in long-distance twin-trailer rigs is, as a single unit, maneuverable on city streets and may be used more frequently in direct deliveries.

Economic Environment

In spite of the human tendency to be optimistic about future economic conditions, truckers have substantial cause for pessimism. Faced with a weak economy and unprecedented competition, operating at about 70 percent of capacity, and forced into severe rate cutting, truckers view the near term as dismal (11). The following remarks are not an economic forecast, but merely some observations or perceptions that transportation engineers, planners, and policymakers ought to be concerned about. Again, a distinction must be kept between the long-haul interstate side of the industry and the urban side.

Most of the current economic ills are manifested on the long-haul side of the industry, which includes price cutting, overgenerous discounts and incentives, falling revenues, and inflation-fueled costs, as well as the pursuit by shippers of rock-bottom rates. On the bright side, the Teamsters union, in the knowledge that as many as 25 percent of its members have been laid off, appears to be more modest in its wage demands, which should help the costs of the long-haul, mostly unionized, carriers. Also, shippers are beginning to cooperate with carriers for their mutual advantage; e.g., putting together packages of inbound and outbound business, making multiyear commitments, balancing distribution patterns against carrier tonnage needs, and helping carriers to develop backhaul traffic. Such moves will benefit both the industry and the public.

On the urban side of the industry, which is more properly the concern of this paper, the picture is a bit healthier, and freight activity, although less abundant than before, does not appear to have diminished radically. This stability occurs because a large portion of the traffic is in service functions and in the carriage of consumable supplies necessary to the life and functioning of the urban area. Moreover, the urban freight sector has been characteristically beset by the overcapacity problem for a long time and yet has managed to survive.

A more critical economic problem that affects both long-haul and urban carriers lies in a 1980 amendment to the Employee Retirement and Income Security Act, which requires that a firm withdrawing from business deposit a sum of money with a central pension fund to protect employee benefits. The size of the required liability is so prohibitively large that it practically prevents a carrier from going out of business or merging with another company. The liability is often more than the firm's net worth. The net result has been that marginal, money-losing carriers choose to continue in business and chase freight at barely compensatory rates. Thus the carrier consolidation that would occur normally under the principles of economics has made little progress.

Role of the Transportation Planner

Planners understand readily enough that planning for urban freight movement theoretically should be part of overall urban transportation planning, but for several reasons integrated planning does not often occur.

1. UGM-related problems may not be perceived or anticipated. They may not appear significant enough to expend effort on them or they may appear to be temporary. In smaller urban areas they may not be evident or may not exist throughout the urban area and thus do not demand attention.
2. There is a lack of systemwide indicators of the existence and magnitude of UGM-related problems and a lack of understanding of the associated costs and benefits.
3. If a problem is perceived, lack of experience and uncertainty about the planner's role often causes the problem to be deferred.
4. There is not any agreed on methodology for freight planning and there is not any agreement on whether data ought to address vehicle flow or commodity flow.
5. UGM problems, even when attacked, are usually treated separately as isolated freight-only situations and not as part of the overall transportation system.
6. The planner usually does not know where to seek information in order to take advantage of the experiences of other planners.

If these reasons for lack of effective UGM planning are to be overturned, high priority must be placed on the development and dissemination of guideline documents in three general areas:

1. Data requirements, collection procedures, and costs of collection, as well as appropriate types and quantities of data;
2. Basic freight planning methodology and step-by-step procedures, ranging from problem identification and categorization to options for alleviating UGM problems, including implementation; and
3. Case studies of UGM projects already undertaken that describe analytical procedures, institutional aspects, time and cost, and effectiveness of improvements.

It is also vital that practice-oriented research be fostered in order to clarify data requirements and methodologies.

Finally, the function and role of the MPO ought to be strengthened. Operating at the local level, where UGM problems usually manifest themselves first, the MPO is perhaps the most sensible planning institution that has been developed to date. Because of its central role, it is a clear link in the chain of responsibility for transportation planning and funding. It can serve as a regional clearinghouse for transportation and urban development problems and as a coordinator between the public and private sectors.

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REFERENCES

1. T.L. Friedman. The Rocky Road for Truckers. The New York Times, Jan. 24, 1982, Section 3.
2. G.P. Fisher, ed. Goods Transportation in Urban Areas I: Proceedings of the Engineering Foundation Conference, South Berwick, ME, August 5-10, 1973. FHWA, Rept. FHWA-32-01-23 (RFP 397), Feb. 1974.
3. G.P. Fisher, ed. Goods Transportation in Urban Areas II: Proceedings of the Engineering Foundation Conference, Santa Barbara, CA, September 7-12, 1975. Office of the Secretary, U.S. Department of Transportation, Rept. DOT-OS-60009, May 1976.
4. G.P. Fisher, ed. Goods Transportation in Urban Areas III: Proceedings of the Engineering Foundation Conference, Sea Island, GA, December 4-9, 1977. FHWA and UMTA, Rept. FHWA PL-78-012, June 1978.
5. G.P. Fisher and A.H. Meyburg, eds. Goods Transportation in Urban Areas IV: Proceedings of the Engineering Foundation Conference, Easton, MD, June 14-19, 1981. UMTA, Rept. UMTA-NY-06-0087-82-2, Jan. 1982.
6. D.L. Christiansen. Urban Transportation Planning for Goods and Services--A Reference Guide. Texas Transportation Institute, Texas A&M Univ., College Station, June 1979.
7. K.W. Crowley, P.A. Habib, S.A. Loebl, and L.J. Pignataro. Mobility of People and Goods in the Urban Environment: Facilitation of Urban Goods Movement. Office of University Research, U.S. Department of Transportation, Rept. DOT-TST-75-102, Oct. 1974.
8. Organization for Environmental Growth, Inc. Requirements and Specifications for Off-Hours Delivery. Traffic Systems Division, U.S. Department of Transportation, Rept. FHWA-RD-79-60, April 1979.
9. P.A. Habib. Curbside Pickup and Delivery Operations and Arterial Traffic Impacts. FHWA, Rept. FHWA/RD-80/020, Feb. 1981.
10. K.W. Crowley, D.G. Sweeney, R. Ricondo, I.P. Brugnoli, and M.C. Helmsworth. Urban Goods Movement: An Overview and Bibliography. University Research and Training Program, Office of Policy Research, UMTA, Rept. UMTA-PA-11-0020, Dec. 1980.
11. Stuck with Overcapacity, Truckers Await the Recovery. Handling and Shipping Management, Jan. 1982.
12. Trucking: Decontrol to Blame. Handling and Shipping Management, July 1982.

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Concept Design and Analysis of a Linear Intermodal Freight System

PETER J. WONG, ANDREW R. GRANT, AND MASAMI SAKASITA

A conceptual linear corridor intermodal freight system was analyzed by using the computer model LINET. The train operating strategy used—freightliner—is an idealized form of a typical railroad strategy for a corridor. The problem formulation for this generic linear corridor freight system is described, and the LINET computer simulation model and the cost equations used to quantify the various trade-offs and relations between fundamental system design parameters as they affect costs and performance are presented. The results of these analyses include trade-offs associated with the most cost-effective system design, feasible system designs with sufficient capacity, minimum-cost system designs, and design for a specified level of service.

The three major components of a truck and rail intermodal freight system are (a) the local service trucks, which pick up and deliver containerized commodities within a local terminal area by using the highway and street network; (b) the line-haul rail component, whereby trains transport the containers between terminals over a rail network; and (c) the terminal component, which aggregates and transfers containers between the truck and rail components.

Little fundamental research has been done to further the understanding of the interrelations and trade-offs between intermodal freight system engineering design and operating parameters. Thus planners have difficulty making the correct decisions at both a national policy level and a detailed engineering design level to ensure the future economical and effective transport of goods that sustain the nation's economy. This is especially important due to current energy and environmental concerns. An attempt to partly fill the knowledge gap in this area is presented in this paper.

An intermodal freight system is complex; therefore, to simplify this analysis the focus of this paper is on a linear corridor system in which the terminals are in series and concentrated on the line-haul and terminal components. (Because the local service component uses trucks on the highway and road system, its performance was treated as given.) So as not to restrict unduly the range of what is feasible and potentially desirable, the study was conducted on a generic system without the current constraints of existing plants, technological limitations, and institutional restrictions.

Only a portion of the issues and trade-offs that must be understood to design an effective intermodal freight system are addressed. The basis for this paper is research findings originally documented for the Office of Systems Engineering, U.S. Department of Transportation (1,2).

STUDY FRAMEWORK

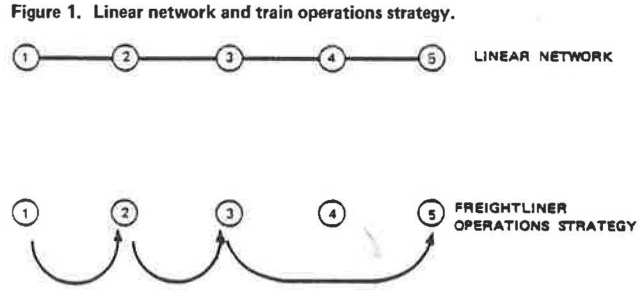
The development of a complete characterization of an intermodal system is a complex undertaking because of the many variables and degrees of interaction. Little research has been done to examine the trade-offs of the intermodal freight system. Therefore, the focus was initially on the simple line-haul system represented by the five-terminal linear network shown in Figure 1. Such a simple linear system has real-world analogs in the numerous heavy-volume freight corridors that exist in the United States. Although the linear network is simple, it provides an abundance of insights that are prerequisites for a systematic examination of a more complex two-dimensional system.

The demand in this simple linear system is characterized by the number of containers (used in a generic sense) going from each origin to each destination. A number of trains move over the line-haul segments and carry containers between terminals; a train moves at a constant speed over the line-haul segments and has a fixed maximum capacity (or size) for carrying containers. All terminals are identical and are characterized by a single processing time that is the combined time needed to load and unload containers from a train; the number of terminal platforms (or berths) determines the number of trains that can be processed simultaneously. (The number of terminal platforms refers to the number of platforms in a terminal for one direction only; it is assumed that the terminals are symmetrical.) Thus the interrelations and trade-offs among the five main engineering system design parameters listed below were studied:

1. Number of trains, N (fleet size);
2. Train speed, V (miles per hour);
3. Train capacity, C (containers);
4. Terminal processing time, P (loading and unloading a train); and
5. Number of terminal platforms, P_L (berths for loading and unloading).

The specification of the simple linear system is incomplete until the train's operating strategy on the network is specified. At one extreme is a local train strategy, in which a train stops at every terminal and picks up containers for all terminals along the route. At the other extreme is the direct-service train strategy, in which a train goes directly between two terminals without intermediate stops and carries only containers for the destination terminal. In this paper the results for an intermediate strategy called freightliner are presented. Freightliner represents an idealized version of a typical railroad operating strategy for a series of major terminals in a corridor. It is essentially a sophisticated local strategy in which stops can be skipped. This means that a train leaves the initial terminal carrying all containers going in the same direction; it stops at an intermediate terminal only if it has containers to deliver or if a specified minimum number of containers are to be picked up. Once stopped, the train will pick up additional containers going in the same direction.

Figure 1. Linear network and train operations strategy.



LINET SIMULATION MODEL AND COST EQUATIONS

A general-purpose simulation system (GPSS) computer model of the linear corridor system was developed for the analysis of trade-offs between the five system design parameters previously listed. This model is called LINET for linear network model. In the LINET model trains go from terminal 1 to 5 or from terminal 5 to 1 (Figure 1) operating in the freightliner mode. LINET is constructed so that the engineering system design parameters can be varied along with the station spacing.

Containers enter the system at an origin terminal with a request to go to a destination terminal. The specification of 24-hr demand is through an origin-destination (O-D) matrix that indicates the container volumes for each O-D pair during the 24-hr period. The actual time when a container enters the system at a specific terminal is randomized and subject to the 24-hr volume constraints imposed by the O-D matrix. The LINET model assumes that the 24-hr demand is repeated daily. The analysis presented here assumes that the system must move 2,300 containers/day.

Once a container enters the system it is not picked up until a train going in the proper direction with sufficient capacity arrives. Trains stop or skip stops according to the freightliner rules. When a train arrives at the end of the system, it is turned around to run in the opposite direction after an appropriate delay.

The LINET model has been instrumented to provide the following system evaluation statistics:

1. Train utilization factor (fraction of train capacity used);
2. Train delay time per link (train delay time to leave a link because of congestion to enter a station); this delay time could be associated with the station or the link; it was convenient for accounting purposes to associate the delay with the link;
3. Time elapsed before a container is picked up at a station;
4. Number of containers delivered during the period under study;
5. Average time containers are in the system;
6. Effective container speed through the system (total distance traveled divided by total time in the system); and
7. Total daily cost of the system.

The last item includes the capital recovery, operating, and maintenance costs. Formulas for total daily cost were developed for various categories in terms of the engineering system parameters N, V, C, P, and P_L. The formulas are given below (the units are dollars per day):

$$\text{Guideway costs} = D(395 + 0.304V^2) \quad (1)$$

$$\text{Terminal costs} = CP_L\,(157 + 133/P) + 1{,}370 \quad (2)$$

$$\text{Crew costs} = 949N \quad (3)$$

where

$$N = (DV + PV^2 - 450)/V(0.33V - 0.83) \quad (4)$$

$$\text{Fuel costs} = \left\{C(16 + 20U)\,[3.8V + V^2\,(0.0515 + 0.89/D)]\,(\text{train miles})\right\}/1{,}000{,}000 \quad (5)$$

where

$$\text{Train miles} = 2.18DC_D/CU \quad (6)$$

$$\text{Equipment capital costs} = 0.003NV^2C \quad (7)$$

$$\text{Equipment maintenance costs} = 0.02C(\text{train miles}) + 0.6(\text{fuel cost}) \quad (8)$$

In addition to the engineering system design parameters, other variables were required in the cost formulas. The variable U is the average train utilization factor (i.e., fraction of train capacity used), C_D is the average number of containers delivered during the period of interest, and D is the average distance between terminals.

The development of the cost formulas is documented elsewhere (2). The critical assumptions in the development of the cost formulas are

1. Current rail technology costs are simply extrapolated to obtain costs for advanced technology systems operating at higher train speeds;
2. The intermodal system bears the entire cost of the guideway;
3. The guideway costs increase with the square of the design train speed; and
4. Terminal processing costs increase with the reciprocal of the terminal processing time (i.e., increase inversely with terminal processing time).

As will be discussed later, other forms of guideway costs were used to test the sensitivity of the results.

MOST COST-EFFECTIVE SYSTEM DESIGN

When more money is spent on a system, improved system performance is expected. At what point is it no longer beneficial to spend more money on a system? To answer this question, a cost-effectiveness (or cost-benefit) analysis is often conducted. The result of this analysis would be the system design that provides the greatest incremental performance improvement per additional cost.

Unfortunately, cost-effectiveness is not well defined for a freight system. Consequently, for this analysis the following composite ratio was created, which can be interpreted as a measure of system cost-effectiveness:

Cost-effectiveness ratio = average effective container velocity ÷ total daily system cost.

A more accurate description of the ratio might be effectiveness-cost ratio, because the numerator is a measure of system effectiveness or performance, whereas the denominator is a measure of system costs. However, the term cost-effectiveness is more standard terminology. (The units for the cost-effectiveness ratio are miles per hour per dollar.)

The average effective container velocity is calculated by dividing the total distance of container travel by the total time a container spends in the system (i.e., total time spent in terminals and in line-haul). The result is a measure of the effective speed at which a container moves through the system, which reflects the level of service the system provides the customers.

Extensive parametric trade-off analyses were conducted by using the cost-effectiveness ratio as a figure of merit. The design speed parameter (V) was varied over a wide range to illustrate the trade-off between equipment and crew productivity and the costs associated with higher speeds. Guideway cost was a dominant component of system costs in all cases and thus mediated against high design speeds. Similarly, terminal processing technology, as embodied in a processing time parameter (P), was also varied widely. The cost component of terminal processing time was assumed to increase with the reciprocal of the terminal processing time. The results of the variation indicated a high payoff for reducing terminal

Figure 2. Cost-effectiveness ratio curve.

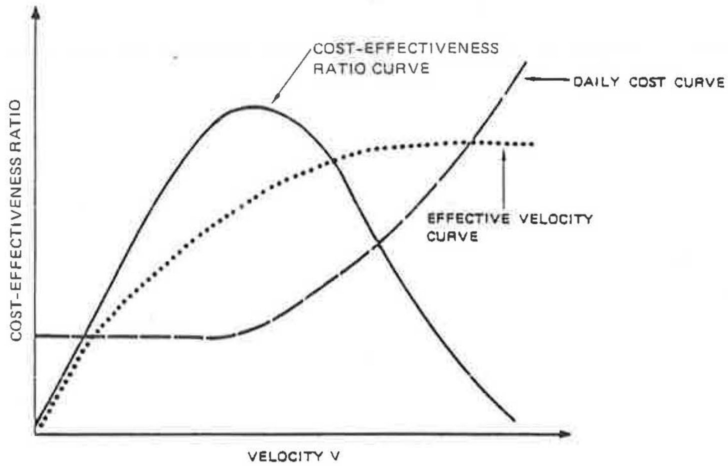
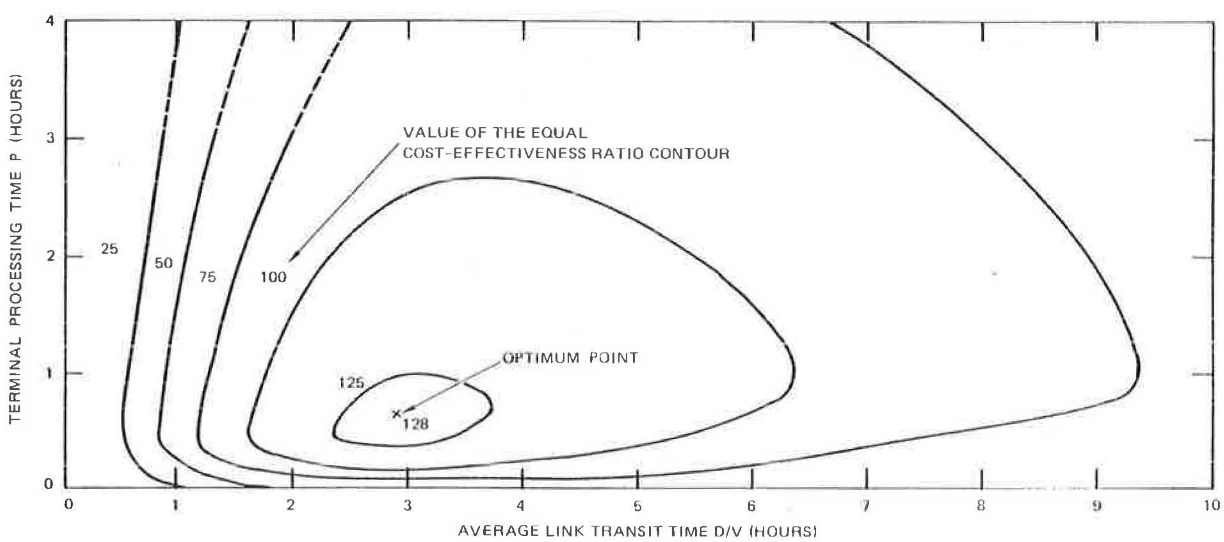


Figure 3. Contour curves of equal cost-effectiveness.



FOR PARAMETER VALUES:

C = 100 Containers

D = 108 Miles/Station

Demand = 2300 Containers/Day

1 Terminal Platform

processing time well below even the best current technologies.

To more fully understand cost-effectiveness relations, the data in Figure 2 show an overlay of three curves that represent cost, effective velocity, and cost-effectiveness ratio. (The data in Figure 2 should actually show three ordinates, but for simplification the ordinates associated with the cost and velocity curves are not shown.) The cost curve increases with V^2. The effective velocity rises rapidly with V and then levels off, which reflects the fact that increasing V adds to the velocity over the line-haul segments but not through the terminal. Thus the curve of the cost-effectiveness ratio has a maximum value. The curve shown in Figure 2 is a function of one parameter, train speed; a family of such curves and an associated set of optimum train speeds exist for various values of the other engineering parameters; e.g., number of trains, train capacity, and terminal processing time.

The data in Figure 3 show contours of equal cost-effectiveness in the two-dimensional parameter space of terminal processing time (P) and the average line-haul transit time between terminals (D/V), where D is the average distance between terminals. From this figure it appears that the contours are closed and that a distinct optimum, marked by an X, exists.

The data in Table 1 indicate that if train capacity is the independent variable and the system capacity remains the same, the optimum system configurations from a cost-effectiveness ratio are nearly identical for the 10- and 25-container capacity trains, which indicates that the optimum in terms of train size is relatively flat. Thus the optimum system configurations have a large number (30 to 60) of relatively small trains (10- to 25-container capacity) that travel at moderate speeds (45 to 60 mph). The associated optimum terminal processing time is in the range of 6 to 12 min to both load and unload a train.

The assumed cost relations play a critical role in determining the most cost-effective system design. For the cost relations and cost-effectiveness ratio criteria assumed here, however, the conclusion is that the most cost-effective engineering design for a freight system calls for a large number of small trains moving at moderate speeds; the associated terminal processing time is on the order of fractions of 1 hr.

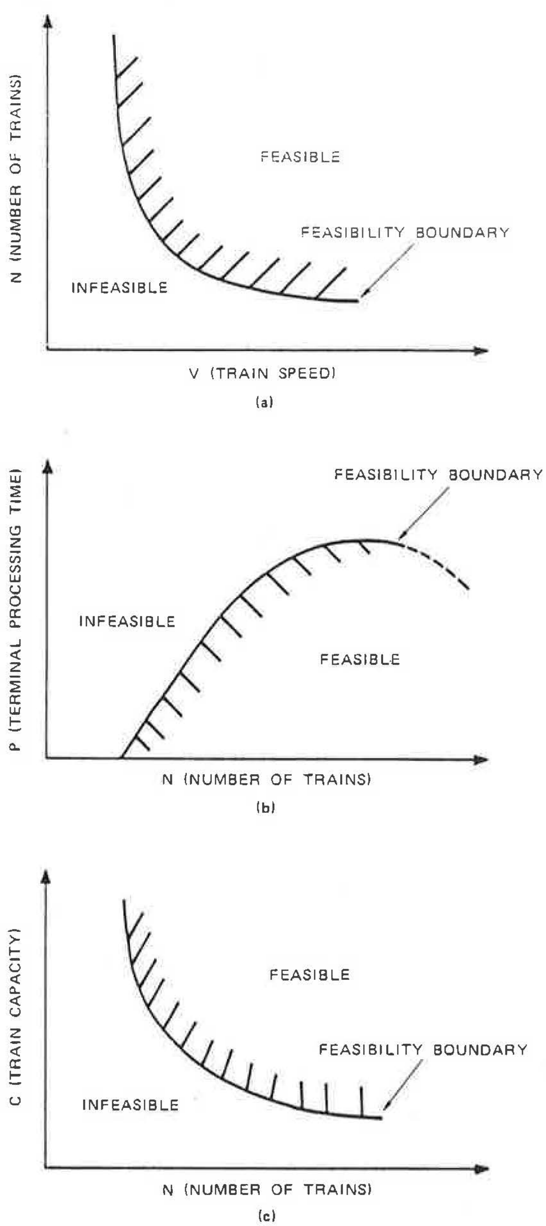
This conclusion remains valid even when the following three modifications to the assumed cost formulation are made:

1. Total guideway cost (fixed plus velocity-dependent terms) is reduced by a factor of one-tenth,
2. Only the velocity-dependent term of the guideway cost is reduced by a factor of one-tenth, and
3. A new guideway cost is formulated to be equal to a $2.00 surcharge on every dollar spent for fuel.

Table 1. Optimum sets of engineering system parameters.

	Optimum Engineering System Parameters by Train Capacity (no. of containers)				
Item	10	25	50	100	150
Cost-effectiveness ratio	175	171	153	128	119
No. of trains	59	31	19	11	7
Line-haul speed (mph)	60	47	40	37	36
Terminal processing time (hr)	0.1	0.2	0.36	0.6	0.85
Effective container speed (mph)	48	34	25	21	22
Daily cost ($000 000s)	0.27	0.20	0.17	0.16	0.18

Figure 4. Feasibility boundaries in two dimensions.



The rationalization or interpretation of these results is as follows. A specified level of system capacity can be achieved through use of a small number of high-speed trains or a larger number of smaller moderate-speed trains. The effective container velocity can be increased by accelerating (a) the speed over the line-haul segment by maintaining higher train speeds or (b) the speed through the terminals by maintaining faster terminal processing time and more frequent train departures (i.e., more trains) to reduce the container wait time for a train connection. Because the cost functions assumed in this study increase rapidly with the square of train speed (Figure 2), and because adding more trains and decreasing terminal processing time is less expensive than increasing train speeds, the most cost-effective strategy is to (a) build terminals that can process trains faster and (b) have more smaller trains moving at moderate speeds rather than fewer high-speed trains. Also, as the number of trains is increased, the arrival frequency at the terminal increases; therefore, the terminal processing for a train must be rapid in order to avoid queuing delays for service at the terminal.

FEASIBLE SYSTEM DESIGNS WITH SUFFICIENT CAPACITY

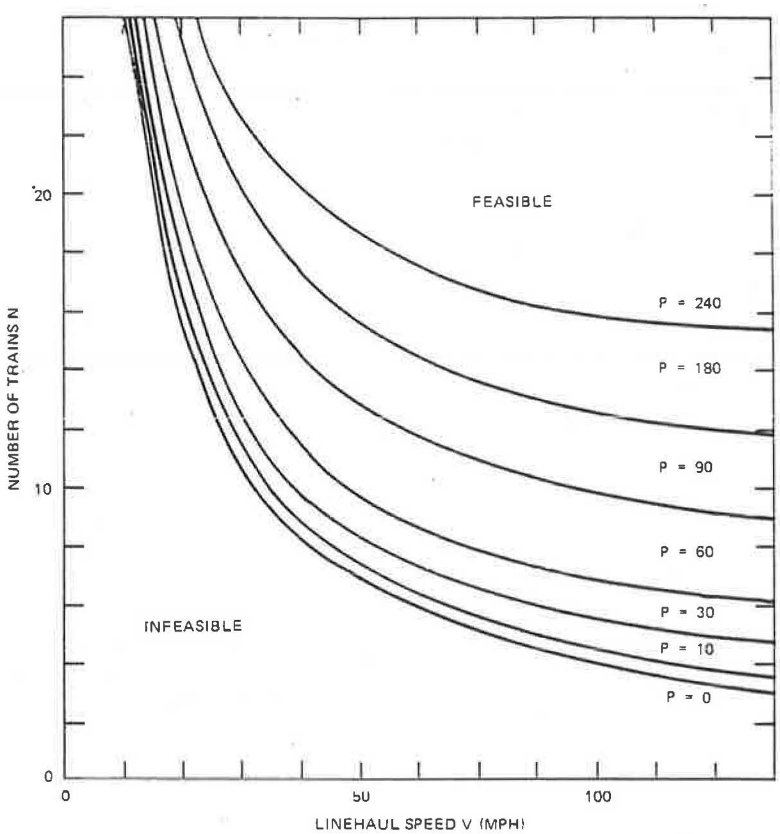
Insight into the fundamental interrelations and trade-offs among system design parameters can be obtained by studying the feasible design alternatives that have sufficient container-carrying capacity to satisfy the steady-state, 24-hr demand for container shipments. A system is defined as having sufficient capacity if essentially all of the containers are shipped within 24 hr.

The multidimensional system parameter space can be divided into two regions. In one region the system is capable of satisfying the demand, and in the other it is not. This analysis focused on the representation of this feasibility region in two dimensions. Examples of these feasibility regions in several two-dimensional parameter spaces are shown in Figure 4. The curve that separates the feasible from the infeasible region is called the feasibility boundary.

In the V versus N parameter space the feasibility boundary is hyperbolic in shape (Figure 4a). The vertical asymptote indicates that a minimum train speed is required to satisfy delivery of the containers. The horizontal asymptote indicates that a minimum number of trains is required.

In the P versus N parameter space the feasibility boundary rises with a slope to the right before leveling off. The initial rise of the curve to the right is explained by the fact that, with few trains initially, the terminal processing time must be fast to satisfy the demand. As more trains are added to the system, however, terminal processing does not have to be as fast to satisfy the delivery of the containers up to the point where the curve begins to bend to the right and level off. The curve bends because, as additional trains are added to the sys-

Figure 5. Feasibility curve family in N-V plane.



NOTE: Feasibility boundaries for linehaul speed versus number of trains for various processing times (P) in minutes

D = 108 Miles
C = 100 Containers
1 Platform/Station
Freightliner Mode
Demand = 2300/Day

Figure 6. Feasibility regions in C-N plane.

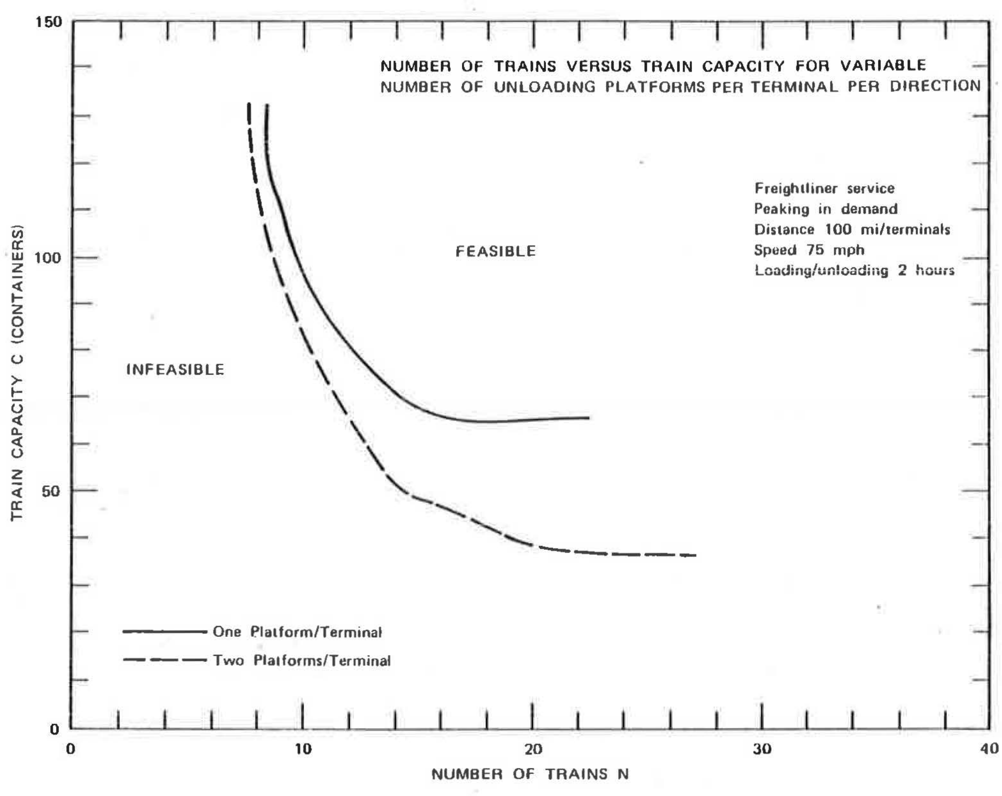
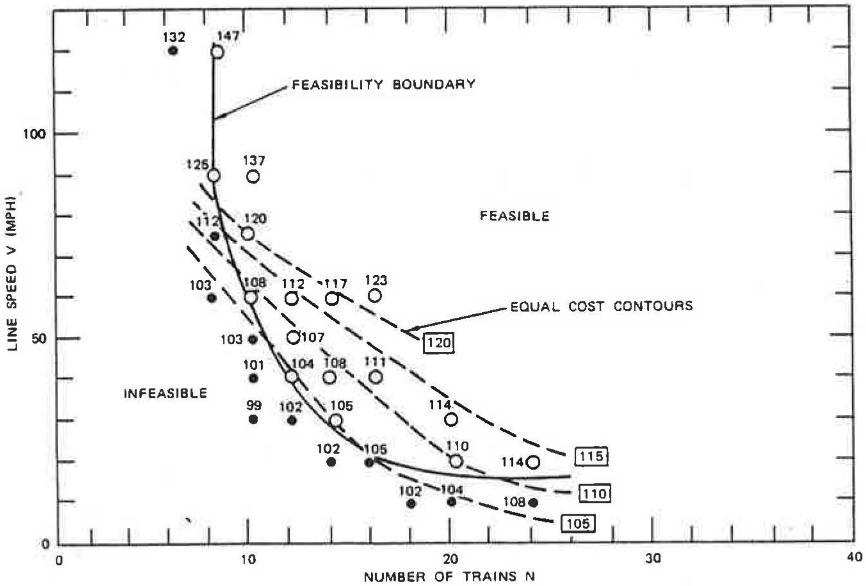


Figure 7. Feasibility curve and equal-cost contours in V-N plane.



NOTE: Numbers Reflect Total Annual Cost (Million Dollars)

tem, the terminal processing time must be sufficiently rapid to prevent queuing delays for trains waiting in the terminal to be processed. (In fact, a portion of this analysis indicates that the curve at some point begins to bend down.)

In the C versus N parameter space the feasibility boundary is again hyperbolic. The vertical asymptote indicates that a minimum number of trains are required to satisfy the demand; the horizontal asymptote indicates there is minimum train capacity.

In reality the feasibility boundary is a surface in a multidimensional parameter space. Slices of this surface in two dimensions are shown in Figure 5; the other associated parameter values are not displayed. The data in Figures 5 and 6 provide examples of how the feasibility boundary changes in the N versus V space as either the terminal processing times decrease or the number of terminal platforms increase; in both cases the feasibility regions increase.

In the N versus V parameter space the data in Figure 5 indicate the enlargement of the feasibility region as the terminal processing times decrease. As they decrease, the feasibility boundaries become a nested set of feasibility curves; therefore, feasible system designs become possible with smaller numbers of higher-speed trains as terminal processing times decrease.

In the C versus N parameter space the data in Figure 6 indicate that the feasibility boundary that assumes one terminal platform is nested inside the feasibility boundary that assumes two terminal platforms. The two-platform system can operate with a larger number of smaller trains than that possible with a one-platform system.

MINIMUM-COST SYSTEM DESIGNS

A typical example of a feasibility boundary and the associated equal-cost contours are shown in Figure 7. The cost curves are somewhat similar in shape and orientation to the feasibility curves but have less curvature. The system costs increase as the distance from the origin increases. Minimum system costs are found in the knee of the feasibility boundary at the point where the feasibility boundary is tangent to a cost curve. The costs in the knee of the feasibility boundary are fairly constant throughout the knee and near the minimum cost. Thus the knee of the feasibility curve is an area where minimum-cost designs, or near-minimum-cost designs, are achieved.

The system designs associated with points in the knee represent a considerable range of design alternatives. In the example the range of approximately equal-cost designs in the knee extends from 11 trains at 50 mph to 16 trains at 20 mph, with perhaps the least-expensive feasible solution using 13 trains at 30 mph.

The minimum-cost design is not necessarily the most cost-effective design. It is merely the least-expensive feasible solution. Points in the interior of the feasible region may provide higher cost-effectiveness even though they cost more.

DESIGN FOR SPECIFIED LEVEL OF SERVICE

One of the most important measures of the service effectiveness of a freight system is the average time a container spends in the system. A family of curves is shown in Figure 8 that represent time in the system plotted against line-haul speed for a specific combination of train capacity, demand, and interstation distance for systems along the feasibility boundary. The hyperbolic shape is clearly evident, and the general shape is typical. Two useful inferences can be made from this illustration.

1. At low speeds the time in the system rises rapidly as speed decreases, and reductions in processing time are not effective in reducing the time in the system.
2. At speeds greater than 50 mph the reverse is generally true; i.e., increased speed does not greatly reduce the time in the system. Increased processing time either increases time in the system or requires considerable increases in line-haul speed if time in the system is to be constant. At those speeds the travel time is small compared with other time components (loading and unloading time, lost time, and waiting time), and the travel time component becomes smaller as speed increases.

Figure 8. Time in system versus line-haul speed.

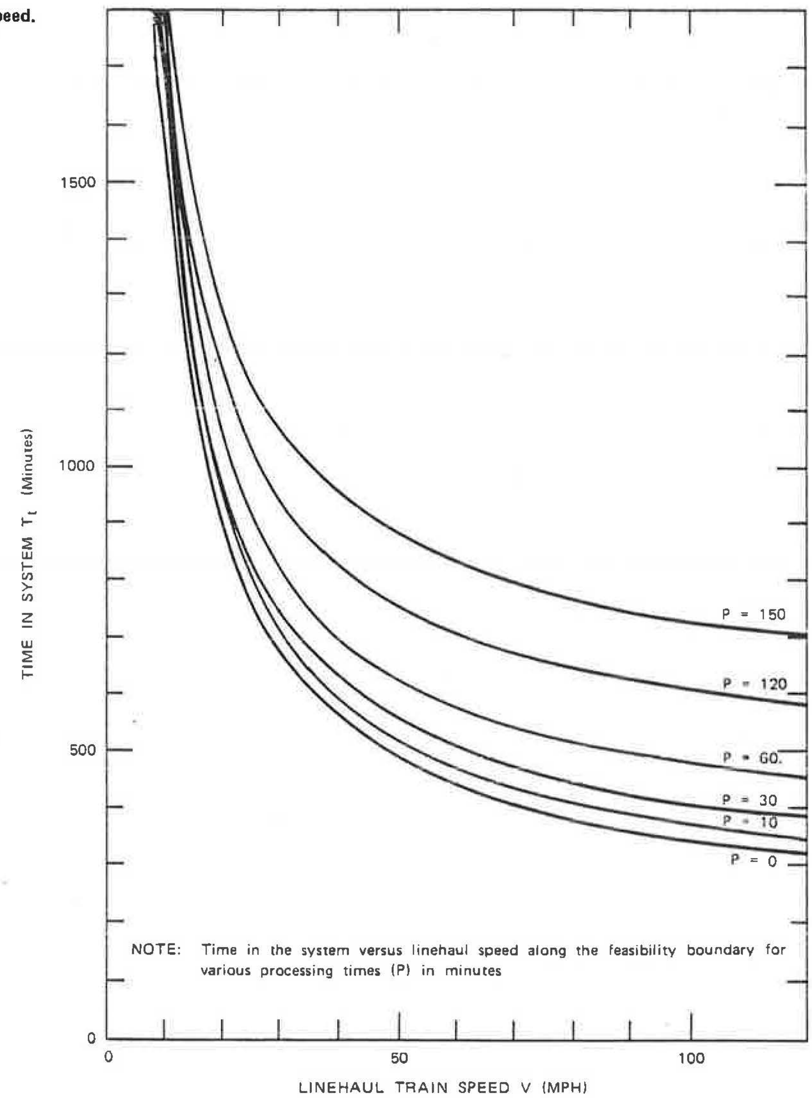
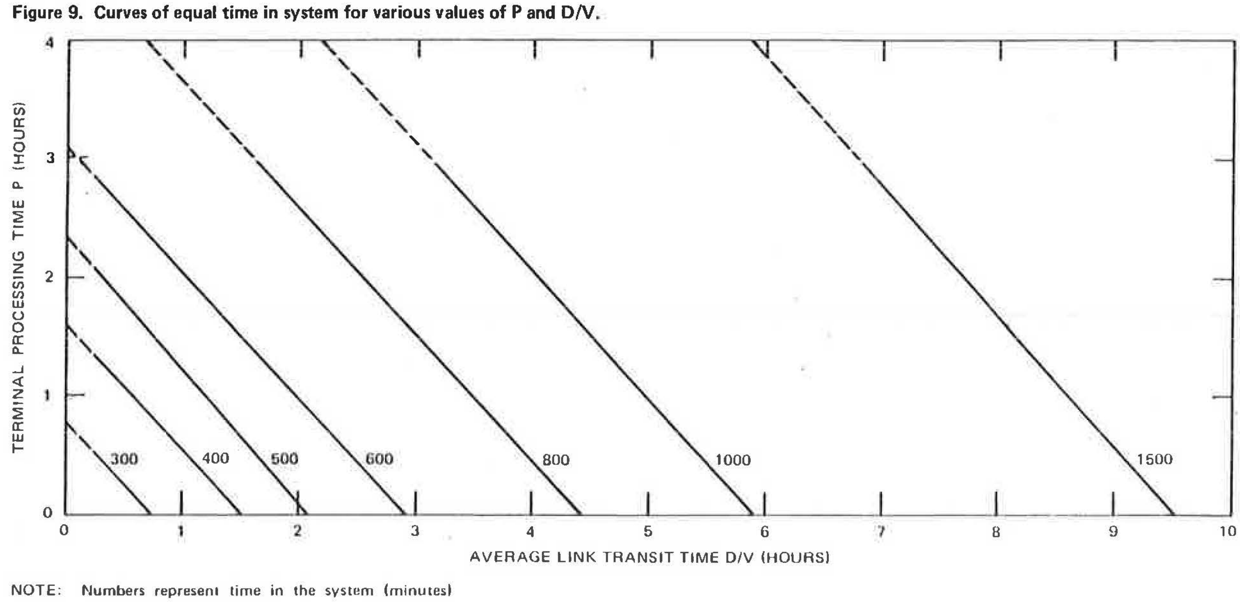


Figure 9. Curves of equal time in system for various values of P and D/V.



NOTE: Numbers represent time in the system (minutes)

C = 100 Containers
D = 108 Miles/Station
Demand = 2300/Day
1 Platform

A plot similar to Figure 8 would be useful in the initial selection of parameters for a system designed to provide a certain level of service. For instance, for a average container time in the system of 600 min, a processing time of 60 min would require a line speed of 55 mph. Reducing processing time to 30 min would reduce the required line-haul speed to 45 mph. A zero processing time would still require a line-haul speed of 38 mph. On the other hand, increasing the processing time to 120 min would require a line-haul speed in excess of 100 mph.

It is informative to plot curves of equal time in the system for various values of terminal processing time (P) and transit time across a line-haul segment D/V. (The use of the variable D/V instead of V versus P is useful because D/V and P are in the same units, i.e., time.) The data in Figure 9 show such curves for a specific combination of other system design variables. The lines in this figure are fairly straight and evenly spaced. This should not be surprising, as P and D/V are combined linearly in calculating time in the system and heavily influence the result.

The data in Figure 9 provide a means of rapidly determining the trade-off between D/V and P for any given level of service. The sections of the curves above P = 3 are unsubstantiated by LINET runs and are therefore indicated with dashed lines. It would be expected that, as the line-haul transit time (D/V) decreases, a breakdown point would occur at which the linear relation would no longer be valid. The curve should begin to bend down with decreasing D/V, which indicates that the terminal processing time (P) must decrease to avoid train queuing delays in the terminal.

The number of terminal platforms influences the size of the feasibility region (i.e., a system with 2 platforms/terminal has a larger feasibility region than a system with 1 platform/terminal). Once a system design is feasible, however, adding extra platforms to terminals has little effect on the average time a container spends in the system. Thus the number of platforms affects the ability of the system to satisfy the demand, but once the system is able to satisfy the demand, the number of platforms has little effect on system effectiveness.

ACKNOWLEDGMENT

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REFERENCES

1. P.J. Wong, A.R. Grant, M. Sakasita, and A.E. Moon. Concept Design and Analysis of Intermodal Freight Systems--Volume I: Executive Summary. Office of Systems Engineering, U.S. Department of Transportation, Rept. DOT-RSPA-DPB-20-80-2.1, Jan. 1980.
2. P.J. Wong, A.R. Grant, M. Sakasita, and A.E. Moon. Concept Design and Analysis of Intermodal Freight Systems--Volume II: Methodology and Results. Office of Systems Engineering, U.S. Department of Transportation, Rept. DOT-RSPA-DPB-20-80-2.2, Jan. 1980.

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Network Analysis of Highway and Intermodal Rail-Highway Freight Traffic

ALAIN L. KORNHAUSER AND MICHAEL BODDEN

The analysis capabilities of the Princeton highway and intermodal rail-highway network models are described. These network models are extensions of the Princeton railroad network model and graphic information system and are based on a geocoded network representation of intermodal transfer locations and the U.S. highway system. The models contain efficient routing and traffic assignment algorithms, highway and rail cost models, and extensive network editing and computer graphic utilities. Examples of highway and intermodal routes and a graphic analysis of the railside flows of 1980 intermodal traffic based on the 1980 one percent waybill sample are presented.

Analysis of U.S. highway and intermodal (highway-rail) traffic has been difficult because precise and broad-based highway traffic data were lacking and because an efficient computer-based network representation of the U.S. highway system did not exist. The unavailability of these data is unexpected given the amount of planning and funding that has been expended on the U.S. highway system. One would have assumed that the FHWA would have sponsored the creation of such a network data system, or that the Interstate Commerce Commission (ICC) or the FHWA would have secured the authority to collect a sample of highway traffic movements similar to the 1 percent waybill sample collected for rail freight (1).

However, because the carrier portion of highway freight transportation is fragmented and some sections of highway transportation are not regulated, no national sample of origin and destination data for highway freight traffic exists. The best publicly available cross-sectional national sample of truck traffic is the 1977 Census of Transportation (2). Although beneficial, this data source is significantly inferior when compared to the rail freight waybill sample. The origin and destination data of the 1977 Census of Transportation are grossly aggregated to state levels or to metropolitan areas, and no revenue data are given. Similarly, there are little or no data available for intermodal traffic because no government agency collects it. (Because intermodal traffic is deregulated, there may not exist a public need to know.)

The rail freight waybill sample only reports rail interchange locations, and not the ultimate highway origin or destination of the traffic. Even the railroads have not maintained traffic data on the ultimate origin or destination of intermodal traffic. Highway traffic data do exist within large trucking companies and within the freight forwarders that perform much of the retailing of intermodal traffic. However, these data sources are not accessible to the public or to the research community.

One reason why origin and destination highway traffic data have not been collected may be that there did not exist a means by which such data could be used effectively. The sheer size and ubiquity of the U.S. highway system did not lend itself to network-type traffic analysis.

A literature search has not uncovered the existence of any publicly available geocoded U.S. highway network. There does exist some proprietary highway networks, such as

1. Lansdown's highway network, which includes some 60,000 nodes and links (3);
2. Rand McNally-TDS's "Mile Make I," which is based on household goods movement mileages (3);
3. Networks by Numerax and others for mileage and rating purposes (3); and
4. Highway networks by CACI, for which little description is available in the literature.

Because of the analytical and problem-solving successes of the Princeton railroad network model (PRNM) (4), construction of a link-node network data base of the U.S. highway system was undertaken. The highway network was coded for the following reasons:

1. A quantitative and computer graphic mechanism could be provided for describing and understanding current freight distribution patterns and options on a national, local, regional, and corporate basis.
2. Alternate highway routings could be assessed. The ubiquity of the U.S. highway system suggests that numerous, essentially equivalent, alternate routes exist between most points. Although this is often true, favored routes tend to emerge, especially when toll facilities, weight restrictions, and legal passage of hazardous materials are taken into account. Many bridges and tunnels ban the shipment of hazardous commodities; states have varying weight limits; and many communities ban the transportation of nuclear materials.
3. Alternate intermodal routes could be analyzed because the highway network was developed so as to be compatible with the U.S. railway network.
4. Highway market service areas could also be analyzed. There is a need to identify the areas served by various elements of the highway system (e.g., toll facilities or segments of Interstate and intermodal facilities). These analyses are accomplished by assembling either all origins (destinations) to (from) a common destination (origin) or both, so that the market service area for intermodal facilities can be assessed.
5. Operational pricing and policy analysis issues could be studied, including estimates of the quantitative effects of variation in the size of the market service areas with changes in the price of fuel, truck sizes and weights, speed limits on highways, tolls, intermodal train service, and intermodal ramp charges.
6. The strategic value of various segments of the highway system, especially bridges and tunnels, could be assessed.

Of the above analyses, only distrbution patterns require traffic (origin-destination) data. The others can be accomplished in a straightforward manner with network data, routing algorithms, and network editing and computer graphic utilities contained in the Princeton highway network model.

If origin-destination traffic data are available, then distribution patterns and opportunities can be studied by the following analysis capabilities:

1. Display of the volume of traffic by highway segment, direction, equipment type, and commodity;
2. Display of empty or loaded factor for weighted volumes by direction;
3. Display and analysis of optimum routing and reload opportunities as part of a vehicle management system;
4. Identification of where backhauls would be most beneficial; and
5. Evaluation of alternate locations of warehouse and terminal operations.

The above analysis capabilities serve as desirable primary goals of a highway and intermodal management information system because they act as basic inputs to a framework for highway policy and plan analysis, and because they aid in ongoing corporate distribution decision making.

HIGHWAY NETWORK DESCRIPTION

The Princeton highway network is a link-node data structure that is similar to the Princeton railroad network. It consists of 8,862 nodes and 14,796 links. Node attributes include x,y coordinates (longitude and latitude equivalent), place names and state, standard point location code, and intermodal ramp code (if applicable). Other geographic files relate highway nodes to counties, business economic areas, census zones, and zip codes.

Table 1. Highway network node and link attributes.

Item	Example
Node attribute	
Node number	1257
Coordinate location	Latitude and longitude
Name and state	Princeton, New Jersey
Standard point location code	194537
Intermodal ramp	Princeton TOFC
Link attribute	
A node	1257
B node	1263
Distance (tenth of miles)	126 (12.6 miles)
Route class (1, 2, 3, 4)	1 = toll facilities; 2 = Interstate, free; 3 = divided highway; 4 = undivided roadway
Route designation	I-95
Hazardous material restriction (yes/no)	Yes

Figure 1. U.S. highway network.

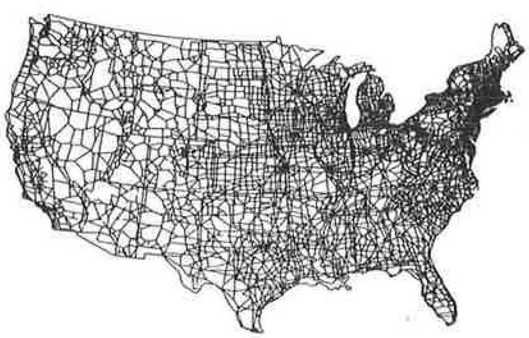


Figure 2. Highway network in vicinity of Mercer County, New Jersey.

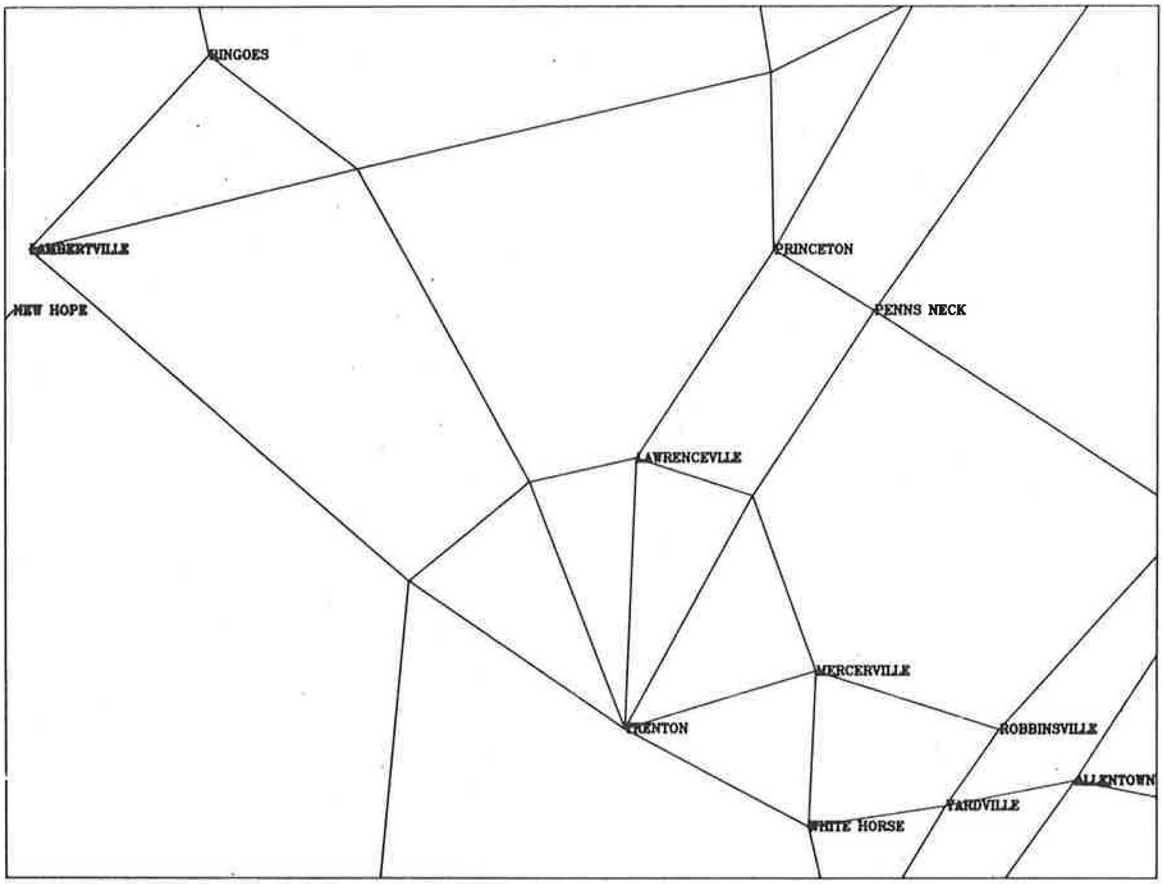
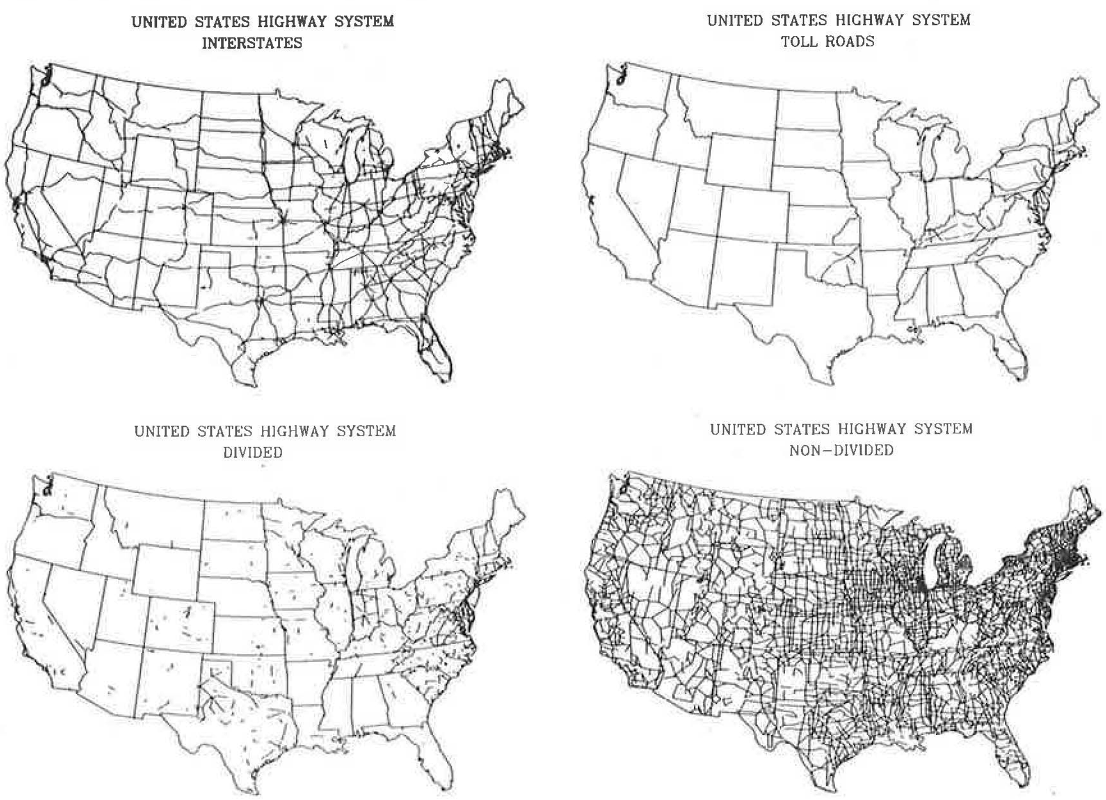


Figure 3. U.S. highway network divided by road type.



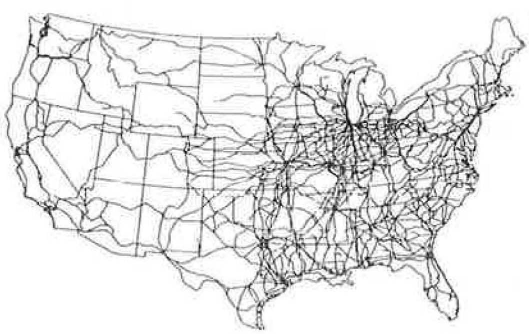
Link attributes include distance, hazardous material restriction, and route designation and type. Up to three route designations have been coded on each segment (i.e., Interstate, U.S. highway, and state highway). Four route types are coded, which include Interstates, toll roads, divided limited-access highways, and nondivided highways. Examples of node and link attributes are given in Table 1.

A geographic depiction of the Princeton highway network for the entire United States is shown in Figure 1. A close-up of a section of the highway network near Princeton, New Jersey, is shown in Figure 2. The network has been coded to an intermediate level of detail. All Interstates and federal roads, most state roads, and a few country roads (but no residential roads) have been coded (see Figure 3).

INTERMODAL NETWORK DESCRIPTION

The link-node network is a combination of the highway network and the subset of the Princeton railroad network that actively served intermodal traffic in 1980. This reduced railroad network contains 7,436 nodes and 8,406 links. Node and link attributes are the same as those for the entire railroad network, except that 1980 trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) link volumes, 1980 TOFC and COFC ramp volumes, and a ramp location code are added. A total of 855 ramps are coded. These ramps had significant (more than 1 car/day) activity during 1980. The Princeton TOFC rail network is shown in Figure 4.

Figure 4. Intermodal rail portion of network.

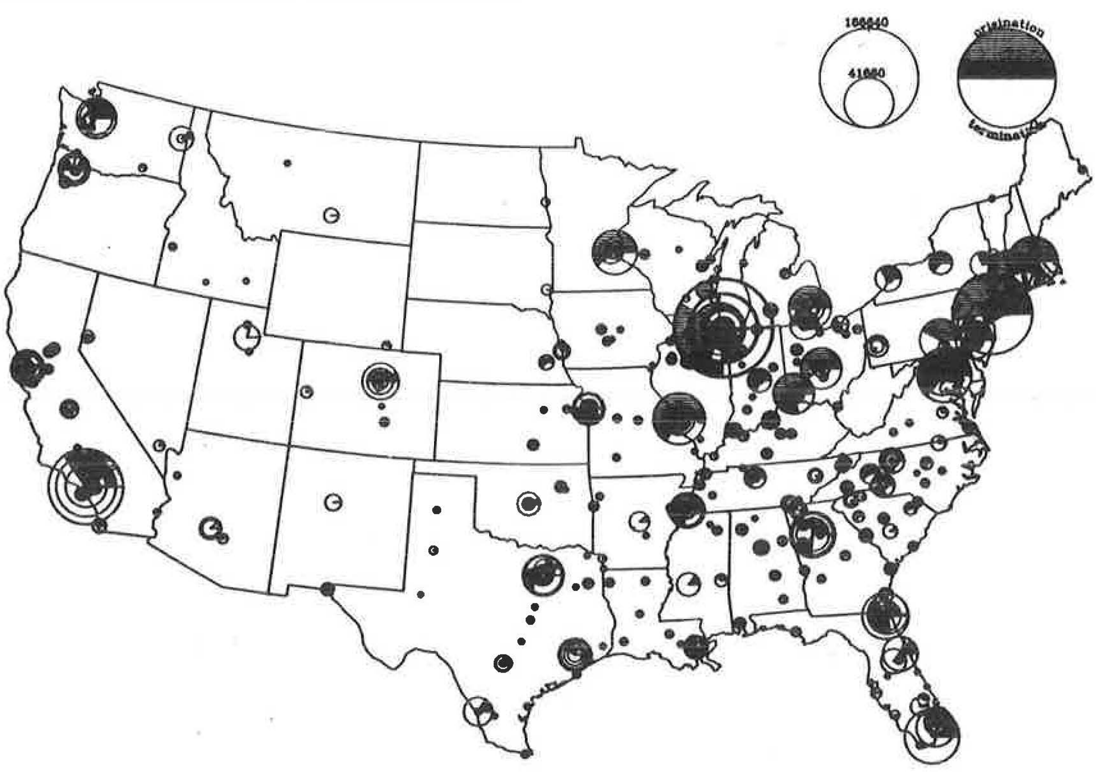


The TOFC ramp volumes for 1980 are shown in Figure 5. The area of the pies are proportional to the total carload volume of intermodal traffic interchanged between highway and rail at each location. The open slice is the highway-to-railway interchange volume, and the dark slice is the railway-to-highway volume.

The ramp volumes are not an accurate reflection of the rail origin and destination volumes of intermodal traffic because of the phenomenon of rubber interchange. This phenomenon principally occurs in Chicago and St. Louis, where intermodal traffic interchanged between railroads is achieved by off-loading the trailer from the flatcar, transferring of the trailer across town on highways to the other railroad's facility, and loading the trailer back onto a flatcar. Such movements are generally transacted by using individual waybills. As such they appear as double-counted rail movement rather than a single inter-railroad movement. Thus the activity represented in Figure 5 is only the rail-highway interchange activity and an overestimate of the amount of traffic that has rail originations or terminations in Chicago and St. Louis.

The Princeton intermodal network, which includes highway (without Interstate links), rail, and ramp

Figure 5. 1980 TOFC volumes from 1 percent waybill samples.

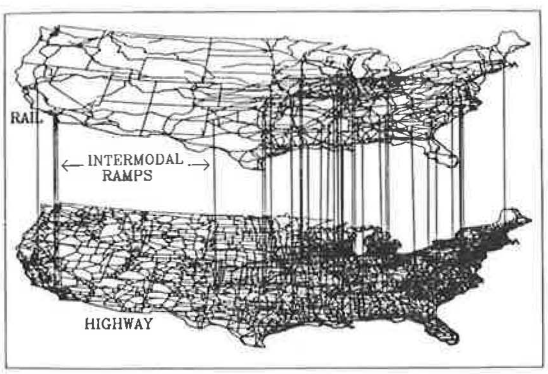


elements, is shown in Figure 6 in the quanta-net perspective (5). This view easily distinguishes the highway network (bottom plane) from the TOFC network (top plane). Also shown (by means of vertical lines) are the locations of intermodal ramp facilities. These vertical links permit traffic to be interchanged from the highway to the railway network and vice versa. With regard to network analysis, they represent the unit cost of transferring equipment from highway to rail. These costs can differ by ramp location due to varied operating practices and available equipment. The total intermodal network consists of 24,058 links and 16,298 nodes.

ROUTING MODEL

Routing of traffic on the Princeton highway or intermodal network is accomplished by using a minimum-cost, unconstrained, path-finding algorithm. It is the same algorithm that is used in the PRNM, except that it operates on highway or intermodal network data instead of railway network data (6). The routing algorithm accepts various cost functions for highway, rail, and ramp elements. The model contains a default cost function that is based on user-specified mileage rates for highway and rail portions as well as for rail form A type (7) ramp charges. Compensation is made for toll roads and divided and nondivided highways. Capabilities exist for the user to modify the link cost data or respecify the cost model, subject only to data availability and that the cost of a route is the linear sum of the cost to traverse each segment of that route.

Figure 6. Quanta-net representation of intermodal network.



Several examples of minimum-cost routes out of Princeton are shown in Figure 7. Note that the total distance to each destination is shown; although the routes are minimum cost, they are rarely minimum distance. The data in this figure indicate that the destinations of Scranton, Pennsylvania, and Boston are best reached by highway-only routes; however, the Philadelphia intermodal facility captures the rail portion of the best routes to other locations.

All of the destinations served by the Los Angeles TOFC ramp for intermodal traffic originating in Princeton are shown in Figure 8. The data in this figure reveal the market area served by the Los Angeles ramp vis-à-vis other (California) ramps for traffic from and to Princeton (and probably most points east of the Rocky Mountains). [Although Princeton does not generate much (if any) traffic, it has been used as an example. Any other city can also be analyzed interactively.]

EDITING AND GRAPHIC FUNCTIONS

The highway network model includes all of the network editing and display capabilities that have been developed for the PRNM. The figures used in this paper are examples of the various graphic capabilities of the model. Because the model operates in an interactive computer environment by using APL as the programming language, its editing utilities allow the user to easily correct or alter the network link and node data. These capabilities greatly simplify the mechanics of doing variational analyses.

HIGHWAY TRAFFIC FLOWS

In order to use the highway network for analysis purposes the highway portion of the 1977 Census of Transportation (2) was geocoded (i.e., encoded with highway network node numbers in place of the origins and destinations of metropolitan areas). A standard traffic assignment procedure was followed to accumulate traffic volumes of chemicals [standard transportation commodity code 28 (STCC28)] over the best highway routes between metropolitan areas. The

Figure 7. Optimal intermodal routings from Princeton.

Figure 8. Optimal routings from Princeton to the highway nodes of Los Angeles (using the TOFC ramp).

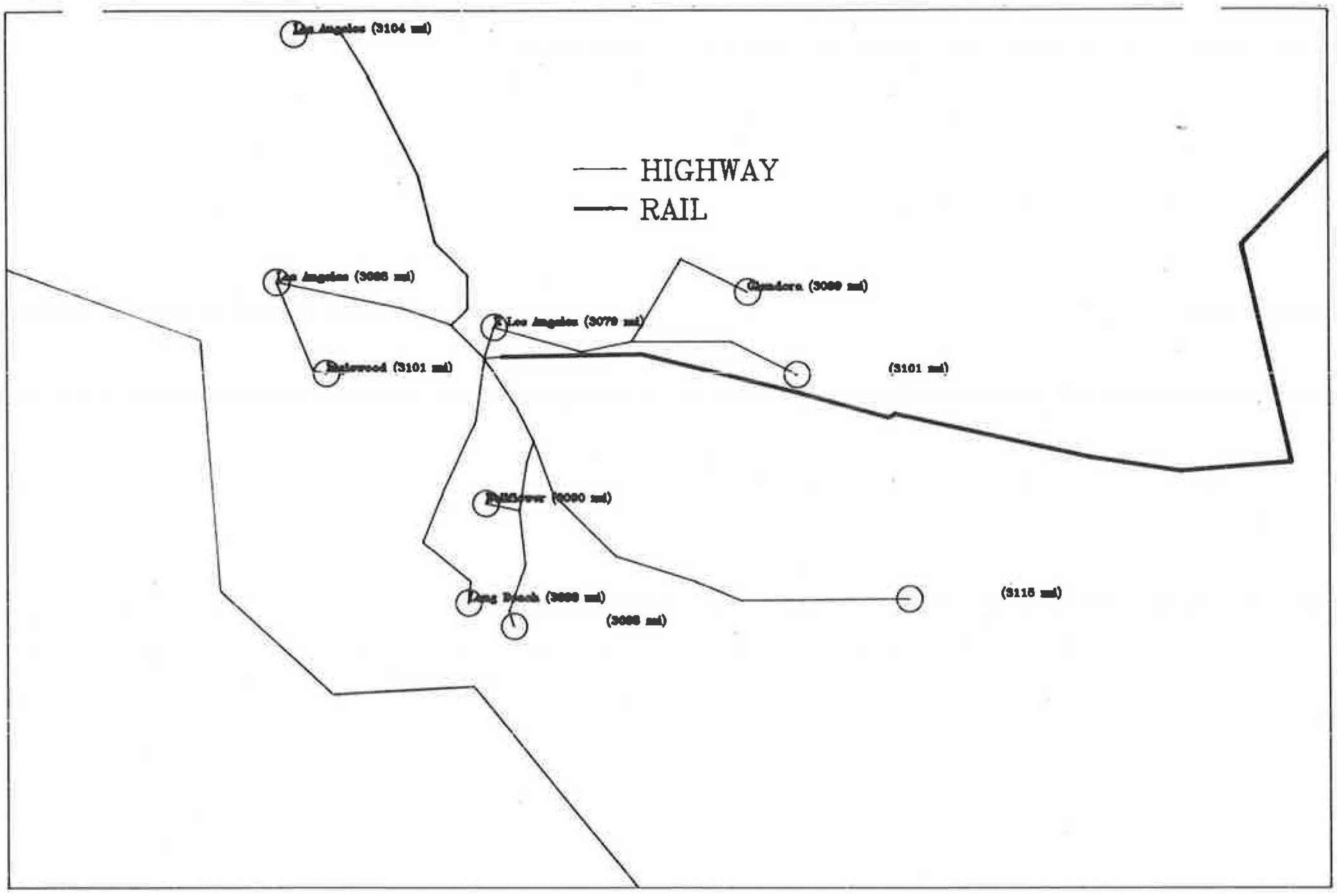
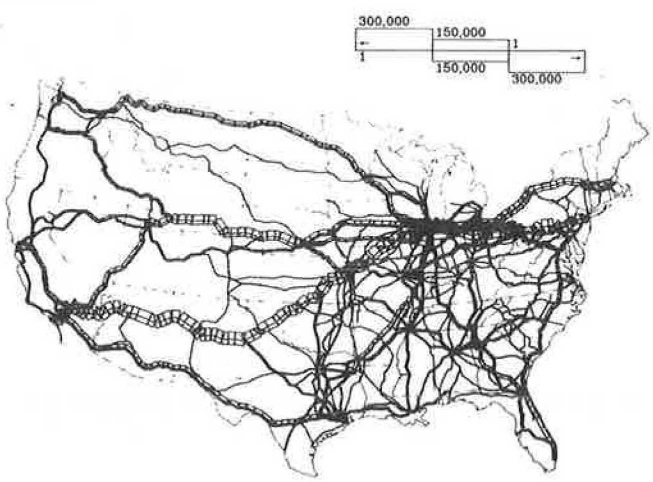


Figure 9. 1980 carload volumes for intermodal traffic (TOFC, COFC, and combinations).



resulting traffic densities were plotted (see Figure 9).

Figure 9 is believed to be the first computer-generated U.S. highway traffic density map. The information on the map reveals the following items:

1. The relative density of chemical traffic by direction over the U.S. highway system.
2. The New Jersey Turnpike is the most heavily traveled route for chemical traffic.
3. The next most heavily traveled highway corridor is the I-80 route across Pennsylvania [i.e., 800,000 net tons/year or about 40,000 trucks/year (an average of 150 trucks/day) travel on I-80].
4. The largest corridors are east-west between the Boston, New York, and Philadelphia areas to and from St. Louis and Chicago.
5. The Texas and Louisiana route to the northeast diagonal route is the next largest corridor.
6. Large westbound movements exist to the Los Angeles Basin and north and south between San Francisco and Los Angeles.
7. The rest of the highways in the United States serve relatively little chemical traffic.

A similar analysis can be performed for other commodities by using the Census of Transportation data. Other truck data bases can also be used.

ANALYSIS OF 1980 INTERMODAL TRAFFIC

Because no ultimate origin and ultimate destination intermodal traffic data base has been available, it is not yet possible to prepare intermodal traffic density charts that display the highway and rail portions. Nevertheless, the 1980 one percent waybill sample does describe the rail portion of intermodal traffic on a ramp-to-ramp basis. The data are coded on a carload (not trailer or container) basis and are specific as to plan and whether the flatcar carried trailers (TOFC), containers (COFC), or a combination (trailers and containers). These data

Figure 10. 1980 TOFC volumes.

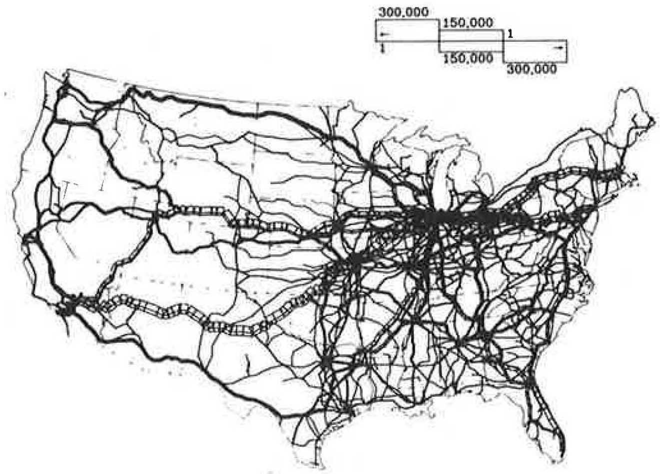
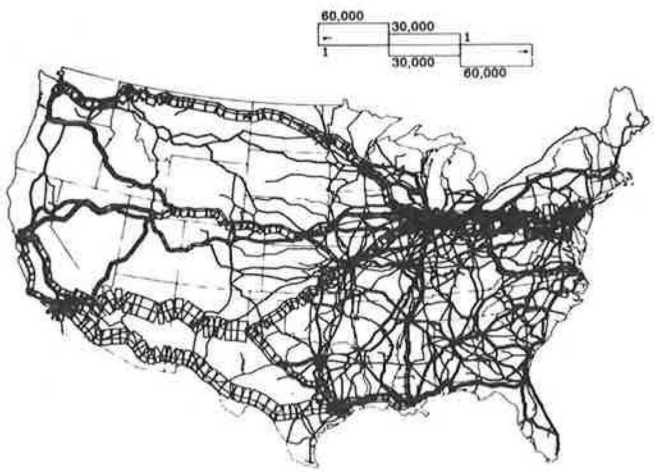


Figure 11. 1980 COFC volumes.



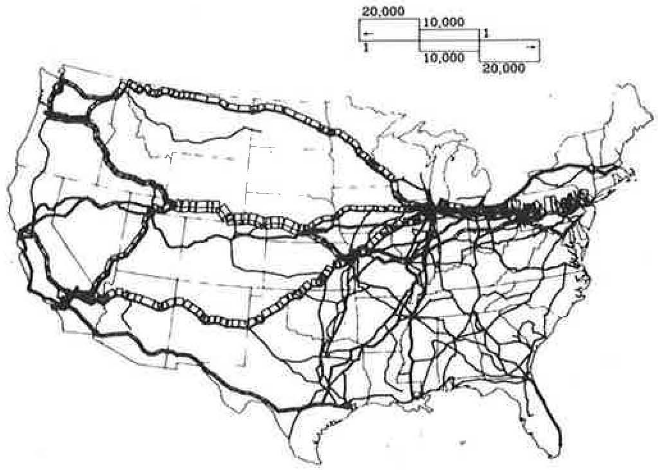
were routed and accumulated (i.e., assigned) to the rail portion of the intermodal network.

The 1980 intermodal rail traffic indicated definite and distinct patterns. The traffic consists of TOFC traffic, COFC traffic, and traffic that mixes TOFC and COFC on the same car. The rail carload volumes of intermodal traffic are shown in Figure 9. TOFC makes up the majority of the traffic.

The rail carload volumes of TOFC traffic are shown in Figure 10. TOFC traffic volumes reveal major flows between southern California and Chicago. The Santa Fe Railroad handles the majority of this traffic, and the Union Pacific (UP) and Southern Pacific railroads also handle substantial traffic. Large volumes travel between Chicago and Boston and Newark and Elizabeth, New Jersey, over Consolidated Rail Corporation (Conrail) lines. Each of these major volume flows is well balanced directionally, i.e., the eastbound flow is comparable to the westbound flow.

Substantial volumes are shown moving south into Florida over the Family Lines System (FLS) and Southern Railway, and a large portion is taken to Ft. Lauderdale and Miami by Florida East Coast Railroad (FEC). Noticeable traffic volumes move between the Pacific Northwest and Chicago on the Burlington Northern (BN) or the UP. There is also a substantial flow of traffic between Texas and Chicago, where the Missouri Pacific Lines (MP) handle a large portion of the traffic.

Figure 12. 1980 TOFC and COFC volumes combined.



The 1980 rail carload volumes of COFC traffic are shown in Figure 11. COFC traffic patterns demonstrate that containerized ocean freight is transhipped at ports to rail. The largest volumes were shown to be on Conrail to Port Elizabeth, New Jersey. Large volumes are shown to travel from Oakland and Los Angeles to the East through Chicago and to the Gulf ports of Galveston and New Orleans. Santa Fe and SP handle the majority of the traffic, and UP also carries substantial amounts. BN handles the majority of traffic between the Pacific Northwest and the East, and UP handles the remainder. Illinois Central Gulf (ICG) carries substantial traffic between New Orleans and various points north.

The combined TOFC and COFC traffic patterns were similar to those of the other two categories. Some differences were apparent in the balance of the flow. There was noticeably more traffic westbound to the West Coast on the BN, SP, and Santa Fe. The 1980 carload volumes of the combined TOFC and COFC traffic are shown in Figure 12.

SUMMARY

The first elements of a nationwide analysis of highway freight and intermodal (highway-rail) movement has been presented, and a newly available link-node network representation of the U.S. highway system and intermodal facilities has been used. The motivation for developing an analytical framework for quantifying U.S. highway freight issues was presented. The highway network was described, and how it has been integrated with the railway network has been discussed.

Examples of the use of the network model in generating minimum-cost highway and intermodal routes was presented. The highway routing capability was used to assign chemical traffic (STCC28) from the 1977 Census of Transportation (2) to the highway network, and the resulting traffic densities were described. Another analysis of the rail portion of highway-rail intermodal traffic was also presented. Nationwide statistics were displayed and described.

These analyses serve as examples of the value of the highway and intermodal network analysis capabilities. Their integration into a graphic information system provides capabilities for under-

standing distribution patterns and doing highway-freight-oriented strategic and policy studies.

REFERENCES

1. R. Antush. Enhanced One Percent Waybill Sample. ALK Associates, Inc., Princeton, NJ, Rept. 81-3, Nov. 1981.
2. 1977 Census of Transportation. Census Bureau, U.S. Department of Commerce, 1977.
3. Software for Distribution. Distribution Sciences, July 1982.
4. A.L. Kornhauser. Railroad Traffic Analysis Using Interactive Computer Graphics: An Update. Presented at 1981 National Computer Graphics Conference, Baltimore, MD, June 1981.
5. A.L. Kornhauser, M. Hornung, and R.J. Caudill. Theory for Estimating Traffic Diversions on a Restructured Railroad System. TRB, Transportation Research Record 758, 1980, pp. 34-43.
6. M.A. Hornung. RRGRAPH-Railroad Oriented Graphics Workspace User Documentation. ALK Associates, Inc., Princeton, NJ, Version 3.0, Aug. 1982.
7. 1977 Carload Cost Scales. Bureau of Accounts, Interstate Commerce Commission, 1978.

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Intermodal Freight Transfer Facilities in California

NOREEN ROBERTS AND WILLIAM FELTS

The increase in international trade through California ports is creating transportation problems in the urbanized regions adjacent to these ports. Most intermodal freight transfer facilities are being planned or constructed as part of seaport expansion due to this increase in trade. Although these transfer facilities may alleviate some problems on the transportation system, they may also exacerbate others. Any modal shifts from truck to rail that result from the relocation of transfer facilities in closer proximity to the ports must be viewed in the context of the overall increase in rail traffic. The projected increase in container cargo and coal and grain exports equates to significantly higher volumes of rail traffic through highly urbanized areas. Although modal shifts may benefit highway truck traffic, increases in rail traffic could create severe problems, particularly at grade crossings in the Los Angeles area. The focus of this paper is on the role of the state, specifically the California Department of Transportation, in port access planning. The role of the state is reexamined in the light of increases in international trade through California's ports and the impact of these increases on the transportation systems that provide access to the ports. In addition, proposed intermodal freight transfer facilities are examined to determine if such facilities will have a significant effect on the problems associated with increased port traffic.

Intermodal freight transfer facilities in California play a key role in the efficient transportation of commodities. Most of the major new intermodal transfer facilities are being planned or constructed as a part of seaport expansion. This expansion is due, in large part, to increasing international trade through West Coast ports. The increased activity at the major seaports in California has had, and will continue to have, a significant impact on the transportation systems that provide access to the port complexes.

The focus of this paper is on the role of the state, specifically the California Department of Transportation (Caltrans), in port access planning. The role of the state is reexamined in the light of increases in international trade through California's ports and the impact of these increases on the transportation systems that provide access to the ports. In addition, proposed intermodal freight transfer facilities are examined to determined if such facilities will have a significant effect on the problems associated with increased port traffic.

CALTRANS' ROLE IN PORT ACCESS PLANNING

Caltrans is a multimodal transportation agency concerned with developing and maintaining a balanced, environmentally sound, and efficient transportation system within the state. This perspective should extend to intermodal freight and port-related transportation facilities and issues.

The rapid growth of international trade through California ports suggests that the Department should expand its capability for port transportation planning. In the past goods movement through California ports has increased at a manageable pace. However, if the anticipated increases in certain commodities occur, port development during the 1980s may result in significant impacts to the highway and other transportation systems in the state. By emphasizing port transportation planning, such impacts may be mitigated and goods movement may be facilitated.

Historically, California has not placed a high degree of state involvement in port activity. Most ports are quasi-public entities, and some are partly funded through taxation. However, unlike certain other states, there is no state authority over port development and operations.

Transportation planning has not been conducted on a port-specific basis. Port access facilities are analyzed on much the same basis as all other departmental projects. The state's role in port transportation planning should be developed on the premise that there are characteristics of port access that require a special planning approach.

Due to the multimodal aspects of port access facilities and the multiplicity of jurisdictions involved along the corridors through which facilities pass, planning and coordination at both the regional and state level is appropriate. However, in the absence of a constituency, much less a mandate, for such a state role, planning activities have been limited. Other priorities place higher claims on available state resources.

As a result, current Department responsibility in port planning focuses primarily on transportation impacts associated with port activity. This responsibility is carried out by (a) actions that implement Department policy, (b) the environmental review process, and (c) policy analysis and recommendation.

Department Policy

The Department recognizes the importance of California's ports to the economy and the need to deal with groundside transportation problems related to their operations. It is Caltrans' policy to encourage and facilitate the efficient movement of goods through California ports in a manner that mitigates port-related impacts. This policy is implemented by the following actions:

1. Port issues are monitored and analyzed in terms of departmental programs, projects, and policies;
2. Measures are developed to reduce congestion on port access roads;
3. The development of intermodal freight transfer facilities are encouraged where appropriate;
4. Means of reducing conflicts between transportation modes in port areas are studied.
5. Means of producing modal shifts in goods movement that benefit the state's transportation system are encouraged;
6. Intermodal projects are recommended for FRA funding when appropriate;
7. Port access studies are conducted under FHWA Highway Planning and Research funding; and
8. Actions are coordinated with ports and other public agencies to facilitate efficient goods movement and reduce transportation conflicts and adverse environmental impacts.

Environmental Review Process

Many port developments are subject to the environmental impact report (EIR) requirements of the California Environmental Quality Act. The Department reviews these port project EIRs. Reviews normally concentrate on the effect that the project will have on state transportation facilities, but the reviews may also include community and other transportation-related impacts. Both the main office and the districts participate in the review and comment process.

Policy Analysis and Recommendation

The Department currently gathers and organizes information relating to ports. Such information is collected from port industry journals and other literature sources. Department personnel also attend port and international trade conferences.

A port inventory document has been developed that lists port characteristics, including capacity, tonnage, commodity types, vessel sizes, channel depths, and related information.

Such information is used in the analysis of port issues and to formulate policy recommendations. The increased interest in port goods movement and its relation to highway and rail facility planning have resulted in a greater emphasis on this aspect of transportation planning. Specific analyses include highway needs for port areas, highway-rail conflicts, international goods movement trends, and port user fee proposals.

The results of these analyses, which are summarized in this paper, suggest that a stronger state role is needed in planning and coordinating port activities.

BACKGROUND: INCREASED WEST COAST PORT ACTIVITY

Although the total volume of international trade through California ports has risen steadily over the past decade, significant increases have been recorded for containerized cargo, coal, and grain.

During the first 6 months of 1980, California's three custom districts (Los Angeles, San Francisco, and San Diego) accounted for 12 percent of the total international trade in the United States and 60 percent of that on the West Coast. The major exports include agricultural products, machinery, electronics, and transportation equipment. Leading imports consist of automobiles, electrical machinery, oil, and natural gas. California's leading trade partners are Japan, Indonesia, Taiwan, South Korea, West Germany, and the United Kingdom.

The Los Angeles Customs District, which includes the ports of Los Angeles and Long Beach, is the third largest district in the United States in terms of value of international trade. In the first half of 1981 it accounted for 62 percent of California's total trade with a value of $18.7 billion (1).

Containerized Cargo

Containerization of cargo has become an important means of transporting commodities and is virtually supplanting break bulk handling. Containerization is a capital-intensive rather than labor-intensive transport method. Goods are shipped intermodally in 20- or 40-ft metal containers, thereby significantly reducing transfer time, handling costs, pilferage, and damage.

In addition to the efficiencies that make containerization popular, its use is increasing because it is often a more economical and reliable alternative to all-water movement of goods through the Panama Canal. Under this alternative, known as bridge service, containers use vessel and rail or truck modes to move across the United States or to inland U.S. destinations.

The combined effects of container transport efficiency and the bridge service alternative account for the dramatic increase in container movements through U.S. ports. The world fleet of containers rose from approximately 300,000 twenty-foot equivalent units (TEUs) in 1971 to about 3,000,000 in 1981. In 1980, approximately 2,800,000 containers (and trailers) were moved through the U.S. bridge system (2).

Between 1972 and 1980 the number of containers moving on the bridge system through the ports of Los Angeles and Long Beach increased by 1,150 percent. The combined monthly volume of containers through these ports rose from 2,000 TEUs in 1976 to nearly 25,000 TEUs in 1980. The two ports estimate their combined annual volume of bridge traffic will surpass 500,000 TEUs in 1984 and 1,000,000 TEUs in 1990 (3). In the San Francisco Bay area, the Port of Oakland, which specializes in container shipping, reported an annual volume of 734,000 TEUs in 1979. Eighty-five percent of the vessels calling at this port were container ships (4).

Intermodal Container Transfer Facilities

Los Angeles and Long Beach

The ports of Los Angeles and Long Beach have proposed the construction of an intermodal container transfer facility (ICTF) at a location approximately 5 miles from their port terminals. The intermodal container transfer operations are currently conducted at rail yards in downtown Los Angeles, some 20 miles from the terminals. Depending on the specific routes, trucks that provide service between the rail yards and the terminals use portions of various state facilities, including State Routes 1, 5, 7, 10, 47, 91, 110, and 405, in addition to local streets. Many of these highways are already heavily congested during peak travel periods.

Both ports will share in the funding of the project's estimated $130 million cost. The Southern Pacific Railroad will also participate in the funding and will be the only railroad to use the facility. The Union Pacific and Santa Fe railroads, which also serve the ports, will continue to use their downtown rail yards. Approximately 54 percent of all rail container traffic in the port area is handled by Southern Pacific, and almost 35 percent of all international containers that pass through the ports is bridge traffic. Accordingly, the ICTF will handle about 18 percent of the ports' container traffic. The number of containers handled by the ICTF is projected to be 136,900 TEUs in 1985 and 315,000 TEUs in 1990. The capacity of the ICTF will be increased in three phases to accommodate predicted demand. The first phase is to begin in 1983-1984 and the third phase in 1996.

San Francisco Bay Area

The need for improved intermodal facilities is becoming apparent in the San Francisco Bay area. This need has been analyzed by the Metropolitan Transportation Commission and the Bay Conservation and Development Commission and is addressed in their seaport plan.

The majority of future terminal developments planned for Bay area ports will serve container cargoes. Approximately 14 new container berths are planned for Bay area ports during the 1980s. Currently 25 percent of the region's nonlocal container cargo is moved by rail. Most of these intermodal shipments require truck transfers of containers between port terminals and rail yards. Several of the planned Bay area development proposals are designed to improve rail access to container terminals and reduce truck transfer distances.

Coal and Grain Movements

Although there is substantial disagreement among forecasters regarding future export levels, coal and grain shipments from West Coast ports are expected to increase significantly. Historically, coal shipments from western U.S. ports have been minimal, but demand by Pacific Rim nations may soon produce substantial coal export tonnages as these nations shift from oil to coal for certain uses and seek to diversify their energy sources.

In southern California the ports of Los Angeles and Long Beach are expanding their existing facilities and proposing new ones. In northern California the ports of Richmond, Redwood City, Sacramento, and Stockton also are studying new coal export terminal projects. A total of 19 West Coast port areas are being analyzed as potential coal terminals (5). Although many ports have plans for coal export facilities, it is expected that foreign demand will warrant only 2 or 3 major West Coast facilities.

Export levels of grain from West Coast ports are projected to rise during the 1980s, although these levels are not expected to increase as rapidly as coal. Exports of U.S. grain rose by 150 percent between 1970 and 1979. Although year-to-year export levels vary because of changes in harvest volumes, exchange rates, and other variables, they are expected to increase steadily over the long term. Currently, no California port has proposed construction of a major new grain export facility (6).

Rising levels of coal and grain exports from California will generate increased rail traffic through the urbanized regions adjacent to the ports. When added to the increased container rail traffic from development of intermodal facilities near port terminals, the combined effect may be significant. Many of the transportation impacts associated with greater port activity will be rail rather than truck related.

IMPACTS OF INCREASED PORT ACTIVITY IN THE LOS ANGELES REGION

The forecasted increases in international trade, especially that related to containerized cargo, coal, and grain, will have significant impacts on the transportation systems that provide access to California ports. In addition to these transportation impacts, higher levels of port activity will also result in environmental, economic, and energy impacts to port regions.

The Los Angeles region adjacent to the major ports of Los Angeles and Long Beach was chosen to illustrate the impacts that increased international trade through these ports will have on the transportation systems in this highly urbanized region. The implementation of plans to construct an ICTF provides the opportunity to evaluate the transportation, environmental, economic, and energy impacts of such a facility.

The increase in port activity will affect the transportation network in the region around the ports of Los Angeles and Long Beach. These effects will be somewhat more complicated than those on many other regions because of the interrelated nature of the multimodal port access network.

Highway Impacts

A significant percentage of all goods moving through the ports of Los Angeles and Long Beach are transported by nonhighway modes. Liquid petroleum products, which constitute approximately 50 percent of the ports' cargo tonnage, are transported primarily by pipeline. Many bulk goods, including the growth commodities (coal and grain), are delivered by rail directly to terminals. In addition, the proposed ICTF will reduce container truck transport to some degree. Nevertheless, the truck mode remains an important factor in port freight movement.

The proposed ICTF will result in a 90 percent reduction in container truck miles traveled for approximately 18 percent of the container trucks moving through the ports of Los Angeles and Long Beach. Virtually all trucks that serve the ICTF will use the Terminal Island Freeway (SR-47). If non-ICTF traffic levels on this highway remain unchanged, total traffic on the facility will increase.

Container truck traffic on port access highways is expected to increase even if the ICTF is constructed. As indicated previously, the state facilities subject to increased container traffic include State Routes 1, 5, 7, 10, 47, 91, 101, 110, and 405. Many of these highways are already heavily congested during peak travel periods.

Despite the ICTF, approximately 82 percent of port containers will still be transported on highways, including those that connect the ports with the downtown rail yards. Because the total number of container TEUs through both ports is predicted to increase from 1.2 million in 1982 to 3.1 million in 1990, highway impacts could be significant. In addition, should non-ICTF trucks be restricted from using the section of SR-47 between the ports and the ICTF, they would then travel on segments of SR-7 and SR-110. In any case, the annual number of non-ICTF-routed container TEUs moved on port access highways is expected to increase by 133 percent, from 1.2 million in 1981 to 2.8 million by 1990. Considering the existing traffic levels on some portions of these highways, especially SR-7 and SR-405, peak-hour traffic problems in this region may well be exacerbated by future container truck traffic alone.

In addition to container traffic, other truck movements through the ports of Los Angeles and Long Beach may well increase during the 1980s. Total volumes may vary yearly, but long-term average increases in both commodity and port support trucks are expected.

Rail Impacts

Increased movements of coal and grain plus the operation of the ICTF will generate substantial rail impacts to the transportation network around the ports. Highway-rail conflicts at highway grade crossings are one important impact; mass transit, environmental, and energy impacts also need to be considered.

Highway-Rail Crossing Impacts

The transportation network around the port region contains numerous crossings of rail lines and roadways. Between the port terminals and its downtown rail yard, Southern Pacific's San Pedro line encounters 90 crossings, 82 of which are at-grade; between the rail yard and the site of the proposed ICTF, the San Pedro line has 78 crossings, 70 of which are at-grade. The Union Pacific's line contains 78 crossings between its rail yard and the port terminals, with 60 of them at-grade. The Santa Fe line contains 110 crossings between its downtown yard and the terminals, 94 of which are at-grade. Except for the San Pedro line crossing at SR-1, all state facilities are grade separated.

The specific types of protective devices vary among the at-grade crossings. Gate devices, which provide physical barriers for vehicular traffic, are installed on 100 of the 236 crossings. The Santa Fe line has 81 gated crossings (86 percent) on its at-grade facilities. Union Pacific has 14 (23 percent) gated crossings, and Southern Pacific has 6 (7 percent). All other at-grade crossings are protected only by visual and audible signals such as swinging signs (wig wags), flashing lights, signs, or combinations of these devices.

Highway traffic volumes vary widely on facilities with at-grade crossings. Six highways have average daily traffic (ADT) volumes of more than 30,000; 22 have daily volumes between 20,000 and 30,000; and 39 have volumes between 10,000 and 20,000. The at-grade crossing on SR-1 has an average daily volume of 35,000 vehicles. Rail volume varies also, but accurate counts are not readily available (7).

The large number of grade crossings indicates that increased rail movements, especially long slow coal trains, may result in longer traffic delays, greater use of state highways with grade-separated crossings, more problems with emergency vehicle response times, and greater accident potentials.

The California Public Utility Commission (PUC) establishes grade-separation project priority. The priority criteria emphasize safety over other factors, such as emergency vehicle needs and facilitation of traffic flows. Because grade-separation funding averages about $15 million annually, and projects often cost $4 and $5 million, few structures can be constructed.

Traffic Delays

Coal unit trains are usually composed of approximately 100 cars. When moving at 20 mph, traffic will be subjected to a 3.25-min delay at each nonseparated grade crossing. During this period automobiles and trucks may back up to such an extent that additional traffic problems, such as blocked intersections, could develop. If such delays become routine, traffic on local facilities may shift to state highways that are grade separated and thus add to peak-hour congestion.

Emergency Vehicles

Additional rail movements through urban regions will increase the number of delays encountered by emergency vehicles. Emergency vehicle delays at rail crossings could mean increased loss of life due to longer response times. Emergency response organizations may be required to develop duplicate facilities in order to avoid the grade-crossing problem.

Accident Potential

On a nationwide basis the accident rate at rail crossings has declined over the past two decades. This has been attributed to improved protection due to gates and other devices and from motorist education programs. The Southern Pacific and Union Pacific main lines that lead to the port terminals have a much lower percentage of gate-protection devices than the Santa Fe line. The large number of nongated crossings on the two lines, which are expected to carry containers and coal in large volumes, is a potential safety issue.

Mass Transit Project Impacts

Increased freight rail traffic in the region around the ports of Los Angeles and Long Beach may complicate development of a proposed Los Angeles to Long Beach light rail transit project. One proposal for a light rail system between these cities recommends use of Southern Pacific's Wilmington and East Long Beach branch lines. Increased port rail activity may require grade-separation structures where the lines used for light rail cross other main port freight rail lines. Grade-separation structures will add significantly to the construction and maintenance costs of the light rail project and may also affect the completion date.

Environmental Impacts

Noise

Rail movements generate noise impacts that affect local communities. The impacts vary with distance, train lengths, speeds, frequencies, and time of day. Unit trains that move coal, grain, and containers to the ports will travel at relatively slow speeds (15-25 mph) and contain between 50 and 100 cars. If train movements are scheduled at night to minimize traffic impacts, noise impacts would probably be more severe. Long, frequent trains traveling at high speeds during the night would have the most severe noise impacts. Some noise impacts are unavoidable. For instance, the California PUC requires that train whistles be blown before each at-grade crossing. Noise impacts may be mitigated by routing train traffic along the lines that pass through fewer residential areas.

Air Quality

The higher volumes of coal and grain movements to the ports of Los Angeles and Long Beach will result in increased train-related air emissions, and the increase in container movements will result in higher levels of truck-related air emissions. Although operation of the ICTF should mitigate air quality impacts to some degree, rail-related emissions will increase. However, the net effect should be a reduction of certain pollutants (8).

Energy Consumption

The increased transportation of coal and other commodities to the ports of Los Angeles and Long Beach will result in higher levels of petroleum fuel consumption. However, operation of the ICTF may reduce fuel use associated with container traffic. Locating an intermodal transfer facility closer to port terminals will take advantage of the greater fuel efficiency of the rail mode. The ICTF will reduce truck mileage by about 19,500 miles/day. It is estimated that the facility will be responsible for an overall reduction of 79 percent in truck fuel consumed in the movement of containers between the ports and the Southern Pacific's trains.

Economic Impacts

Locating the container transfer facility closer to port terminals will reduce truck transfer costs in addition to highway maintenance expenditures. It is estimated that the ICTF will reduce truck transfer costs from the current $110 to only $35/container.

SUMMARY AND CONCLUSIONS

Increased goods movement through California ports will affect the transportation facilities that provide access to these ports. Many of the transportation impacts associated with the increased goods movement will be rail rather than highway related, but highway facilities will be subjected to higher volumes of truck traffic due to increased container and general freight movements, and more serious highway-rail conflicts will develop.

The landside transportation and environmental impacts associated with higher levels of activity at the ports of Los Angeles and Long Beach may be significant because they will affect highly urbanized areas and a complex and congested transportation network. Highway impacts include greater congestion, pavement damage, maintenance costs, safety problems, and facility improvement requirements. Rail impacts include additional delay and accident problems at grade crossings. Future mass transit projects may also be affected by increased port activity. Environmental problems include air quality deterioration, increased energy consumption, increased noise, and other community impacts.

The authority of the state and the Department over port activity is limited. There is no state agency that has overall responsibility for port development or operations. The Department's role is also limited, even though state facilities are directly affected by port activity.

The expected increases in goods movement through California ports and the concommitant transportation and other impacts will require a greater emphasis on port transportation planning by the Department. Port transportation planning can be improved by conceptually focusing on port areas as trip generators, developing port expertise, improving coordination between the Department and local entities (including the ports), and supporting measures that facilitate the efficient movement of goods through the ports.

Intermodal transfer facilities may alleviate some of the problems caused by an increase in container traffic through California ports by promoting a modal shift in the vicinity of the port. However, the benefits of this modal shift must be viewed in relation to the cumulative impacts of increases in container, coal, and grain rail traffic. The potential for major transportation impacts at grade crossings resulting from this increased rail traffic warrants particular concern.

Federal, state, local, and private-sector funding for improved safety measures at these crossings is extremely limited, and the commitment of these resources is constrained by other priorities. Both the public and private sectors are not prepared and, to a certain extent, are precluded from making improvements until such time as safety or delay problems at grade crossings become an immediate and critical public or political issue.

Increased port activity may therefore lead to a reconsideration of the roles that public and private agencies play in the planning and development of port access facilities. Existing organizational and funding arrangements may not be adequate under conditions of unprecedented levels of goods movement through highly urbanized port regions. However, if transportation planning is responsive to the changing situation in port regions, the benefits of international trade and modal shifts can be realized, and adverse transportation and other impacts can be mitigated.

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The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of Caltrans, the State of California, or FHWA. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. California's International Trade. Security Pacific Bank, Los Angeles, 1982, p. 3.
2. J.A. Smith. The Common Denominator for Intermodal Transportation. Transport 2000, Sept./Oct. 1981, pp. 36-37.
3. Intermodal Container Transfer Facility--Feasibility Study. Ports of Los Angeles and Long Beach, Los Angeles, July 1981, p. 4.
4. Harbor Terminals--Directory of Specifications. Port of Oakland, Oakland, CA, Jan. 1981, p. I-16.
5. Coal Export Capacity Could Exceed Demand by 1985, MarAd Warns. Traffic World, July 27, 1981, p. 29.
6. W.W. Gallimore. Transporting Food and Agricultural Products. In Agricultural Food Policy Review, U.S. Department of Agriculture, April 1981, pp. 82-92.
7. Form J, Rail-Highway Crossing List. California Public Utilities Commission, Sacramento, 1981.
8. Intermodal Container Transfer Facility, Draft Environmental Impact Report. Ports of Los Angeles and Long Beach, Los Angeles, June 1982, pp. 3-12.

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Direct Costs of Maintaining a Regulatory Structure: A Case Study of One Canadian Jurisdiction

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The majority of research completed in North America has been directed to the study and analysis of the cost of trucking regulation relative to the rate structure. Little work has been completed on the analysis of the direct cost of regulation as it relates to carriers, shippers, government, and regulatory bodies. The results of a study of the direct costs of maintaining a regulatory structure in the for-hire sector of the trucking industry are discussed. The province of New Brunswick, 1 of 10 Canadian jurisdictions, was used for the case study. The data obtained from a series of mailed questionnaires were used to analyze the direct costs incurred by carriers and shippers. In addition, their views regarding the regulatory process were studied. The primary focus was on the costs incurred in making application for a motor carrier license in the case study area. Personal interviews were conducted in an effort to quantify the direct cost associated with the Motor Carrier Board and related government agencies. The direct cost of maintaining the motor carrier regulatory process in the study area did not appear to be of significance to shippers and carriers that have secured operating rights. In addition, the provincial administrative process does not appear to impose a financial burden on general revenues. Carriers that responded to the survey heavily favored continued regulation of the for-hire trucking industry. General freight and specific commodity carriers were also found to be in favor of ensuring that rates within the province of New Brunswick remain unregulated.

During the past two decades considerable research has been devoted to the question of the costs imposed on society by the regulation of transportation. The majority of this research has focused on the question of the deadweight welfare losses associated with value-of-service pricing and the consequent misallocation of traffic among competing modes. Felton's research (1) is an exception to this practice. Felton's work focused on the costs to the Interstate Commerce Commission arising from motor carrier regulation.

By contrast, one aspect of the cost of regulation that has received comparatively little attention in the literature is the direct cost imposed on carriers, shippers, and government agencies by the regulatory processes. Such costs are real, and yet they are hidden from the broader types of research initiatives suggested above. For example, with inverse elasticity marginal cost pricing, the direct costs of regulation, which are insensitive to short-run changes in output, do not form part of the charged rates. Thus they are excluded from estimates of the costs of regulation.

These direct costs must be estimated separately, and one approach to that estimation is the subject of this paper. A case study approach to the problem has been adopted by focusing on a single Canadian jurisdiction--the province of New Brunswick. Nevertheless, with appropriate adjustments to account for institutional differences, the research methodology developed can be adapted without difficulty to any other jurisdiction.

In order to estimate the total costs of regulation to society, these direct costs must be incorporated into the other analyses. The total social costs of regulation would then be the sum of the deadweight welfare losses; the costs of the regulatory agency; and the direct costs of regulation to carriers, shippers, and other government agencies. Only the direct costs of regulation are addressed in this paper.

REGULATORY AGENCY

Motor carrier regulation in the province of New Brunswick is carried out by the New Brunswick Motor Carrier Board. In both intraprovincial and extraprovincial trucking, regulation is limited to the control of entry into the industry. Although statutory authority does exist to permit the Motor Carrier Board to influence the rates charged by for-hire truckers, this power is not used. In practice, rates need only be filed with the Motor Carrier Board.

The entry process is initiated by the application of the potential entrant, who is required to give formal notice of his intentions to the public. This requirement is met by publishing a notice in the Royal Gazette. Publication must be made in two successive issues at least 21 days before a hearing. The hearing of all applications for operating authority, with the exception of those for furniture licenses where there are no objectors, is obligatory. The Board is not empowered to waive a hearing in any other instance. The hearings are quasi-judicial in nature.

The activities of the New Brunswick Motor Carrier Board for the study period are given in Table 1. The data reveal that the ratio of applications granted to applications made increased from 71 to 81 percent over the 3-year period. During this period there was only a modest increase in the number of objections filed. Based on this information, it appears that the entry control process in the study area is not greatly restrictive.

Hearings at which there are no objectors are informal in character. This is not the case where there are objectors. The issues addressed are the same as found elsewhere: service of existing carriers, extent of the market, and the financial ability of the potential entrant. From statements given to the Law Reform Commission, apparently larger firms tend to object "only if the application poses a definite threat. On the other hand, other firms may appear regularly with the intent of impressing on the Board the limited market" (2, p. 34). The Law Reform Commission views the role of

Table 1. Summary of Motor Carrier Board activities for selected fiscal years.

Activity	No. of Cases by Fiscal Year 1977-1978	1978-1979	1979-1980
Applications for new operating authority	214	230	241
Applications opposed	72	79	86
Applications granted	154	179	195
Other dispositions[a]	60	51	46
Temporary operating authorities granted	2,070	2,115	1,880

Notes: Data are from annual reports of the New Brunswick Motor Carrier Board for various years.
The ratios for applications granted per application received are as follows: 1977-1978 = 71 percent, 1978-1979 = 79 percent, and 1979-1980 = 81 percent.

[a]Other dispositions include denied, withdrawn, or set over to a later date.

the objector as extremely important in proceedings. It is of the opinion that "as the Board requires only limited filings and as the Board relies primarily on the evidence presented during the hearing, the objectors raise relevant arguments concerning the carrier's financial status, capacity and the necessity for the service" (2, p. 34).

Decisions of the Board appear to be rendered quickly. In most instances the decision is rendered either at the hearing where the application is presented or at the next Board meeting.

The purpose of this paper is to estimate the direct costs associated with the regulation of entry into the New Brunswick for-hire trucking industry. Only the general freight and specific carriers are considered in the analysis. Carriers of furniture are excluded.

RESEARCH METHODOLOGY

After a review of the literature on the subject revealed that little research on the specific topic had been completed, it was decided to adopt a case study approach to the problem. New Brunswick was selected as the study jurisdiction, and information concerning the regulatory activity of carriers and shippers was compiled for the period 1977-1978 through 1979-1980. Following the development of the survey methodology, a questionnaire was designed and pretested to ensure that the necessary information was available and could be collected with an acceptable level of reliability. The data were then collected, processed, and analyzed.

Survey Development

After discussions with both industry representatives and government authorities, it was determined that attention should be focused on four groups. The first was the for-hire truckers. Both private trucking and carriers of exempt commodities were excluded from the analysis. This decision was based on the fact that, because neither group requires operating authority, they are therefore not involved in the regulatory process. Shippers domiciled in the province of New Brunswick were also included in the analysis, as this group has a record of appearing before the Board on their own initiative. Consumer groups, however, were excluded, because they have not played a role (to date) in the regulatory process in the study area. The other groups included in the survey were the Motor Carrier Board and the Policy Division of the New Brunswick Department of Transportation. This latter division was included because it provides services to the Board and therefore incurs direct costs as a consequence of the existence of the regulatory process.

Questionnaire Design

Because of resource limitations the research was carried out through a mail questionnaire that solicited details of the various costs incurred by firms in connection with their appearances before the New Brunswick Motor Carrier Board. The initial questionnaires were pretested on a sample of shippers and carriers and then revised with the assistance of experienced staff of the carrier and shipper agencies. The revised questionnaires were then distributed to a sample of shippers and carriers.

Sample Size and Response

The shipper sample was drawn from the firms listed in the New Brunswick Manufacturers and Products Directory (3). Only firms that had 50 or more employees were included in the sample because past records indicated that smaller firms would have not had any dealings with the Motor Carrier Board. Questionnaires were sent to 183 firms drawn from this list. Of these, 18 percent were returned--a return ratio generally regarded as acceptable for this type of survey.

The carrier sample was based on information contained in the Atlantic Provinces Transportation Directory (4). This directory contains a complete listing of licenses issued by the motor carrier boards of the four Atlantic Provinces. In addition, it provides a complete listing of licenses by province broken down into general freight carriers and specific commodity carriers. All carriers of both types holding a license from the New Brunswick Motor Carrier Board were sampled. In total, 321 questionnaires were mailed to for-hire carriers. In both cases the return ratio was within the acceptable range based on the 100 percent sample population.

Data Processing and Analysis

Detailed analysis on the responses focused primarily on the direct costs of the regulatory process. Shipper and carrier views of the regulatory process were also considered.

It appears that the sample size and investigative technique were adequate. Both shipper and carrier responses were representative of those two groups.

DIRECT COSTS OF NEW BRUNSWICK MOTOR CARRIER REGULATION

The results of the analysis of the direct costs of motor carrier regulation in the province of New Brunswick are presented in this section. The focus is on the most costly aspect of the regulatory process, i.e., the direct costs incurred by the carriers themselves. The costs of seeking new operating authority and objecting to the grants of such authority are considered separately. Data are also presented separately for general freight carriers and specific commodity carriers. Attention is focused on the costs incurred by shippers in the regulatory process in those instances where they appear on their own initiative. Shipper costs, where they appear in the role of carrier witnesses, are included in carrier costs. Next, the direct costs incurred by the government in connection with motor carrier regulation are considered. Finally, the total costs of all participants are totaled.

Direct Regulatory Costs to Motor Carriers

The initial step in estimating the direct regulatory costs to motor carriers was to focus on the number of appearances before the Motor Carrier Board. Data on appearances for the study period are given in Table 2 and broken down by type of appearance and type of carrier.

The data in Table 2 indicate that specific commodity carriers accounted for the largest number of applications during the study period. These applications were for new operating authority and accounted for more than 80 percent of the applications in the 3-year period. By contrast, general freight carriers sought new operating authorities infrequently. The roles are reversed when oppositions to new licenses are involved. On balance, it appears that general freight carriers account for more than three-quarters of the objections to new licenses. Specific commodity carriers objected infrequently. Such a result is to be expected intuitively, because any grant of specific commodity authority would have adverse impacts on the general freight carriers.

Table 2. Carrier appearances before the Motor Carrier Board.

Carrier Type	No. of Carrier Appearances by Year		
	1977-1978	1978-1979	1979-1980
Applications for new operating authority			
General freight	6	7	7
Specific commodity	184	193	210
Furniture carriers	24	30	24
Total	214	230	241
Oppositions to new operating authority			
General freight	206	257	265
Specific commodity	27	20	26
Furniture carriers	54	40	52
Total[a]	288	316	344

Note: Data are from annual reports and other sources of the New Brunswick Motor Carrier Board.

[a]Columns may not add to total because of rounding.

Table 3. Direct carrier costs of New Brunswick motor carrier regulation.

Carrier Type	Direct Carrier Costs ($) by Year		
	1977-1978	1978-1979	1979-1980
General freight carriers			
Seeking authority	2,868	5,131	6,202
In role of objector	128,544	131,327	218,095
Total	131,412	136,458	224,297
Specific commodity carriers			
Seeking authority	148,029	143,310	221,748
In role of objector	8,694	10,220	18,226
Total	156,723	153,530	239,974
Both types of carrier			
Seeking authority	150,897	148,441	227,950
In role of objector	137,238	141,547	236,321
Total	288,135	289,988	464,271

The second step in the analysis was to estimate the average cost per appearance by type of appearance and type of carrier for each year in the study period. The data for general freight carriers appearing before the Motor Carrier Board are given in the table below:

Fiscal Year	Avg Cost for General Freight Carriers ($)	
	Seeking New Authority	In Role of Objector
1977-1978	480	625
1978-1979	730	510
1979-1980	885	825

The data for specific commodity carriers appearing before the Motor Carrier Board are as follows:

Fiscal Year	Avg Cost for Specific Commodity Carriers ($)	
	Seeking New Authority	In Role of Objector
1977-1978	930	320
1978-1979	840	510
1979-1980	1,275	710

Data were collected on a variety of cost categories in the study, but in the interests of brevity only the total costs per appearance are presented. At the disaggregate level, the overwhelming proportion of the costs were related to legal fees and the costs of witnesses.

General freight motor carriers incurred costs of between $480 and $885/appearance before the New Brunswick Motor Carrier Board. The costs were higher for specific commodity carriers, ranging from $930 to $1,275. In the first year for which data were available, the objecting role was the more expensive element. It appears that the average appearance costs of both activities are increasing more rapidly than inflation; therefore, the real cost is rising.

A similar approach was used to assess the cost to specific commodity carriers. Carriers were asked to list their regulatory costs by type of cost for each year of the study period. These costs were then aggregated; the data are presented in the above in-text table. As in the previous case, the greatest proportion of the cost is accounted for by legal and witness costs. The data suggest that the specific commodity carriers spend considerably more money in seeking new authority than they do in objecting to other applications. As before, although a definitive statement is not possible, it does appear that the real cost per appearance for this category of motor carrier is increasing.

The direct cost to each type of carrier of the motor carrier regulatory process is found by combining the data in Table 2 with the data in the in-text tables on costs to general and specific commodity carriers. These direct cost estimates are given in Table 3. The results given in the table are predictable from the previous discussion. General freight carrier direct costs are mostly incurred in the role of objector. Specific commodity carrier costs are mostly incurred when seeking new operating authority. The latter group tends to incur more direct cost than the former, although over the study period the gap narrowed considerably. For the first 2 years of the study period the combined direct regulatory costs were virtually constant. They increased sharply in the final year. The data suggest that this was because of increased activity in seeking new authority on the part of the specific commodity group matched by increased opposition from the general freight carriers.

A study completed for the Economic Council of Canada in connection with the Regulation Reference by Bonsor (5) estimated the direct cost of regulation for each of the Canadian provinces for the year 1977-1978. By using a different methodology, this study estimated that in that year the New Brunswick direct costs were $163,000, with lower and upper bounds of $122,000 and $240,000. The present study estimates that, for the same year, the direct regulatory costs were $288,135. The present estimate is, then, about 20 percent above Bonsor's upper bound. A brief discussion of these disparate results is necessary.

First, the Bonsor estimate is based on the perceived costs of regulation on carriers as a percentage of their gross operating revenues. The resulting percentage is then multiplied by the Statistics Canada estimate of carrier revenue to obtain estimates of direct regulatory costs. (Note that Bonsor made an adjustment to total revenues by assuming that 15 percent of the published figure was accounted for by nonregulated movements. The current approach builds from average appearance costs from the carriers and the actual appearances before the Board.)

Second, the Economic Council study sampled only 40 firms in the Maritime Provinces, and received 12 responses from New Brunswick. The current investigation focused on carriers with New Brunswick operating rights, regardless of the location of their head office.

Table 4. Annual Motor Carrier Board revenue and expenditure.

	Annual Motor Carrier Board Expenses ($)		
Revenue and Expenditure	1977-1978	1978-1979	1979-1980
Carrier plate for revenue	272,800	393,900	388,400
Expenditures			
Other acts	40,000	40,000	40,000
Motor carrier activities	137,300	143,300	154,600
Total	177,300	183,300	194,600
Excess of revenue	135,500	250,600	233,800

Note: Data were provided by the New Brunswick Motor Carrier Board.

Finally, the Council's study resulted in 8 of the 12 responses coming from class I carriers. The sample response in this study is more widely distributed and thus more representative of the industry. On balance, the current approach--building from the bottom with checks in the form of number of appearances as provided by the Motor Carrier Board--appears to be preferable. The Bonsor estimates understate the direct costs of motor carrier regulation in New Brunswick.

Direct Costs of Regulation to Shippers

Shippers become involved in the regulatory process in one of two ways: on behalf of a carrier applicant as an objector or in support of a carrier, or on their own initiative. Costs of the former activity are borne by the carrier in question because the shipper appears as the carrier's witness. These costs are therefore included in the estimates of carrier costs presented earlier. It is the cost of the latter activity, where the shipper appears on his own behest, that is of interest here. In this case, the shipper bears his own costs. Their inclusion in the analysis, therefore, does not involve any double counting of expenses.

Shipper direct costs of appearing before the New Brunswick Motor Carrier Board amounted to $200/appearance in 1977-1978. These increased to $250/appearance in the following year, and were the same in the final year of the study.

On the basis of the data available, shippers appear only infrequently on their own initiative. In 1977-1978, for example, New Brunswick shippers appeared on their own volition once in New Brunswick and five times elsewhere. The 1978-1979 data are identical with those of 1977-1978. In the final year of this study shippers appeared before the New Brunswick Motor Carrier Board on three occasions, and made five appearances elsewhere in Canada. Shipper activity in this role, although not substantial, does result in direct costs. These costs must be included in the direct costs of regulation. The shipper direct regulatory costs per appearance on their own initiative before the New Brunswick Motor Carrier Board were determined to be $200 in 1977-1978, $250 in 1978-1979, and $750 in 1979-1980. Total shipper direct costs are minor when compared with total carrier costs.

Nevertheless, such costs must be included for an accurate estimate of the direct costs of regulation. The fact that they are small in the case of this jurisdiction does not mean that they can be generalized.

Direct Costs of Regulation to Government

The final aspect of direct costs considered was the cost incurred by the government in maintaining regulation. Two aspects of these costs were identified. The first cost incurred by government departments was in the provision of services to the regulatory agency. The other component is the direct cost of operating the regulatory body.

With respect to the former item, there are a variety of costs that exist. Among them are the costs of enforcing the Motor Carrier Regulations, including the prosecution of violations. It has not been possible, due to the reliability of the data base, to make these cost separations. One service provided to the Board that could be readily identified and cost related to the Policy Division of the New Brunswick Department of Transportation is the maintenance of several computerized files for use by the Board. Information provided by that government branch indicated that the annual cost of providing this information was on the order of $1,200. This amount must be added to the other direct costs estimated above.

The final cost element identified was the costs of operating the New Brunswick Motor Carrier Board itself. A summary of the direct costs associated with maintaining the regulating agency is given in Table 4.

The data in Table 4 reveal not only the direct cost of operating the Motor Carrier Board but also the subsidy to other activities of government implicit in the fact that the Board was in a surplus position in all 3 years of the study period. There is some question as to whether the direct costs of operating the Board or the carrier plate fee revenue should be the relevant cost incorporated into the analysis. On balance, it appears best to employ the latter, for this is the escapable cost. It is escapable in the sense that this is the cost burden that would be removed from carriers should a decision be made to move to a deregulated environment. For the initial year of the study, the direct costs of this component were $272,800. The total increased substantially to $393,900 in the following year because of an increase in plate fees. In the final year of the study this cost component amounted to $388,405.

Total Direct Costs of Regulation

The total direct costs of regulation are the sum of the cost elements discussed. That is, total direct cost of regulation comprises the direct regulatory costs of motor carriers, shippers, and the two government sectors. These costs are given in summary form in the table below:

	Total Direct Regulatory Costs ($) for New Brunswick by Year		
Group	1977-1978	1978-1979	1979-1980
Motor carriers	288,135	289,990	464,270
Shippers	200	250	750
Government	274,025	395,110	389,625
Total	562,360	685,350	854,645

During the study period the total direct cost of the regulatory structure in New Brunswick rose from $562,000 to about $855,000, an increase of 7 percent. In the aggregate, however, they remain relatively small. In the first year of the study, for example, these direct costs of regulation amounted to less than one-half of 1 percent of the revenues earned by for-hire truckers in New Brunswick.

SUMMARY AND CONCLUSIONS

A frequently neglected aspect of the costs of regulation--the direct costs of maintaining the regulatory structure--was examined in this paper. A case study approach to the problem was adopted, and the Canadian province of New Brunswick was chosen as the jurisdiction of investigation. Entry into the motor carrier industry in New Brunswick is controlled, although rates are not. The relevant costs are those associated with entry control. Both a survey and a questionnaire were developed, pretested, and sent to a sample of shippers and carriers.

The study revealed that the two types of carriers have differing roles in the regulatory process. The specific commodity carriers are generally concerned with acquiring new operating authority, whereas general freight carriers are mainly involved in objecting to new applications. Costs for each type of carrier for each type of activity were developed. Overall, costs ranged from $288,000 to $464,000 during the study period. These are higher than one other available estimate for this Canadian jurisdiction, but the approach taken in this study, being disaggregated in nature, provides more accurate cost estimates.

The study also revealed that, in New Brunswick, the shipper plays only a minor role when acting on his own behest. The shipper more often appears in support of a carrier. Costs to the government due to this process are more than offset by motor carrier plate fee revenues; therefore, carriers are, in effect, carrying more than the entire public cost burden of the regulation.

Total direct costs of maintaining the regulatory structure in New Brunswick ranged from $562,000 to $855,000 during the study period. In the aggregate, this total cost amounts to less than one-half of 1 percent of revenues earned by for-hire truckers in the jurisdiction.

REFERENCES

1. J. Felton. The Costs and Benefits of Motor Truck Regulation. Quarterly Review of Economics and Business, Vol. 18, No. 2, 1978, pp. 7-20.
2. The Motor Carrier Board. Law Reform Commission, New Brunswick Department of Justice, Fredericton, New Brunswick, Canada, 1979.
3. New Brunswick Manufacturers and Products Directory. New Brunswick Department of Commerce and Development, Fredericton, New Brunswick, Canada, 1980.
4. Atlantic Provinces Transportation Directory. Atlantic Provinces Transportation Commission, Moncton, New Brunswick, Canada, 1979.
5. N.C. Bonsor. The Impact of Regulation on For-Hire Highway Carriers. In Regulation Reference--Volume II: Studies in Trucking Regulation, Economic Council of Canada, Ottawa, Ontario, Canada, 1980.

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