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

FINDINGS

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

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

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

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

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Abridgment

Truck Forecasts and Pavement Design

ROBERT J. HAGE

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

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

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

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

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

VARIABILITY IN TRUCK VOLUMES

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

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

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

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

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

VARIABILITY IN TRUCK FACTORS

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

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

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

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

TRUCK FACTOR VALIDITY

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

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

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

OTHER AREAS OF UNCERTAINTY

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

Lane Distribution

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

Other Variables

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

CONCLUSIONS

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

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