

THE TRANSPORTATION RESEARCH BOARD'S "TURNER PROPOSAL" STUDY

Joseph R. Morris
Transportation Research Board, National Research Council
2101 Constitution Avenue N.W.
Washington, D.C. 20418

Prepared for

Second International Symposium on
Heavy Vehicle Weights and Dimensions

Kelowna, British Columbia
June 18-22, 1989

The Turner Proposal study is sponsored by the National Cooperative Highway Research Program. The views expressed in this paper are those of the author and do not necessarily reflect those of the National Research Council, the NCHRP, or the committee conducting the study.

ABSTRACT

THE TRANSPORTATION RESEARCH BOARD'S "TURNER PROPOSAL" STUDY

Joseph R. Morris
Transportation Research Board

A Transportation Research Board committee, at the request of the American Association of State Highway and Transportation Officials, has been evaluating a proposal for a new approach to regulating truck sizes and weights on U.S. roads, which promises to reduce road wear while increasing freight productivity. Truckers would gain productivity through greater weights and lengths. Operators who chose to operate at these limits would be required to add enough extra axles to their vehicles to reduce the load carried by each one, thus reducing pavement wear. This approach, known as the Turner Proposal, was advocated in an address to AASHTO by former Federal Highway Administrator Francis Turner.

The committee is analyzing impacts on productivity, bridges, safety, traffic, and pavements for various vehicle options; and will recommend policy actions. The prototypes being analyzed include a seven-axle tractor-semitrailer and seven-, nine-, and 11-axle doubles with various trailer coupling arrangements.

The committee will not publish findings until 1990, but preliminary results of research on impacts can be reported. The productivity analysis indicates that the prototypes would be attractive to bulk commodity haulers, and that Turner doubles could replace part of the existing less-than-truckload freight traffic in shorter doubles. Logistical difficulties using doubles and complications of operating fleets of mixed equipment types would limit use in truckload sectors. Pavement savings would be substantial. Current practice would dictate posting of thousands of bridges on all road systems if the heavier prototypes came into use. Bridge considerations may be the principal limit on the size of new trucks and the extent of their use. Safety and traffic impacts of the Turner doubles would be similar to those of existing short doubles.

The committee is now deciding what policy recommendations are supported by these findings. It must decide to endorse or discourage the overall concept; what routing restrictions would be necessary; whether taxation should reflect differences in highway costs between Turner and current trucks; and what specific equipment restrictions would be cost-effective in reducing adverse impacts.

THE TRANSPORTATION RESEARCH BOARD'S "TURNER PROPOSAL" STUDY

The American Association of State Highway and Transportation Officials has asked the Transportation Research Board to evaluate a proposal for a new approach to regulating the sizes and weights of trucks using U.S. roads. The proposal promises to reduce road wear caused by truck traffic while simultaneously increasing the productivity of freight transportation. Truck operators would gain productivity through higher allowable gross weights, but would add enough extra axles to their vehicles to reduce the load carried by each one. Highway pavements would last longer because of the decreased axle loads. This approach to size and weight regulation was advocated in a 1984 address (1) to AASHTO by former Federal Highway Administrator Francis C. Turner, and has come to be known as the Turner Proposal. The study is directed by a committee that includes public and private transportation administrators, representatives of the driving public, and experts in the relevant engineering and economic disciplines. The committee will report its conclusions in March 1990. This paper gives the background of the study, describes preliminary technical findings, and discusses policy issues that would arise in implementing Turner's proposal.

In the U.S., all the states and the federal government regulate truck dimensions, to balance the economic benefits of efficient freight transportation against the costs that trucks impose in the form of wear on roads and exposure to the risk of accidents. Size and weight regulations historically have been subject to nearly continual incremental revision, and the vehicles that have resulted probably are far from ideal from the standpoint of highway wear, freight productivity, or safety. Highway engineers are dissatisfied because heavy truck traffic accounts for a large fraction of road wear. Throughout the country, roads and structures are not standing up well to the loads they must carry, and highway agencies lack the funds to perform more frequent maintenance. At the same time, motor carriers and shippers point out, economic analyses have repeatedly concluded that the benefits from reduced freight costs of allowing larger trucks greatly outweigh the costs of repairing the added road wear that larger trucks could cause; and safety advocates and the public at large are greatly concerned that trucks are involved in a disproportionate share of the most severe highway accidents.

Thus, the situation today is that substantial economic benefits could be gained through use of larger trucks, but chronic funding shortages in state highway maintenance programs and fears of the hazards of larger trucks stand as obstacles to attaining these benefits.

Part of the solution to this impasse must come through improved size and weight regulation, addressing both the urgent need for more efficient highway transport and the growing concern with truck safety. A better approach to regulation would replace the older incremental approach with an optimization perspective, seek positive means to mitigate the road wear and accident hazards associated with large trucks, and emphasize basic vehicle design improvements as a method of attaining these goals.

BACKGROUND TO THE TURNER PROPOSAL

The sections below will describe the scope of the Turner proposal study, historical trends in highway conditions and finance that motivated the

proposal, an earlier feasibility study of the proposal, and the issues that remain to be resolved by the current study.

Study Scope

Turner's proposal, the study's starting point, was as follows:

1. reduce legal single axle loadings to a maximum of 15,000 lb and tandem axles to 25,000 lb;
2. allow greater vehicle lengths; and
3. raise maximum gross weights to as much as 112,000 lb.

Turner proposed that these limits apply to all trucks, but where axle weights could not practically be brought down to the indicated maximums that special permits and higher annual registration fees would be assigned. His example of a truck meeting the proposed limits was a double trailer combination with four tandem axles and a gross weight of 112,000 lb, which he estimated would reduce pavement wear per payload ton-mile by two-thirds compared with a 80,000 lb five-axle tractor-semitrailer.

While retaining the basic concept of a truck that is both more productive and less wearing on pavements, the current study's scope is broadened beyond Turner's original proposal in three ways:

- o It is considering a voluntary version of the proposal, under which truckers would choose whether to comply with the new weight regulations or continue to follow the previously existing rules.
- o It is considering trucks for which the total weight would exceed the limits imposed by a provision of the existing federal regulations intended to prevent trucks from overloading bridges (the provision known as the bridge formula). Turner's original proposal was constructed so that his example truck would satisfy the bridge formula.
- o It is considering a range of possible values for the axle weight and length limits and other vehicle characteristics, to try to find the truck that offers the best overall performance, considering productivity, pavement, bridges, and safety.

The study entails a comprehensive evaluation of all anticipated benefits and costs of introducing vehicles fitting the Turner prescription into nationwide use. Impacts are expected in four areas: highway pavement wear, bridge deterioration and construction costs, highway safety, and freight transportation costs. The steps of the study's procedure are as follows:

1. Prototype Turner trucks and regulatory options to be evaluated have been defined. These are specifications for hypothetical vehicles that fit alternative regulatory limits.

2. The extent of use of the prototype vehicles and the net changes in freight costs resulting from this use are being estimated.
3. The effects of the predicted traffic on pavement condition and maintenance and construction costs are being estimated.
4. Effects of predicted changes in truck traffic on bridge condition and maintenance and construction costs are being estimated.
5. Effects of predicted traffic changes on safety are being estimated.
6. On the basis of the impact estimates, the committee will determine its recommendations for changes in truck regulations.

Trends in Highway Condition and Cost and in Truck Freight

Turner's proposal arose from the frustration of highway engineers pressed by public demands for better road conditions, a growing maintenance backlog, and a shortage of resources for maintenance; and at the same time compelled, because of the economic importance of trucking, to accommodate larger truck sizes and growing volumes of traffic of the heavy trucks that have the greatest responsibility for road wear. In outline, the circumstances lying behind the proposal are the following.

Accelerating Pavement and Bridge Costs

The rate of wear of pavements and bridges on the U.S. road system has been accelerating. Since the mid 1970s, pavement condition has changed little, with about 10 percent of main rural roads in immediate need of pavement repairs in any given year (2) (that is, with a Serviceability Index--a measure of the extent of cracks, ruts, and other damage in the pavement surface--of 2.0 or less, or 2.5 on Interstates). However, maintaining the status quo has been at the cost of a great increase in expenditures for pavements. For example, in 1986 dollars, state agencies spent \$300 million for pavement reconstruction and rehabilitation in 1981 on rural Interstates and other arterials, and \$1.1 billion in 1986 (3).

Pavement wear is a problem because travel costs more on rough pavement. Travel times and vehicle operating costs increase sharply as pavement deteriorates: up 15 cents/mi for a car and 40 cents/mi for a tractor-semitrailer on very poor pavement as compared to new pavement (4). Deferring pavement repair also eventually increases the cost of repairs once they are made and raises the cost of maintaining the road over its entire life. In one estimate (5), incremental increases in spending for rehabilitation and reconstruction of the Interstates would have a rate of return of 40 percent, from reduced travel times and vehicle operating costs. Such a high rate of return is an indicator of the magnitude of underspending for highway improvement.

Efforts to maintain bridge condition have been less successful (2). From 1982 to 1986, rural Interstate bridges judged to be structurally deficient or obsolete according to federally defined standards grew from 900 to 1,500, 5.4 percent of the total, in spite of large increases in spending for bridge work in this period. (Turner trucks will not contribute to solving bridge wear problems.)

Growth of Truck Traffic

Pavement wear is strongly affected by the loads imposed by heavy trucks. Historically, the average weight of large trucks and the volume of large truck traffic have grown continuously. Between 1981 and 1986, combination truck traffic on rural Interstate highways grew 28 percent, from 21 billion to 27 billion vehicle-miles per year (3) (although this growth rate is exaggerated by the depressed economic conditions in the early 1980's). Trucks also have been getting heavier, and consequently the pavement-wearing impact of all traffic on rural Interstates doubled between 1976 and 1986 (3), as measured by equivalent single axle loadings (a measure equaling the number of passages of a standard axle that would produce the same pavement wear as the actual trucks using a road).

Economic Importance of Trucking

Although more and bigger trucks exacerbate highway maintenance problems, they also provide an economically vital service. Trucking is the principal freight transportation mode in the U.S., in terms of the cost of providing its services. Expenditures for intercity trucking are \$150 billion annually, 70 percent of the nation's freight bill (6). Thus marginal improvements in trucking productivity can have large economic benefits.

Past studies that looked at productivity gains and pavement and bridge wear costs from greater truck sizes and weights uniformly found that highway cost increases were overwhelmed by freight cost savings, with ratios of freight benefits to highway costs of 15:1 and 6:1 in 1969 and 1981 federal studies (7, 8), for example. These ratios were subject to an important qualification--pavements and bridges would have to be upgraded to carry heavier loads to achieve the full benefits predicted, and the cost of this upgrading might be beyond the means of highway agencies. According to the 1969 federal study (9), "any substantial increase in legal loads without a massive program to update, monitor, and maintain the highway system would create disastrous effects in many states."

Feasibility Study Results

Before the large study now underway, AASHTO asked TRB to conduct a brief feasibility study to review the range of issues involved. To simplify the initial analysis, the feasibility study (10) focused on one vehicle configuration that illustrates Turner's proposal: a double-trailer combination with 28-ft trailers, nine axles, and gross weight up to 105,000 lb. The length of this vehicle complies with limits currently applied on federal-aid highways, and the gross weight is within the limits imposed by the federal bridge formula. The feasibility study estimated that, if one quarter of all combination truck travel were attracted to such a vehicle, annual pavement costs to highway agencies would decline by \$250 million (about 7 percent of annual state highway agency resurfacing, restoration, and rehabilitation expenditures), while bridge costs would increase by \$75 million (probably an underestimate of bridge costs, according to results of the current study). Pavement costs would decrease because the weights on the individual axles of the 105,000-lb 9-axle combination would be less than the axle weights of a 5-axle tractor-semitrailer of 80,000 lb gross weight. Bridge costs would be higher because the heavier Turner vehicle would stress some long-span steel bridges beyond the overstress criteria implicit in the federal bridge formula. This overstress was assumed to

reduce the service life of these bridges and necessitate replacement sooner than planned. Productivity gains were projected to reduce shipper costs by more than \$3 billion annually, 2 percent of the cost of truck freight.

These projections assumed that the new weight limits would be voluntary, in other words, that truck operators could choose to operate under either the new limits or the ones now in effect. They also assumed that the Turner vehicles would be confined to the Interstates and the primary roads and access routes currently designated for 5-axle twin trailer trucks.

The feasibility study concluded that the proposal did appear feasible and that it might yield important benefits to all road users, but that further examination would be necessary in the areas of carrier acceptance, alternative Turner vehicle configurations, potential safety impacts, the costs of bridge overstress, and pavement wear effects under varying assumptions concerning which roads the new trucks would be allowed to use.

The feasibility study also considered a policy of building heavier pavements as an alternative that would also make operation of heavier trucks feasible while controlling pavement costs. If strengthening pavements were cheap enough, it might make sense to undertake the extra increment of expense to accommodate heavier trucks, and dispense with the axle weight reductions of the Turner proposal. This thicker pavement option is suggested by the relationship between pavement thickness and load carrying capacity that is assumed to hold in standard pavement design practices, which predicts greatly increased load carrying capacity for only small increases in pavement cost.

The feasibility study concluded that overlays in pavement rehabilitation projects thicker than ones now most commonly employed would reduce total costs (maintenance, resurfacing and user costs) under existing traffic, if it is assumed that nearly all pavement wear is directly related to traffic load. However, assuming that even modest amounts of pavement wear are due to environment or random factors sharply reduces the least-cost overlay thickness, because building a heavier pavement means that the losses from weather or other non-load-related wear are more costly.

Unresolved Issues--Potential Objections to the Turner Proposal

The feasibility study showed that the Turner proposal holds promise for reducing both the cost of building and maintaining pavement and the cost of freight transportation. However, it identified three potential objections to proceeding to implement it.

First, there are grounds for concern about the relative safety of the new trucks that would come into use if the proposal were put into effect. These trucks probably would be multi-trailer vehicles, longer, heavier, and more complex than most trucks now in use. Second, widespread use of the new trucks would add to bridge fatigue, replacement, and rehabilitation costs, possibly enough to negate the benefit to highway agency budgets of reduced pavement wear. The current study is investigating ways that the safety and bridge costs of Turner trucks can be mitigated by restrictions on the trucks' design and operation.

Finally, adopting the Turner proposal might not be the best policy choice because alternative approaches to truck size and weight regulation yield greater benefits. These other approaches include:

1. The thicker pavement option: Allowing heavier and larger trucks with the existing or even greater axle load limits, together with a road investment program to strengthen pavements and bridges, might yield greater net benefits. The enormous positive benefit-cost ratios estimated in the earlier truck size and weight studies that compared the freight savings of larger trucks to the added highway construction and repair costs they would cause are evidence supporting this alternative, as are estimates such as the one cited above of high rates of return on highway reconstruction and rehabilitation spending through reduced operating cost and time savings, with no change in allowable weights.
2. Other ways to redesign trucks: Recent pavement research (11) suggests that it may be possible, through design and selection of truck suspensions, tires, and axle configurations, to substantially reduce the pavement wear caused by a truck, thus achieving some of the benefits of the Turner proposal without reducing axle loads.
3. Regulation based on user fees: Economic gains could be made from introducing some reliance on the market mechanism in governing truck dimensions. The highway agency would charge each carrier the actual costs imposed on the agency and on other road users by each truck movement. Carriers would be allowed to operate equipment with weights and dimensions of their choosing so long as they were willing to pay these costs. Advantages of this approach are: the carrier has incentive to consider road maintenance costs in addition to its own operating costs in designing its equipment and operations; the highway agency is encouraged to invest in maintenance where the payoff would be greatest; financial constraints on the highway agency that are an obstacle to freight productivity improvement would be removed; and trucking productivity can be increased.

Practical difficulties stand in the way of each of these alternatives. The most significant for the thicker pavement option is the problem of financing the needed improvements. The highway program does not have a tax system in place that can respond efficiently to changes in demands on the system or accurately charge users for the costs that each imposes. Another difficulty with the thicker pavement option concerns pavement engineering. As the feasibility study showed, to the extent that pavement wear is caused by weather or random factors unrelated to traffic, the payoff from strengthening pavements is reduced.

Controlling road wear through redesign of truck components also must overcome technical obstacles before it can be applied extensively, and ultimately could be expected to have only limited effectiveness in increasing road capacity for carrying larger trucks. Finally, obvious practical obstacles exist to applying the user fee approach to size regulation in many situations, although in some specialized operations it would be relatively simple to charge carriers for actual highway costs.

A full evaluation of all these alternatives would have involved highway finance and pavement engineering issues that are beyond the scope of the study committee's charge. This limitation of the study scope does not reduce the validity of its conclusions. The Turner proposal, the option of undertaking major road upgrades, proposals for changes to truck suspensions and tires to reduce road wear, and user-fee-based regulation should not be

regarded as mutually exclusive alternatives. Turner trucks would still have benefits if roads and truck suspensions were improved, and the best policy probably involves a mix of all these approaches. Rebuilding highways or fundamental changes in taxes are long-range propositions, and the Turner proposal could be an important interim measure to maintain service during the transition to a better system.

REGULATORY ALTERNATIVES AND PRELIMINARY RESULTS

The sections below report progress in the current study, including definitions of regulatory options and estimates of the impacts of Turner trucks. The work of the Turner Proposal study committee is still underway. The definitions of regulatory options and the impacts estimates are preliminary and subject to revision, and the committee has reached no conclusions about policy recommendations. Nonetheless, these tentative findings are presented to indicate the possible scope and format of study outcomes, assuming that the committee reaches the conclusion that some form of the Turner proposal ought to be enacted. The committee may decide in the end that because of uncertainties in impacts or availability of better regulatory alternatives, the proposal should not be implemented.

Prototype Vehicles and Regulatory Options

The analysis of the Turner proposal is organized around a set of prototype vehicles--predictions of the kinds of trucks that would gain acceptance if a version of the proposal were implemented; and regulatory policy options--alternatives for specific changes in size and weight rules.

Four prototype Turner trucks are being analyzed in detail (Table 1):

1. Seven-axle tractor-semitrailer (tri-axle tractor and tri-axle semitrailer);
2. Nine-axle double (tandem tractor and two tandem-axle semitrailers coupled by a tandem-axle dolly of either the single-drawbar or double-drawbar design);
3. 11-axle double (tandem tractor and two tri-axle trailers);
4. Nine-axle B-train double (tandem-axle tractor, a four-axle semitrailer with a fifth wheel permanently affixed at the rear of its frame, and a tandem-axle semitrailer).

Many other vehicles that conform to the concept of the proposal might be possible, and experience shows that truck operators usually respond to a change in size and weight regulations by devising a variety of vehicle modifications to suit specific needs. However, for practicality it was necessary to concentrate the evaluations on a small number of types that are intended to represent the Turner trucks that would be most popular.

The selection of vehicle options was limited by three considerations:

- o Consistency with the concept behind the Turner proposal:
 - The vehicle options must have lower maximum axle loads and cause less pavement wear per vehicle-mile than existing trucks.
 - They must have greater cargo weight capacity than existing trucks.

- o Geometric compatibility with existing roads:
 - The options comply with existing height and width limits.
 - Length of trailers is constrained by requiring acceptable offtracking (e.g., low-speed offtracking should be no worse than the worst common existing combination).
 - The number of axles in multi-axle groups and the span of multi-axle groups is limited by cornering ability.
- o Primary reliance on existing equipment and technology: Vehicles with configurations similar to the prototypes are in use today, so the prototypes pass a first test for feasibility. Fundamentally new technology would be slow to come into widespread use, and its form would be difficult to predict.

Characteristics of each of the prototype vehicles must be specified before impacts can be evaluated. Table 1 shows midpoint values of the most important descriptive features. Certain detailed characteristics, in addition to overall size, strongly influence the safety, pavement and bridge wear, and productivity of the prototype vehicles. For example:

- o Tires: Because of lower axle weights and more wheels, operators may specify very different tires on Turner vehicles than on conventional trucks. Dual tires may be replaced by single wide-based tires, and smaller-diameter tires may be used to increase cargo volume. Concentrating loads on fewer, smaller tires could increase pavement wear. Tires also affect vehicle handling. Tires are a major component of operating costs and also influence cargo capacity.
- o Suspensions: The characteristics of the suspensions (e.g., stiffness and degree of damping) that operators would choose for Turner trucks would affect the consequences of adopting the proposal. Suspension design influences the dynamic load that pavements are exposed to, and consequently pavement wear. Good load equalization among axles in multi-axle groups is a function of the suspension that has important pavement wear consequences, especially for the many-axled prototype vehicles. Suspensions affect vehicle handling and operating costs.
- o Coupling: The choice among the various designs for coupling the second trailer in the double-trailer prototypes (single-drawbar dolly, double-drawbar dolly, and B-train) affects stability and offtracking, and also affects ease of using the equipment.
- o Dimensions: The overall length of the vehicle, the length of each trailer, the distances from points of articulation to the rear axles of semitrailers, and the spreads between consecutive axles influence the road space requirements of the vehicle (turning ability and offtracking), traffic impacts, stability, pavement and bridge impacts, ease of loading, and economy of operation.

All the vehicle evaluations are comparative, with reference to the performance of vehicles in use today. The baseline vehicles are the alternatives to Turner trucks for carrying the same freight, under traditional size and weight regulation. The baseline trucks are the five-axle tractor-semitrailer, the five-axle twin trailer truck, and the nine-axle turnpike double, operating under present limits.

The study is evaluating the impacts of several categories of regulatory alternatives, that is, possible recommendations for government actions:

- o New limits for truck sizes and weights and standards specifying allowable vehicle configurations;
- o Performance standards or design standards intended to reduce pavement wear, improve safety, or reduce traffic flow impacts, for example, suspension design standards or brake performance requirements;
- o Route restrictions limiting Turner trucks to certain roads;
- o Changes in road and bridge design and maintenance practices to accommodate Turner trucks;
- o Mandatory versus voluntary forms of the new size and weight provisions. The feasibility study concluded that to be practical, Turner vehicle options must be voluntary; that is, each truck operator must be allowed to choose between the new limits and existing size and weight rules.
- o Tax treatment: whether taxes should be adjusted for differences in cost responsibility between Turner and other trucks.

A possible set of restrictions on motor vehicles, consistent with the cases the study has considered, includes restrictions of three kinds: (1) limits on weights, dimensions, and configurations; (2) other requirements for equipment of the vehicles; and (3) restrictions on the roads over which the vehicles are allowed to travel (Table 2). For the Turner proposal to become reality, most states and the federal government would have to adopt changes to existing regulations to allow vehicles satisfying restrictions along these lines to operate. Under the voluntary version of the Turner proposal, the restrictions would be enacted in such a way as to allow any truck that previously had been legal to continue operate in the state; that is, the Turner trucks would be an added option beside existing trucks. To ensure reasonable uniformity, the definitions and format of the Turner truck restrictions would have to be the same in all states.

Any bridge formula restriction included with the recommended Turner vehicle restrictions will be consistent with the recommendation of the TRB Truck Weight Study currently in progress (12). The illustrative restrictions do not include an explicit limit on gross combination weight, but this weight would be effectively limited by the bridge formula and the length limit. The restrictions probably will rule out the extremely heavy prototypes (i.e., trucks with more than nine axles). The 33 ft limit for each trailer of a double trailer would prevent Rocky Mountain doubles from operating as Turner vehicles.

The selection of recommended restrictions for Turner vehicles will be made with the intent that the vehicles be safe and practical to use on most roads that have significance as truck freight routes. Therefore, Turner vehicles should be legal to operate on all roads except where excluding them would be essential for safety or because of inadequate bridges. Route restrictions other than those relating to bridges will be consistent with the recommendations of the TRB Access Study (14).

Table 3 lists the impact preliminary estimates: the kinds of Turner truck configurations that would come into use; the volume of freight and truck travel that would be via Turner trucks and the effect of this travel on freight costs; effects of Turner trucks on bridges; impacts on safety and traffic flow; and impact on pavement condition and cost. The estimates of traffic volume and impacts of Turner trucks necessarily will be uncertain, and the final report of the study will illustrate the effect of this uncertainty on the overall outcome of the impacts evaluation.

Likely Configurations and Uses

The estimates of the extent of use of Turner trucks and resulting changes in freight costs were derived primarily from interviews of motor carriers, shippers, and truck manufacturers, and from examining experiences in regions where regulations already allow trucks similar to the prototypes.

The productivity analysis indicates that the most attractive configuration meeting the size and weight limits outlined above is a nine-axle double with twin 33-ft trailers and a practical maximum gross weight of 111,000 lb. Industry segments where the double trailer prototypes would gain acceptance include tank and dry bulk operations and high-density truckload van freight (in nine-axle doubles), and less-than-truckload freight (in nine-axle doubles or in a similar configuration with six to eight axles).

The attractiveness of the single-trailer prototype is limited because it gives a much smaller added payload weight, and no added volume, compared with existing trucks, than do the double-trailer prototypes. It would find applications where added payload weight is crucial and double trailers are impractical. Examples of these applications are heavy 40-ft containers, heavy machinery, and specialized tanker operations.

Turner trucks would not be widely accepted in all trucking applications. They would not be used in industry segments that do not use the largest sizes available today or that already use trucks larger than those under evaluation. In other segments, logistical problems of operating double trailers are an obstacle to use of the new trucks. Logistical objections relate to two kinds of costs:

- o Reduced utilization rate for equipment and drivers. These costs arise because of added time required for pickup and delivery; and because of less efficient use of equipment when a fleet operation must dispatch several different sizes of trailers and tractors, effectively dividing each traffic lane into several lower-traffic-density, less efficient lanes.
- o Requirements for modification of facilities at loading and unloading points: e.g., acquiring more yard space for maneuvering and storing trailers, or increasing the number of loading bays.

One important segment where these obstacles to use of Turner trucks are significant is light-density truckload van freight.

Considering these limitations, the eventual potential market for Turner trucks may be about one-fourth of existing combination-truck-miles of

traffic. This level of use would come about over a period of five to ten years after nationwide (or nearly nationwide) legalization of Turner trucks, after carriers had time to adjust their equipment and operations and major bridge restrictions on routes were corrected.

The savings to carriers adopting Turner trucks would average 15 percent of line-haul operating costs. Aggregate savings in the cost of freight transportation would be \$2.5 billion per year (two percent of the cost of shipping freight by truck) at today's prices and freight traffic volumes, not considering effects of traffic diverted from rail to truck.

Lower truck freight costs would attract freight from rail. The rail diversion analysis is not completed, but an order of magnitude estimate is that freight diverted would be equivalent to about two percent of freight ton-miles in trucks before the shift, adding 10 percent to Turner truck travel. The loss would be 1.5 percent of rail ton-miles.

Considering diversion from rail and the greater capacity of Turner trucks compared with the vehicles replaced, the net effect of adopting Turner trucks would be a slight decrease in annual miles of combination truck travel. Turner trucks would be 20 percent of the total, and would be relatively common on all classes of roads and in all regions.

Safety and Traffic Impacts

The safety analysis has three components. First, the intrinsic safety of the prototype trucks is to be compared with that of the trucks they would replace. Second, the systemwide safety impact of introducing Turner trucks is to be determined, considering changes in the volume and distribution of truck traffic resulting from introducing them as well as the intrinsic safety of the vehicles. Finally, possible means of mitigating the hazards of operating Turner trucks are being evaluated.

The assessment of intrinsic safety has been derived from a synthesis of several sources. Handling and stability characteristics of the prototype trucks and the trucks they will replace have been examined by means of simulations and limited testing. A review of past research on the performance of similar trucks has been the source for the estimates of traffic interactions and potential accident rates and severity for the prototypes compared with the trucks they will replace.

Handling and Stability

- o The double trailer prototype with single-drawbar dolly has a tendency for rear-trailer sway in response to abrupt steering maneuvers. This behavior, called rearward amplification, is less severe for the Turner prototype than for current twin-28-ft-trailers because of the prototype's greater length.
- o Rollover threshold--the horizontal force needed to cause rollover--of the double trailer prototype with van or flatbed body is better than for current five-axle tractor semitrailers.
- o The B-train configuration eliminates rearward amplification and may be a means to improve stability of double tank trailers.

- o At slow speeds the rear wheels of a combination truck deviate from the path of the front wheels (offtrack) toward the inside of the curve. Slow speed offtracking performance is about the same for the prototype single-drawbar dolly double and existing tractor-semitrailers with 48-ft trailers. Therefore the prototype is equally as maneuverable as the longest common tractor-semitrailer at low speeds, as when driving on city streets.
- o Braking performance of the prototypes is similar to that of current trucks, provided the brakes are properly designed and maintained.

Traffic Interactions

- o The prototype vehicles are not expected to have significantly different traffic-operation characteristics from the existing trucks, on a per-vehicle basis, provided their hill-climbing speed and acceleration performance are comparable to those of the existing combination vehicles they will replace.
- o Turner vehicles operated on non-Interstate roads would be effectively limited in overall length by the need to have low-speed offtracking within the limit of the road space available.
- o Operations of Turner vehicles substantially longer than existing combination vehicles may degrade traffic operations or safety in extreme urban congestion, due to difficulties of merging, lane-changing, and exiting maneuvers.

Accident Rates and Severity

- o Driver-related factors are the most important contributing factors in truck accidents. These include driver judgment, fatigue, inattention, long service hours, inadequate training or experience, driving behavior and history, and alcohol and drug uses. Road and traffic conditions are also highly important in explaining differences in accident rates. In general road and driver characteristics would be the same for Turner trucks as for the truck traffic the Turner trucks were replacing. Vehicle-related factors are much less important than road and driver. The influence of vehicle configuration (e.g., doubles versus tractor-semitrailers), per se, on truck accident rates is small.
- o Rearward amplification can lead to rollovers as the result of steering actions in lane-changing or evasive maneuvers and on ramps at high speed. As much as 10 percent of all accidents of existing five-axle doubles may be related to this property.

For the double trailer prototypes, lighter axle loads and longer trailers will enhance directional stability, and lighter axle loads and the added number of axles will enhance rollover resistance and rearward-amplification behavior, compared with existing five-axle doubles. Some of these advantages may be reduced if the components for Turner doubles are "downsized" to take advantage of the lighter axle loads. Nonetheless, Turner doubles are not expected to have higher rates of rollover crashes per mile traveled than existing doubles, and may not have higher overall accident rates than the existing doubles or tractor-semitrailers they will replace.

- o Turner vehicles are not expected to have significantly different accident severity from existing doubles or tractor-semitrailers they will replace.

Systemwide Safety

Since the rate of accidents per mile travelled for Turner vehicles and the severity of accidents would not be different from that of the trucks they replaced when operated under identical conditions, the only source of a systemwide impact on the frequency of accidents or the magnitude of accident losses would be changes in the volume and distribution of total truck traffic resulting from introduction of Turner trucks. This effect would be positive, because total annual miles of combination truck traffic would decline through use of Turner trucks.

Mitigating Hazards

Several measures have been identified which may have the potential to reduce accident losses from operation of Turner trucks: use of the B-train configuration for double tank combinations; minimum speed and acceleration performance standards; improved design of the truck front end to reduce severity of car-truck accidents; and anti-lock brakes on the drive axles and dolly. These are now being evaluated.

Impacts on Bridges

The bridge analysis is estimating, for new and existing bridges, two kinds of costs: fatigue effects from the change in the repeated loadings bridges would be subject to after Turner trucks came into use, and changes in the load-bearing capacity required for bridges to carry Turner trucks. The key assumption of the analysis is that highway agencies would continue to follow current practice regarding design standards for new bridges and criteria for posting existing bridges to restrict truck traffic. The criterion that determines whether existing bridges must be posted or replaced in the analysis is that loads not exceed a bridge's operating rating, a rating of the maximum safe load for a bridge determined according to criteria defined by AASHTO and which for steel bridges nominally equals 75 percent of the yield load. The estimates are produced by comparing bending moments for various traffic loads to capacity ratings for all bridges in the Federal Highway Administration's bridge inventory data file. Costs are based on historical average costs.

Preliminary findings are:

- o Costs to repair and replace steel bridges because of increased fatigue damage would be on the order of \$50 million annually, once Turner traffic volume reached its predicted long-run level.
- o The predominant costs would be capacity related--to raise the design capacity of new bridges and reconstruct or replace existing bridges to meet the specified safety margin. Four thousand Interstate and primary bridges (3 percent of the total) would fail the overstress criterion, over and above those which do not meet the criterion today. Replacing these would cost \$2.0 billion, an average of \$500,000 each. The change in the number of non-primary bridges not meeting the criterion would be 4,000, 1 percent of the total. The cost to replace non-primary bridges would be \$2.0 billion.

Altogether, the cost to replace bridges rendered deficient by introduction of Turner trucks would equal one and one-half years' of today's total bridge construction expenditures. In addition, designing new bridges to carry Turner trucks would add \$150 million per year to their cost, at today's rate of new bridge construction.

- o Critical bridge types include steel continuous spans, 21 percent of bridges on Interstates and primaries, which account for 48 percent of replacement costs.
- o In a scenario with traffic in the extreme-case Turner vehicle, a 73-ft wheelbase 141,000 lb, 11-axle double; 24,000 Interstate and primary bridges (16 percent of the total) fail the criterion, over and above the base case. These would cost \$11 billion to replace. 22,000 previously adequate non-primary bridges, seven percent of the total, fail the overstress criterion.

Such impacts would have significant implications for the feasibility of the Turner proposal:

- o The largest prototype truck the study has been considering, the 11-axle double, may be impractical because of high bridge costs.
- o Potential bridge costs may be comparable to pavement wear savings in some jurisdictions, and the proposal would lose a key element--that it represents a "win-win" arrangement, one seen as beneficial both by truck operators and highway agencies.
- o Bridge postings forbidding passage of Turner trucks, either initially until needed bridge work could be performed, or in the long run as an alternative to replacing some bridges, could be so extensive that the potential use of Turner trucks would be substantially curtailed.

Current bridge posting and design practices are very conservative and tend to hide a reserve of unused load-carrying capacity in the existing bridge system. The estimated replacement costs should thus be considered upper bounds. Potential modifications to current practice that would allow the states to use existing capacity more efficiently are described in the section below on implementation. The numbers of apparently deficient bridges might be reduced substantially by more sophisticated screening to take advantage of actual capacity.

Pavement Impacts

The analysis of pavement impacts and costs has two steps. First, the change in the rate of pavement wear resulting from the predicted truck traffic change is estimated, using the AASHTO pavement design method. That method incorporates a relationship between the condition of a pavement and the number of standard axle loadings on the pavement since it was built, and relationships for converting the actual distribution of kinds and weights of axle loadings on a road to equivalent standard axle loadings. The method has been modified so that it can reflect the effects of differences in tires, suspensions, axle configuration, and other vehicle features between the prototype trucks and conventional vehicles.

The second step estimates the change in the cost of maintaining pavements resulting from the change in the rate of wear, under the

assumption that highway agencies act to keep pavement condition and intervals between resurfacing the same as they would have been if traffic had not changed. The cost difference has two components: the time to the next resurfacing of a pavement is altered, and the thickness of subsequent resurfacings is altered. The costs were estimated by life-cycle cost simulations of hypothetical representative pavements.

The preliminary results indicate that the trucks now carrying freight that would be diverted to Turner trucks account for about 30 percent of all equivalent-axle loadings, and that, per truck mile, a Turner truck is typically about half as wearing as the trucks replaced. After allowing for the Turner truck's greater capacity and projected diversion of freight from rail, the net effect is a 17 percent reduction in annual equivalent-axle-miles of pavement loadings. The cost savings to highway agencies would be \$400 million annually.

These savings would be reduced if substantial numbers of Turner trucks adopted, in place of dual tires, single tires with higher pressures and smaller total contact area. Such tires could narrow the per-truck-mile pavement advantage of Turner trucks over the trucks replaced by about half. However, even if such tires were allowed under law, they have drawbacks that would limit their market among Turner truck operators.

Relation of Turner Vehicle Size Limits to the Estimated Impacts

If the study committee recommends changes in truck size and weight regulations, they must be justified by the expected impacts. The first and most important justification would have to be that introducing Turner trucks would be economically beneficial for the nation as a whole. Second, recommended limits also would have to meet the criterion at the heart of the Turner proposal--that the outcome be a "win-win" situation, in which industry gains productivity and highway agencies gain relief from escalating maintenance burdens.

The preliminary estimates summarized in Table 3 suggest both these criteria could be met. For the assumed use projection, truckers, shippers, and consumers gain \$2.5 billion annually in reduced freight transportation costs from the two percent improvement in trucking productivity. The impact on highway agency budgets would depend on the extent of bridge upgrading undertaken. It appears that highway agencies would about break even if they replaced three-fourths of all deficient (according to the criteria of the bridge analysis) bridges; then pavement savings would pay the annual cost of added bridge capital expenditures. If bridge costs were reduced without greatly curtailing use of Turner trucks--by posting, new approaches to rating, and use of rehabilitation instead of replacement--governments might in the end save perhaps \$100 million to \$200 million a year in the cost to maintain highways in the condition that would prevail if Turner trucks were not in use. At lower use levels than that projected, states would have to reduce their bridge investments to maintain this positive outcome. Overall highway accident losses would be unaffected.

There will be some degree of arbitrariness in any specific dimensional restrictions the committee recommends; that is, any single dimensional limit could be changed within a range without greatly affecting the overall outcome. However, the combined results of the productivity, safety and traffic, bridge, and pavement analyses place some definite boundaries on what these restrictions must be to attain the objectives of the Turner

proposal. Selecting restrictions will involve trade-offs among the objectives of reduced highway maintenance costs, increased freight productivity, and avoiding increased accident risk. An important principle in selecting the restrictions will be that the Turner truck be as nearly universally applicable as possible, i.e., that the Turner trucks be compatible with the conditions of most truck routes in all regions. Many types of large trucks other than Turner trucks may be useful and valuable on more restricted networks of roads or in certain regions, but it is beyond the scope of the study to evaluate such restricted options.

IMPLEMENTATION

If the study committee should decide to recommend that a version of the Turner proposal be adopted, translating that recommendation into reality would require formation of a consensus supporting it among state and federal governments, highway engineers, truck operators, and shippers. The public also would have to recognize the benefits of the proposal. Supported by such a consensus, the state and federal governments would then need to take action in three areas:

- o Legislative changes to size and weight limits;
- o A program for lessening over time the restrictions imposed on use of Turner trucks by deficient bridges;
- o A program to review needs for access restrictions in special cases.

In addition, the committee is considering recommending, and government could decide to enact, adjustments to truck taxes to avoid inappropriate discouragement of use of Turner trucks.

Legislative Changes to Size and Weight Limits

The American Association of State Highway and Transportation Officials could take a leadership role in the implementation of the Turner proposal, by, first, adopting Turner vehicle restrictions (presumably following the committee recommendations), together with procedures for dealing with deficient bridges and special routing problems, as a policy guide to the states; and by promoting adoption of its model Turner truck regulations by all states, in as uniform a manner as possible.

The major role of the federal government would be to clear the way for adoption of state Turner truck regulations by removing impediments in current federal laws and rules. Legislation would be necessary providing that, in states that have adopted Turner truck regulations which meet federal criteria, trucks in compliance with those state regulations are allowed on all roads, notwithstanding any other federal law.

Finally, all states individually would have to enact size and weight regulations and procedures for deficient bridges and for special routing problems consistent with the AASHTO model Turner truck regulations. Under the voluntary version of the proposal, no state or federal Turner truck regulation would have the effect of preventing other currently legal vehicles from operating.

Procedures for Deficient Bridges

The inaccessibility of certain routes and places because bridges were inadequate to carry Turner vehicles would be a major initial impediment to gaining the benefits of Turner trucks. Therefore, the states would need to develop plans for alleviating over time constraints on the use of Turner trucks from deficient bridges. A plan might have these components:

1. A priority ranking of major truck routes in the state, based on the volume of truck freight routes currently carry, which identifies bridges that are obstacles to use of Turner trucks.
2. A timetable specifying when deficiencies will be removed.
3. A finance plan earmarking a proportion of bridge funds available each year for projects that correct deficiencies on priority truck routes. The finance plan could provide for direct private sector participation in certain bridge projects.
4. A set of short term measures for mitigating obstacles caused by bridge deficiencies until needed bridge reconstruction can occur, including identification of alternative routings and interim size and weight limits for certain routes or bridges.
5. Adoption of new practices for posting and inspection of bridges, bridge rehabilitation, and design of new bridges, including inspection and posting practices that recognize accurately the strength capacities of steel continuous span and concrete bridges, and new bridge design methods that recognize the Turner truck as the critical load when this is the case.

To expedite removal of bridge obstacles to use of Turner trucks, the FHWA could modify its standards for federal-aid bridge strengthening or rehabilitation projects so as to allow more bridges inadequate for carrying Turner trucks to be rehabilitated rather than replaced than would be possible under current practice. Allowing rehabilitation rather than replacement might be especially appropriate for bridges that are adequate for non-Turner traffic.

In keeping with the objective of the proposal that use of Turner trucks offer relief of financial pressures on state highway budgets, each state would be able to adjust the level of spending for removing obstacles to Turner trucks according to the potential level of demand for the trucks in the state and the pavement wear savings the state might expect to attain from use of Turner trucks. Conceivably, a mechanism to redistribute gains and losses among states might be found.

Procedures for Special Routing Problems

Trucks that complied with Turner truck restrictions such as those described above would be as compatible with existing geometric and traffic conditions on U.S. roads as are many other combinations in general use today. Therefore, there would be few circumstances other than bridge capacity which justified excluding a Turner truck from a road regularly used by other combination trucks. Nonetheless, to ensure safe operation, the states would need to implement procedures for assessing adequacy of

roads to accommodate the new trucks. The procedures would need to be standardized, uniform from state to state, and based on objective safety and engineering considerations. They would entail assessment of individual routes based on each route's geometric and traffic characteristics, focusing on the compatibility of the critical vehicle performance characteristics--offtracking and length--with critical road characteristics: curves on two-lane roads, turning space at intersections, passing and intersection sight distance, and ramp and interchange design. The reviews would have to be timely, decisions affecting roads open to Turner vehicles clearly communicated to industry and police, and a mechanism established for industry and government to resolve problems. This process is consistent with the one recommended in the TRB Access Study for determining routes for 48 ft-semitrailers and twin 28-ft trailers (14).

Tax Treatment of Turner Trucks

Adjusting highway user tax and fee systems to reflect the differences between Turner trucks and other combinations in highway maintenance and construction costs occasioned would have certain advantages. Such adjustments would provide truck operators with the proper incentives to choose trucks that are truly the most efficient, considering both highway and truck operating costs. The adjustment would be particularly important in tax systems, such as exist in many states today, under which a Turner truck that occasioned lower highway costs than a conventional tractor-semitrailer would pay higher taxes than the semi at current rates. The adjustments could be carried out in such a way as to leave total revenues collected from trucks unchanged.

The Turner truck study has not explicitly addressed cost responsibility for tax purposes and its results will not be usable as the basis for setting tax rates. Appropriate tax rates depend on the circumstances of each jurisdiction: its current tax structure and established principles for assigning cost responsibility; the volume and characteristics of Turner truck traffic that occurs; traffic volume for other trucks; and the conditions of pavement, bridges, and traffic on its road system. The states would have to conduct their own cost responsibility studies in order to properly take into account all these local factors.

As an indication of the order of magnitude of tax adjustments necessary, the impact estimates of this study imply that each mile of travel by a Turner truck would save roughly 1¢ in highway costs compared with the costs if the freight were hauled in a conventional tractor-semitrailer, if annualized bridge costs were kept to \$250 million. However, a Turner nine-axle double would pay typically about 1¢/mi federal and 1¢/mi state in higher fuel, highway use, and excise taxes and registration fees than a 5-axle 80,000 lb tractor-semitrailer because it had a higher purchase price, lower miles per gallon, and a higher gross weight than the semi. Therefore a 3¢/mile decrease in the Turner truck tax or a 3¢/mi increase in the semi's tax would be necessary to make the tax difference equal the cost difference. The semi pays typically about 12¢/mi total highway taxes today.

In practice, there would be difficulties adjusting taxes to reflect the relative cost responsibility of Turner trucks. The most serious is that the needed adjustments do not fit well with most states' current tax structures. In most states the only existing taxes that depend explicitly

on weight or configuration are the annual registration fees for tractors and trailers. (At the federal level, the heavy vehicle use tax and excise taxes refer to weight or equipment type.) Registration fees would be far from the ideal means to adjust Turner truck taxes, because they do not depend on the miles travelled by the vehicle, and because they do not provide any means to adjust the taxes of operators who wish to use their equipment interchangeably in Turner configurations and conventional configurations. A carrier who planned to dedicate a tractor and trailers to Turner use during a year could register them as such and pay the appropriate fee, but no adjustment would be practical for the carrier who needed to maintain flexibility to operate either at the Turner limits or the previous limits with all its equipment.

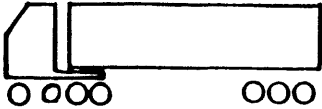
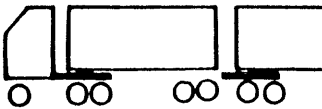
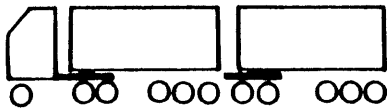
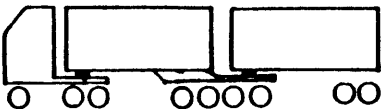
In the long run, the only way to satisfactorily tax trucks according to their cost responsibility would be to institute true axle-weight/distance taxes, that is, taxes that depend on the miles travelled by particular axle types (e.g., single axles, tandem axles) at particular loadings. With an ideal truck tax in place, size regulation could in effect be accomplished by means of the tax system, and complicated sets of dimensional limits, such as those in effect today or discussed here for Turner trucks, would no longer be needed. Each carrier could select equipment, or design specialized equipment, that was the most productive for its hauls. The highway agency would then estimate the change in its costs for providing the roads for the carrier's operations, considering the proposed equipment, pavement and bridge conditions, and expected traffic volume; and charge the carrier this amount. The economic trade-offs would determine truck sizes, subject only to restrictions deemed necessary for safety. Government analysis would focus solely on determining the correct fees for any specified truck and route by measuring the highway costs generated by trucks.

Today, no direct connection exists between the charge and the cost incurred by a particular truck trip, and serious practical obstacles exist to applying the approach in many situations. Nevertheless, greater pressures for efficient highway management and freight transport, together with advances in automated vehicle monitoring and communications systems and in understanding of vehicle impacts, eventually should make such a marketplace approach to regulating truck sizes and weights feasible.

REFERENCES

1. F. C. Turner, "Addressing the Highway Mode," AASHTO Quarterly, Vol. 64, no. 1, January, 1985.
2. The Status of the Nation's Highways: Conditions and Performance; Report of the Secretary of Transportation to the United States Congress, U.S. GPO, (biennial), 1983-1987.
3. Highway Statistics, Federal Highway Administration, U.S. Department of Transportation, (annual), 1981-1986.
4. D. L. Lewis, et al., Public Works Infrastructure: Policy Considerations for the 1980s, Congressional Budget Office, U.S. Congress, April 1983.
5. "Highway Trust Fund Examined," AASHTO Journal, March 4, 1988.
6. F. Smith, Transportation in America, Transportation Policy Associates, Washington, D.C., March 1985.
7. An Investigation of Truck Size and Weight Limits, U.S. Department of Transportation, August 1981.
8. Review of Safety and Economic Aspects of Increased Vehicle Sizes and Weights, Federal Highway Administration, September 1969.
9. D. Solomon et al., Summary and Assessment of Sizes and Weights Report, Federal Highway Administration, August 1972.
10. Relationships Between Vehicle Configurations and Highway Design (A Feasibility Study of the Turner Proposal), National Cooperative Highway Research Program, Transportation Research Board, November 5, 1986.
11. J. R. Morris, Effects of Heavy Vehicle Characteristics on Pavement Response and Performance--Phase 1, National Cooperative Highway Research Program, Transportation Research Board, December 1987.
12. Truck Weight Study, Special Report, Transportation Research Board, Washington, D.C., (forthcoming) 1990.
13. Guide for Maximum Dimensions and Weights of Motor Vehicles and for the Operation of Nondivisible Load Oversize and Overweight Vehicles, American Association of State Highway and Transportation Officials, Washington, D.C., revised December 6, 1987.
14. Providing Access for Large Trucks, Special Report 223, Transportation Research Board, Washington, D.C., (forthcoming) 1989.

TABLE 1 Prototype Truck Characteristics

				
Characteristic	7-axle Tractor-Semitrailer	9-Axle Double	11-Axle Double	9-axle B-Train Double
<u>Dimensions:</u>				
Overall Length (ft)	60	81	81	81
Trailer Length (ft)	48	33	33	33
Trailer Axle Width (in.)	102	102	102	102
Other Dimensions ^a				
<u>Weights:</u>				
Gross Weight if Limited by Axle Weights Only ^b (1000 lb)	91	111	141	111
Gross Weight if Limited Also by Federal Bridge Formula (1000 lb)	91	111	127	111
Payload (1000 lb)	60	73	101 or 87	73
Other Weights ^c				
<u>Tractor:</u>				
Type	conventional	conventional	conventional	conventional
Power				
Trailer Type	flatbed, van, bulk	flatbed, van, bulk	flatbed, van, bulk	flatbed, van, bulk
<u>Tire Characteristics:</u>				
No. of Tires on Loaded Axles	1 or 2	1 or 2	1 or 2	1 or 2
Other Tire Characteristics ^d				
Dolly Type	none	single, double drawbar	single, double drawbar	none
<u>Suspension Characteristics^e</u>				

^aFor evaluating impacts, axle spacings, kingpin and fifth wheel positions must be specified.

^bSingle axle, 15,000 lb; tandem axles, 25,000 lb; tri-axles, 40,000 lb.; steering axle practical limit, 11,000 lb.

^cEmpty weights and axle weight distributions must be specified.

^dTire size and pressure must be specified.

^eSuspension types, use of lift axles, use of steerable axles, use of belly axles or other arrangements within multi-axle groups must be specified.

Table 2: Possible Turner Vehicle Restrictions

<u>Dimension</u>	<u>Restriction</u>
Weight Limits:	
single axle	15,000 lb maximum
tandem axle	25,000 lb "
tri-axle	40,000 lb "
gross combination	(not specifically limited)
Bridge Formula Restriction	[Consistent with recommendation of TRB Truck Weight Study (<u>12</u>)]
Length Limits:	
single trailer	48 ft maximum
double trailers	33 ft maximum each
overall	85 ft maximum
Width Limit:	102 in.
Configuration Restrictions:	double tank trailers permitted only in B-train or double-drawbar-dolly configurations
	truck-trailers and triples not permitted
Other Equipment Restrictions:	
tires	loading not to exceed 600 lb/in tire width
brakes	anti-lock braking system on drive axles and dolly
lift or VLS axles	must comply with AASHTO recommended guidelines (<u>13</u>)
Route Restrictions	permitted on all roads except: <ul style="list-style-type: none"> o route segments blocked by bridges failing to meet specified load capacity criteria o routes failing procedures for assessing adequacy for large combinations [consistent with TRB Access Study recommendations (<u>14</u>)]

Table 3: Preliminary Estimates of Impacts of Nationwide Introduction of Turner Trucks (continued)

Accident rates and severity	No difference between Turner prototypes and current tractor-semitrailers under similar conditions.
Systemwide safety	No overall increase in highway accident losses. Projected decline in truck travel a potential safety gain.
<i>Impacts on Bridges</i>	
Structural deficiencies	4,000 Interstate and other primary bridges, and 4,000 non-primary bridges, that currently are adequate would be structurally inadequate to carry Turner truck traffic, according to current bridge posting criteria. Numbers could be reduced by careful screening to take advantage of actual capacity.
Replacement costs	\$2.0 billion one-time cost to replace all inadequate Interstate and other primary bridges (\$500,000 per bridge); \$2.0 billion to replace non-primary bridges. (Equal to 1.5 years' total bridge construction expenditures today.)
Critical bridge types	Steel continuous spans, 21 percent of bridges on Interstates and primaries, account for 48 percent of replacement costs.
Added costs for new bridges	\$150 million/yr to allow for structural demands of Turner trucks.
Bridge fatigue costs	\$50 million/yr to repair and replace steel bridges because of increased fatigue damage from Turner trucks.
<i>Impacts on Pavements</i>	
Pavement wear per truck	Turner double causes 50 percent less wear than a current tractor-semitrailer per truck-mile.
Systemwide pavement cost	When Turner fully adopted, \$400 million /yr reduction in cost to maintain pavement at current condition (12 percent of current resurfacing, restoration, and rehab. costs).
Effect of tire configuration and other vehicle features	Widespread use of single tires on Turner would moderately reduce pavement gains.

Table 3: Preliminary Estimates of Impacts of Nationwide Introduction of Turner Trucks

Use and Productivity Gains
Turner configurations

9-axle double with 33-ft trailers and 111,000 lb maximum weight most popular. 7-axle single-trailers and other doubles find limited use.

Traffic diverted from other trucks

24 percent of all travel in current combination trucks will divert to Turner trucks once major bridge restrictions on routes corrected. Highest usage in dry bulk & LTL freight.

Traffic diverted from rail and net traffic change

2 percent increase in truck freight from traffic attracted from rail by cost savings. Net truck travel declines 4 percent; Turner trucks 20 percent of total.

Freight cost savings

\$2.5 billion/year--2 percent of intercity truck freight costs.

Transition period:

Conversion to Turner slowed by pace of regulatory change, bridge restrictions, and by needs for equipment turnover and operational adjustments in trucking. Full effects after 10 years.

Safety and Traffic Impacts
Handling of Turner doubles

Have tendency for rear-trailer sway in response to abrupt steering maneuvers--less severe problem than with current 5-axle twins. Cornering ability--tracking of rear wheels turns at city street speeds--comparable to current 48-ft trailers. Rollover threshold--sideways force needed to cause rollover--better than for current configurations. B-train important for tanker stability. Braking performance similar to current trucks, with proper specification and maintenance.

Handling--other prototypes

Turner single: no special problems compared with current trucks.

Traffic interaction

Length of Turner double makes passing more difficult. Difficulties merging, lane-changing, and exiting because of double's length may degrade traffic operations in urban congestion.

CLOSING SESSION: DEVELOPING THE RESEARCH AGENDA

Chairman: Bob Mayes, Transport Canada

1. **Vehicles**
Bob Ervin, University of Michigan Transportation Research Institute
2. **Pavements**
Pat Ring, Transportation Research Board
3. **Traffic Engineering**
J.B.L. Robinson, University of New Brunswick
4. **Safety**
R. Landis, Federal Highway Administration

