sented in the matrix can be combined by operators into a comprehensive, fleetwide energy conservation program. A list of references for the matrix is also included.

# Limited Trucktrain: A Concept for Energy Conservation and Truck Productivity

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**The widespread use of turnpike double and western triple trucks constrained to operate only on the Interstate system offers the potential not only for a reduction in U.S. diesel fuel consumption but also for a major increase in trucking productivity. This option is based on two 40- or 45-ft trailers (doubles) or two 27- to 30-ft trailers (triples) with axle weights maintained at the present 20 000-lb single/34 000-lb tandem level. Under this approach, the Interstate would be modified to provide for adequate access to truck stops and to provide parking areas or "corrals" where doubles and triples would be made up for intercity movement and disassembled for city delivery. Two scenarios are evaluated for their potential in fuel savings. Fuel improvements are estimated to be about 22 percent. A turnpike double offers nearly the same energy intensity as conventional trailer-on-flatcar unit trains traveling at similar speeds. Potential productivity improvements in trucking are so substantial that the industry may have to consider changes in its mode of operation. Under this scheme, about 500 trucks can do the job of 900, resulting in a reduction of drivers and capital equipment. The road stress as expressed in terms of equivalent axle load is slightly below that for single trucks moving the same freight. For the investment in road alterations and tractor upgrading, fuel savings equivalent to $15 000 to $40 000/bbl/day are realized (oil shale plants require an investment of about $35 000/bbl/day). Considering the reduced number of drivers and tractors, dollar savings much greater than the fuel cost are achieved. The overall benefit/cost ratio exceeds 10 for a nominal road rehabilitation cost factor, which makes trucktrain a very attractive option. Negative factors concern highway safety and the potentially severe impact on the railroads.**

Liquid fuel limitations make it imperative to explore all avenues to conserve petroleum. Although intercity trucking consumes only about 8 percent of the petroleum used in transportation, it needs to be considered. The trucking community has been engaged in near-term and longer-term efforts to improve fuel economy (1,2). Substantial increase of truck size and weight offers a significant opportunity for fuel economy. The concern, of course, is to prevent any measure from becoming counterproductive by making trucking seem more attractive than its more energy-efficient competitors, the railroads and barges.

The approach suggested here, which expands the concept presented by Michael and others (3), is to open the Interstate highway system to trucks whose weight is close to the "bridge-formula" load limit and whose lengths are commensurate with that limit. Weight limitations of 20 000 lb for a single axle and 34 000 lb for tandem axles would be retained. A maximum gross vehicle weight of 125 000 lb has been suggested. Commensurate lengths would be equivalent to about 85 ft of cargo-carrying capacity.

The federal Interstate system would be revised to provide numerous "trailer parking lots" or corrals. These corrals, like those provided on the Massachusetts Turnpike or the New York Thruway, would be convenient to most urban centers and major freight depots. They would be the only locations where doubles and triples could be made up for intercity movement and disassembled for delivery. No doubles or triples would be allowed to leave the Interstate. They would be disassembled as they passed through the corrals, and, if desired, trailer weights could be determined and user fees assessed at these points.

The Interstate would also be altered to provide ingress and egress to truck stops. These areas, similar to the service areas on toll roads, would be special for trucks; therefore, in the trucktrain configuration, trucks would not use the regular interchange ramps and local highways.

Walton and Burke (4) looked at similar truck configurations (although they used 102-in width) on all Texas highways, computing costs, energy saving, and commodities carried. In general, their results for energy saving are consistent with those presented here. This study should be viewed as a "first-cut" evaluation aimed at reviewing one option for saving liquid petroleum versus investment to provide the savings. Productivity gains in freight movement offer further very significant benefits. Potential disbenefits are considered qualitatively.

## SCENARIOS

In the present political climate, wholesale permission to operate 40-ft doubles and 27-ft triples on the Interstate would not be granted. A major, but not emergency, petroleum shortfall will see truckers pressing hard for the system proposed here (because it improves labor and capital productivity at the same time that it reduces fuel consumption). Perhaps the 14 western states might become the first to allow the double or triple (100-ft-rig) approach. For purposes of calculation of the medium scenario, it has been assumed that 10-15 contiguous states in the West would open their limits in weight and size. Currently, the 14 continental states west of the Mississippi account for about 31 percent of heavy-combination truck miles.

Only under an extreme emergency would the federal government require the Interstate highway system to accommodate 100-ft rigs with maximum gross vehicle weight (GVW) of 125 000 lb. If this were to happen, it is likely that this carriage would be sufficiently attractive to general freight and specialized carriers that (except for movement of hazardous materials) they would make a maximum effort to use it. Private carriers, especially industries that have their own fleets, would also find ways to use the system. However, exempt haulers, under their contractual arrangements, might not be free enough or have the incentive to use such a system. Thus, for this short analysis, the following assumptions have been used:

1. Scenario A--No additional savings will occur beyond those already occurring with turnpike doubles and the present western doubles and triples.
2. Scenario B--With an additional 10 states per-

mitting doubles and triples, it has been assumed that about 50 percent, or an additional 15-18 percent, of truck ton miles will benefit from the savings.

3. Scenario C--A federal mandate that allows 40-ft doubles and 27-ft triples on the Interstate will mean that this type of traffic will be preferred when compared with limits on other roads. It is estimated for the purpose of this analysis that at least 80 percent of freight could be subject to the benefits of the Interstate. Since there will undoubtedly be some circuity to take advantage of the increased productivity offered by doubles and triples, it appears reasonable to estimate that about 65 percent of the total traffic would shift to movement by doubles and triples.

Using the forecast from the National Transportation Policy Study Commission (5), Table 1 provides two growth levels for the freight traffic in each of the study scenarios B and C. Scenario A is assumed as zero and is therefore not included in the table. The freight growth of level 2 is an average of the medium and high forecast levels (5, Appendix Table 37), whereas level 1 is slightly more optimistic than the low forecast.

**Table 1. Forecast of ton miles subject to carriage in limited-trucktrain concept under two scenarios.**

| | | Forecast (billion ton miles) | | |
|---|---|---|---|---|
| | Level of Growth in Freight | | Subject to Improvement Scenario | |
| Year | Traffic | Total U.S. | B (15-18%) | C (65%) |
| 1980 | | 580 | 90 | 380 |
| 1985 | 1 | 735 | 110 | 480 |
| | 2 | 840 | 140 | 550 |
| 1990 | 1 | 800 | 130 | 520 |
| | 2 | 1000 | 160 | 650 |
| 1995 | 1 | 875 | 140 | 570 |
| | 2 | 1250 | 200 | 800 |
| 2000 | 1 | 950 | 160 | 620 |
| | 2 | 1540 | 250 | 1000 |

FUEL SAVINGS

The truck size and weight study at Purdue University (3) provided, from currently available data, the fuel used and the road stress caused [equivalent 18 000-lb axle loadings (EALs)] by an average fleet carrying 14 300 tons of freight per day. Table 2 (3) identifies fleet characteristics for the present 80 000-lb GVW limit moving 14 300 tons. [Purdue University (3) used the 1974 Interstate Commerce Commission (ICC) "empty/loaded" data (6) to derive the traffic weight model. The movement of 14 300 tons in 1000 trucks with 26 percent empty was considered the median. Table 2 reflects the more recent change from 73 280- to 80 000-lb GVW in all states.] Table 3 results from loading the same amount of freight into double and triple bottoms and calculating both gallons per mile and EAL for the new fleet. It can be seen from Table 3 that total GVW is considerably reduced because only 484 trucks are needed to move 14 300 tons in the limited-trucktrain concept compared with the 906 trucks in Table 2. This reduction results in an anticipated amount of road damage for this amount of freight movement that is actually less than that for the traffic considered in the base case (Table 2).

The fuel used by this fleet of doubles and triples is reduced by 22 percent. The tables illustrate that the gasoline saved is 165.5-129.3 gal/movement of 14 300 tons of freight for 1 mile. [Walton (4) gives a fuel-saving improvement on In-

**Table 2. Baseline of average truck fleet with weight limits at 80 000 lb.**

| | | | | | | 906-Vehicle Fleet | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| GVW (lb 000s) | Avg Weight Used (lb 000s) | Percentage of Fleet | EAL per Truck | Freight per Truck (tons) | Avg Fuel Economy per Truck (miles/gal) | Vehicles | Freight (tons) | EALs | Gross Weight (lb 000 000s) | Fuel Consumption (gal/mile) |
| 20-35 | 29 | 28.7 | 0.2 | 0-3 | 8.0 | 260 | 89 | 52 | 7.54 | 32.5 |
| 35-50 | 45 | 15.5 | 0.5 | 8.5 | 6.2 | 140 | 1 190 | 70 | 6.31 | 22.6 |
| 50-65 | 60 | 7.1 | 2.3 | 17.0 | 5.0 | 64 | 1 086 | 1473 | 3.84 | 12.8 |
| 65-75 | 75 | 16.7 | 2.9 | 24.5 | 4.5 | 151 | 3 700 | 438 | 11.33 | 33.6 |
| 75-80 | 80 | 27.4 | 4.1 | 28.0 | 4.1 | 248 | 6 944 | 1017 | 19.84 | 60.5 |
| 80-85 | 85 | 4.7 | 5.1 | 30.0 | 3.9 | 43 | 1 290 | 219 | 3.65 | 3.5 |
| Total | | | | | | 906 | 14 300 | 1943 | 52.50 | 165.5 |

**Table 3. Increase in weight limits to 125 000 lb GVW, 20 000 lb single axle, and 34 000 lb double axle to move 14 300 tons.**

| | | | | | | | To Move 14 300 Tons | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | EAL | | | | | | EAL | | | |
| GVW (lb 000s) | Avg Weight Used (lb 000s) | Truck Type | Rigid Pavement | Flexible Pavement | Freight per Truck (tons) | Fuel Economy (miles/gal) | No. of Trucks in Fleet | Freight (tons) | Rigid Pavement | Flexible Pavement | GVW (lb 000 000s) | Fuel Consumption (gal/mile) |
| 20-35 | 33 | | 0.2 | 0.2 | 0.3 | 7.6 | 82 | 86 | 16.4 | 16.4 | 2.71 | 10.8 |
| 35-50 | 45 | | 0.5 | 0.8 | 8.5 | 6.2 | 24 | 204 | 12.0 | 12.0 | 1.08 | 3.9 |
| 50-65 | 60 | | 2.6 | 2.0 | 17.0 | 5.0 | 24 | 408 | 62.4 | 48.0 | 1.44 | 4.8 |
| 65-85 | 80 | Semi | 3.7 | 2.2 | 28.0 | 4.1 | 42 | 2 352 | 155.4 | 92.4 | 6.726 | 20.5 |
| | | 27-ft double | 2.0 | 2.2 | 28.0 | | 42 | | 84.0 | 92.4 | | |
| 85-110 | 105 | 27-ft triple | 4.1 | 4.4 | 36.0 | 3.5 | 100 | 3 600 | 410.0 | 440.0 | 10.5 | 28.6 |
| 110-125 | 125 | 27-ft triple | 7.0 | 7.6 | 45.0 | 2.8 | 50 | 7 650 | 350.0 | 380.0 | 21.25 | 60.7 |
| | | 40-ft double | 4.5 | 2.9 | 45.0 | | 120 | | 540.0 | 348.0 | | |
| Total | | | | | | | 484 | 14 300 | 1630.2 | 1429.2 | 43.7 | 129.3 |

Note: Maximum single-axle and double-axle load = 20 000 and 34 000 lb, respectively.

Table 4. Fuel saved by using trucktrain.

| Year | Level of Growth in Freight Traffic | Fuel Saved (bbl 000 000s/day) | |
|---|---|---|---|
| | | Scenario B | Scenario C |
| 1980 | | 15 000 | 62 000 |
| 1985 | 1 | 18 300 | 79 000 |
| | 2 | 23 300 | 90 000 |
| 1990 | 1 | 21 700 | 84 000 |
| | 2 | 26 500 | 100 000 |
| 1995 | 1 | 23 300 | 92 000 |
| | 2 | 32 600 | 130 000 |
| 2000 | 1 | 26 500 | 97 000 |
| | 2 | 41 700 | 163 000 |

terstate highways of 0.82 over 20 years. The ratio for this model (129.3/165.5), suggestive of average U.S. truck movement on the Interstate, is 0.78.] This saving amounts to about 0.0025 gal/ton mile. Projected fuel savings in barrels per day, using the ton miles subjected to this system (Table 1), are given in Table 4.

## CAPITAL COSTS

The capital costs required for the limited-trucktrain option fall into four categories.

### Truck Upgrading

The first area of capital costs is the upgrading of the truck to handle the extra loads. Some tractors already have the capability to pull the extra load. Heavy-duty axles, larger engines, improved brakes, etc., will be required to upgrade others. The improved productivity resulting from upgrading will more than offset these costs. In 1990, for an estimated 50 000 miles/year/tractor, 50 000 heavy-duty tractors would be needed for scenario B, and about 250 000 to 380 000 tractors for scenario C. The heavy-duty cab is estimated to cost about $10 000 to $15 000/tractor. Under these assumptions, the investment would amount to about $750 million for scenario B and $3.5 billion for scenario C.

The investment costs for truck improvement are related to the amount of freight subjected to the higher loads and to the operating principles. For example, do you keep the upgraded trucks (probably less fuel efficient than their nonupgraded equivalents) on the Interstate and meet most traffic at the corral, or do you simply unhook the trailer(s) at the corral and take the single trailer for further delivery?

### Interstate Upgrading

The second area of capital costs is in upgrading the Interstate to provide for truck stops. This analysis assumes that a truck stop is needed about every 40 miles and that about 600 are required. The investment cost considered is to provide access roads to the stops, each of which requires the equivalent of 1-2 miles of two-lane Interstate-type construction. At $1.5 million/mile for good freeway construction, Yoder of Purdue University estimates that $1.4 billion would be required.

### Provision of Corrals and Access

The corrals used for the make-up and disassembly of the doubles and triples must be paved and freeway access provided. Upgrading the non-Interstate access to some corrals may also be required. Corrals closer together than 50-75 miles would not be appropriate and, for most areas of the country, 200 miles is a more reasonable distance between corrals. These calculations assume that corrals near intersections of two Interstates can serve both. Two corrals will be needed in some areas where one corral cannot serve both directions. Two-hundred corrals for the entire country would be a conservative estimate. The cost components of each corral break down as follows:

1. An access road to the Interstate is assumed to represent 3 miles of two-lane road, for a cost of $4.5 million/corral.
2. The corral itself needs to accommodate about 100 trailers at one time and will need room for maneuverability. This will require approximately 4 acres of high-grade parking lot plus the land; at $10/yd$^2$ of Interstate-type concrete and $150 000 for the land, this means that it will take $2 million to construct each corral.
3. Local roads leading to the corral may need upgrading. For many cases, it can be assumed that the truck will enter the corral by taking the normal entrance to the Interstate and move to the closest corral over the Interstate. A conservative estimate suggests that perhaps about 80 corrals will need about 5 miles of additional high-grade, two-lane highway to provide new or upgraded access routes. This will increase the cost by about $600 million, or an average of $2 million/corral.

The total investment cost is approximately $8.5 million/corral.

### Road Upgrading

The fourth element of potential cost is the upgrading of roads. The EAL (measure of road damage) will actually be somewhat less for the same freight carried without the trucktrain (3). Therefore, the only reason for added cost to upgrade will be increased traffic. If traffic grows by 10 percent, the increased traffic will require an increase in road rehabilitation costs somewhere in the range of 0.1-0.5 ¢/total ton-mile of trucktrain carriage. (Estimates of rehabilitation costs vary. The whole area is being evaluated by the U.S. Department of Transportation in their studies of user charges and truck size and weight. This paper uses a rough computation by assigning the total Interstate costs to trucks.)

### Investment Cost for Two Scenarios

For scenario B, some minor upgrading of the road and truck-stop egress will be needed. Twenty corrals are anticipated at $10 million each and 100 truck stops at $4.5 million, which makes a maximum investment of $900 million ($650 million for road and corrals plus $250 million for tractors). Implementation of scenario C will require a minimum of $6 billion total investment.

Each investment cost for the roadway and the corrals is independent of the year, except for inflationary updating. It will probably take five years to implement all the road changes, but it is reasonable to assume that the system can be put into effect on a makeshift basis very quickly if necessary.

## PRODUCTIVITY INCREASES

Implementation of the limited-trucktrain concept will greatly improve the productivity of the line-haul portion of trucking. Several important measures are estimated:

1. Ton-miles per dollar (up 32 percent)--The

cost of line-haul is a function of distance and percentage loaded return (backhaul). Based on data given by Suckanec (7), the costs per mile range from about $1.20 with a 50 percent backhaul to about $0.90 with a 100 percent backhaul for a trip of 300-600 miles. The table below gives an estimate by line item of the line-haul costs, which decrease from about 7.5 to 5.67 ¢/ton-mile for trucktrain:

| Item | Truck Cost ($/mile) Without Trucktrain | With Trucktrain |
|---|---|---|
| Labor | 0.45 | 0.62 |
| Depreciation | 0.35 | 0.44 |
| Fuel | 0.24 | 0.35 |
| Maintenance | 0.36 | 0.08 |
| User costs | 0.10 | 0.20 |
| Total | 1.20 | 1.70 |

2. Ton-miles per gallon (up 26 percent)--Based on the traffic models of Tables 2 and 3, the energy productivity increases by about 26 percent, from 87 to 110 ton miles, for each gallon of fuel.

3. Ton-miles per labor hour (about 40 percent increase)--The productivity for labor includes an allocation of stem time for assembly and disassembly in the corrals and strictly enforced speed limits. Strictly enforced driving times may also increase labor hours over minimum. For example, a 400-mile run for a single truck might take about 9 h (710 truck miles/h) whereas for a double with two drivers it could take 13 h (1000 truck miles/h) split between the two drivers, which is an increase of 40 percent. Even allocating 8 h for the two drivers with the double gives an improvement of about 16 percent.

4. Annual ton-miles per tractor (up 56 percent)--Based on the fleet model of Tables 2 and 3, it takes only 486 tractors to do the job formerly done by 906. With corral time and more stringent inspection and maintenance, tractor availability will likely be reduced. A 20 percent increase in tractors, which has been granted for the trucktrain, is assumed in the productivity computation.

## BENEFITS AND COSTS

Trucktrain produces significant benefits for the highway system, trucking, and, potentially, the general public:

1. The highway system will be better preserved if weight limits are enforced and travel over secondary and local rural highways is reduced. The trucks will, of course, develop a different travel pattern. If the suggested approach generates increased use of 27-ft trailers over the large number of 40-ft trailers now involved, congestion resulting from city pickup and delivery might be reduced.
2. Trucking, of course, benefits by achieving a significant increase in productivity. A number of industrial and operational adjustments will occur, probably including the development of some special over-the-road long-haul companies. Many more drivers will be able to spend more time at home, a benefit they often request (8).
3. Road conditions should improve if new mechanisms are provided to enforce weight and to collect costs. In addition to the inherently better safety suggested by some of the western carriers, the new mechanisms will make it possible to maintain control of drivers who are allowed access and require them to have extra training, insurance, and special licenses. Safety should also improve if new travel patterns emerge that decrease or limit travel of combination trucks on non-Interstate highways.

Note should also be taken of the following potential problems if a maximum shift to the suggested system occurs:

1. Because of a reduction in the use of tractors, there will be a corresponding decrease in the number of drivers. At the present time, there are about 2 million truck drivers in the United States (9). Installation of scenario C could create unemployment for about 30 percent, or 600 000 drivers.
2. The excessive number of unused tractors would cause problems in the used-tractor market and could result in the failure of companies that depend on that market. Changing systems affects both the sales and service industries and the large companies that turn over their fleets every two or three years. The productivity gains probably outweigh this concern.
3. Truck size and weight are factors in certain types of highway accidents. Increased disparity of size and weight between trucks and other vehicles could result in greater damage to the smaller vehicles. The heavier trucks will have poorer acceleration-deceleration capabilities (10), cause more splash and spray (11), and require longer passing distance and longer stopping distance. Added brake wear will result from increased weight (12). In addition, even though the total number of vehicles will be less, the impact of large numbers of double trailers may be psychologically forbidding to the motoring public. If the average motorist feels too unsafe, an alternative, potentially less safe, non-Interstate road would be chosen.
4. There will be a minimal impact on the manufacturers of tractors, who will experience an increased demand for more substantial tractors and for heavy-duty parts for retrofit. Increased maintenance, particularly for brakes, will be required.
5. Perhaps the most significant effect will be on the railroads. If the costs of truck transportation and the service offered by this new use of the Interstate become very attractive, then some percentage of the traffic (13) will move from the more energy-efficient rail mode to trucks. The transition from rail to truck was not quantified because of insufficient data and the difficulty in adequately estimating the traffic that will move from rail to truck. Hymsom (13) begins to identify some of the possible effects of the new system but, for a good forecast, factors such as spatial distribution of markets, fleet mix, equipment, utilization and availability, reduction in circuity, rate structure, empty truck/haul ratios, intermodal coordination [trailer on flatcar (TOFC)] potential, and average revenue yields must be analyzed on a region-by-region basis.

Energy intensity calculations that compare truck and rail, especially TOFC, are quite variable. In examining a number of results (14-16), a 40-ft average truck seems to vary from about 1600 to about 2200 Btu/ton-mile on line-haul. For example, where 32 loaded (16.6 tons/trailer) and 4 empty trailers are hauled and fuel use is 4 miles/gal full and 8 miles/gal empty, an energy intensity of 2200 Btu/ton-mile results.

For the double 40, the extra weight reduces fuel efficiency by about 25 percent to 3 miles/gal, resulting in 1400 Btu/ton-mile for the example of 16 loaded double bottoms and 2 empty doubles. The double-bottom fleet of Table 3 shows about 22 percent reduction over that of Table 2.

The standard TOFC depends on operating conditions, loaded versus empty trailers, percentage use, grade, wind, and speed. Based on a 20-car dedicated standard flatcar (TTX) train carrying 36 trailers (32 loaded and 4 empty) and the use of Sprint data

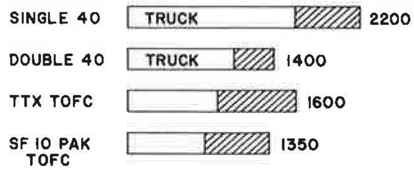


**Figure 1. Estimated Btu per ton mile for TOFC versus truck.**

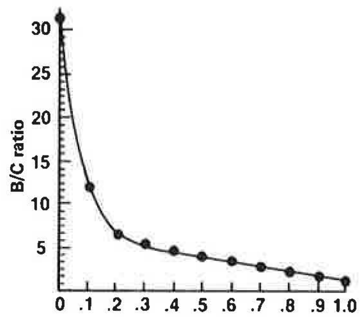


**Figure 2. B/C ratio versus road rehabilitation costs.**

(14) of 3.88 gal/1000 gross ton-miles, an energy intensity of 1600 Btu/ton-mile results. Other references show results as low as 800 Btu/ton mile (15). Even for the consist fully loaded with 20 tons of cargo in each trailer and 3.5 gal/1000 gross ton-miles, the energy intensity is 1130 Btu/ton-mile. The Santa Fe "Fuel Foiler" (10-PAK) provides an improvement in energy intensity of 15 to 20 percent.

It is probably safe to say that TOFC thus is about twice as energy efficient as conventional truck and about equivalent to the double 40 concept. Figure 1 shows the comparison.

The benefits of this approach considerably outweigh the costs, as shown below:

| Discount | Billions of Dollars | | B/C |
|---|---|---|---|
| Rate (%) | Benefits | Costs | Ratio |
| 0 | 220 | 14 | 15.4 |
| 10 | 74 | 6.2 | 12 |
| 20 | 33 | 3.6 | 9.3 |

Three discount rates are identified, and 0.1 ¢/total ton-mile is assumed in the simulation for road rehabilitation. Figure 2 shows how the B/C ratio (using a 10 percent discount rate) varies as a higher assessment is made for road rehabilitation.

## CONCLUSIONS

There is no question that a trucking system such as that described in this paper would save diesel fuel, improve productivity, and ultimately save consumer costs. Implementing such a system nationwide would save more than 100 000 bbl/day, which is equivalent to an investment of about $6 billion for synthetic fuel plants.

Enhanced productivity for truck and better use of tractors mean that truckers would see some or all of the cost as being advantageous to them. The amount can easily be raised by increasing the user charge. Any increase in the user charge will be more than offset by the reduction of costs per ton-mile that will occur with reduced labor (25-40 percent) and equipment (20-40 percent). Insurance and special pay to drivers of doubles will rise. Stem time will increase as will benefits to the unemployed.

Obviously, a number of questions remain. Two in particular are highest priority:

1. What, in fact, will be the modal shift from rail to truck if such a configuration is considered?
2. Can the motorist's safety concerns be overcome?

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