during 1979 alone, and this kind of price increase may continue this year. With this increase in the price of jet fuel has come the stark reality that short-haul jet transportation in those market segments of 150 miles or less simply has become uneconomic, no matter how high the average load factors. Yet those markets do not necessarily have low passenger densities. They include, for example, American Airlines suspending its flights between Dallas-Fort Worth to Oklahoma City, TWA dropping Wichita-Kansas City schedules, and United Airlines eliminating service in a number of substantial California markets, such as Bakersfield, Visalia, Fresno, Merced, Santa Barbara, and Sacramento. Nor is an end to this trend in sight. As the price of fuel increases, so do the stage lengths that continue to be profitable for jet air-carrier service.

AIRPORT SERVICE AND MARKET IMPACT

Commuter air carriers serve 819 U.S. airports. Nearly 400 of the U.S. airports receiving regularly scheduled air service are dependent on commuters for that service. One-quarter of all scheduled flights in 1979 was performed by commuter air carriers. Commuters are increasingly being relied on by the U.S. Civil Aeronautics Board (CAB) to meet the essential air transportation needs of the nation's small cities, which are guaranteed service for a period of 10 years by the Airline Deregulation Act. The CAB is mandated to guarantee continued air service at these points and, in every instance to date, is relying on commuter air carriers to provide such service. In order to meet these mandated public-service needs, it is essential that commuter air carriers have sufficient fuel to provide the increased service expected of them. Commuters, however, are not being allocated their current requirements. In fact, allocations range down to 60 percent of their 1978 allocation base. Thus, airline deregulation and the service mandated to small cities by the Airline Deregulation Act are being jeopardized by the lack of fuel.

The market impact of a special allocation of current requirements for commuter air carriers would be negligible. As a form of efficient mass transportation, the commuter air carriers offer the traveler the direct benefit of both energy and time savings. In 1979, commuter airlines carried more than 12 million passengers and 545 million pounds of cargo, up 22 percent and 35 percent, respectively, over comparable 1978 statistics. In doing so, they consumed only 0.7 percent of all aviation fuel. When compared to the other modes of transportation, this fuel translates into only 0.06 percent of all fuel used for passenger transportation purposes.

Commuters also use fuel-efficient aircraft. Given a 100-mile stage length, the average commuter aircraft attains 51.8 seat-miles/gal of fuel when all seats are occupied. The most efficient commuter aircraft, the Shorts SD 330, attains a figure of 58.3 seat-miles/gal of fuel. These figures are all the more impressive when compared to the average jet airliner, which, on average, attains a comparable figure of 31.8 seat-miles/gal over a 400-mile stage length. In comparison, the average commuter aircraft is 61 percent more efficient than the larger aircraft.

The wide geographic dispersion of the points served by commuter air carriers and the small size of aircraft used in the service make it infeasible for commuters to tanker (carry) fuel from one point to another. Thus, it is important that fuel be available at all points for commuters. The Commuter Airline Association of America estimates that commuter air carriers will need about 80 million gal of jet fuel this year, about 20 percent more than in 1979, and about 35 million gal of aviation gasoline, an increase of 15 percent over last year.

Commuter air carriers provide a mass transportation service to otherwise isolated small cities. The market impact of fuel allocation on them would be slight. Their service is provided in fuel-efficient aircraft. Unless these carriers receive sufficient fuel, the essential air transportation program mandated by the Airline Deregulation Act is in danger, as well as airline deregulation in general.

Effect of a Sudden Fuel Shortage on Freight Transport in the United States: An Overview

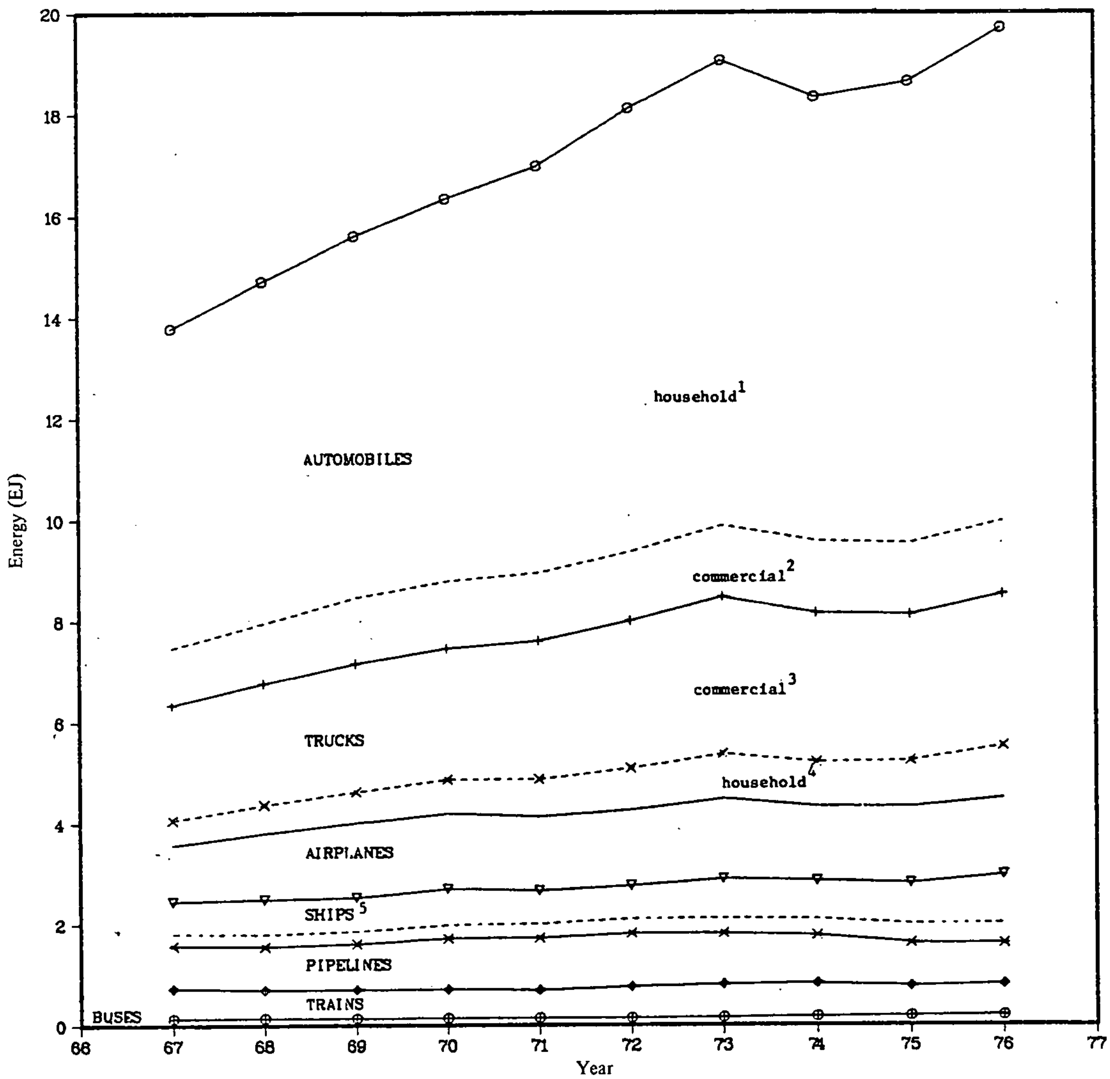
John N. Hooker

Rock oil was a curiosity in 1870—a time when the U.S. economy was powered by coal, wood, wind, water, and muscle (1). In 1977, oil and its distillates provided 49 percent of our energy and natural gas, 26 percent. During the period 1950-1975, petroleum's share rose from 40 to 46 percent, and consumption rose from 1.0 million to 2.6 million m^3/day (6.5-16.3 million bbl/day) (2).

To satisfy our thirst for oil, we have slipped into a dependence on foreign sources for which it is difficult to find a parallel in our history. The hard necessity of maintaining proper relations with some of our suppliers has become the anvil on which our foreign policy is shaped. Our vulnerability has forced us to compromise our principles in many instances. Our dependence on oil has reached the point where it would be foolish not to consider the potential effect of a sudden reduction in our foreign supply. The difficulty, of course, is that we import 45 percent of our crude oil and that 79 percent of this comes from OPEC nations (3). Some 43 percent of these imports is supplied by nations of the Middle East, a part of the world that is traditionally unstable and becoming more unstable. It is true that a cutback in foreign production would probably be mollified by the same determination to secure petroleum that got us into this predicament. But a relatively small perturbation of supply can precipitate a large disruption of distribution.

This paper will examine the potential effects of a sudden supply disruption on freight transport in particular. The paper discusses what freight transport is like, especially as it relates to the use of energy; it is important to understand where the energy goes and what affects the level of its consumption. It then sets out some of the main conservative responses transport firms might make to a shortage, with a rough indication as to their potential effectiveness. Modal shifts and opportunities within these modes are examined, and suggestions about whether and how our knowledge in these areas can be improved are made.

Figure 1. Energy used by civilian transport modes in the United States, 1967-1976.



ENERGY CHARACTERISTICS OF FREIGHT TRANSPORT

In 1976, the United States burned 895 million m^3 (5633 million bbl) of petroleum products. Transportation, which is 96 percent oil fueled, not only uses 61 percent of this fuel but favors the lighter, more-expensive distillates. All gasoline, nearly all jet fuel, and 74 percent of distillate fuel were used for transportation purposes in 1976 (4). Figure 1 (5), however, reveals that most of this fuel moved people not freight. [In Figure 1, household[1] includes fuel used by commercial automobiles not in fleets of four or more, as well as a relatively small amount of fuel used by state and local government automobiles, state and local government buses and trucks (except school buses), and vehicles not classifiable as automobiles, trucks, motorcycles, or buses (e.g., motor homes). Commercial[2] includes fuel used by commercial automobiles in fleets of four or more. Commercial[3] includes all fuel consumed by trucks used primarily for purposes other than personal transportation, plus all fuel used by federal government trucks. Household[4] includes all fuel consumed by trucks used primarily for personal transportation. In regard to ships[5], the area above the dashed line indicates fuel used by commercial vessels; the area below the dashed line indicates fuel used by pleasure boats.] Commercial freight transport in 1976 accounted for 111 million m^3 (701 million bbl) of liquid fuel, only 22 percent of the 505 million m^3 (3178 million bbl) used by civilian transportation as a whole. Freight transport is also better at operating with the heavier crude-oil fractions. In 1976, all of civilian transportation's residual oil and only 11 percent of its gasoline were used for moving freight (5). [It should be emphasized that no one knows for sure how much of each fuel is used for freight transport or for each mode of transport. The most uncertainty exists in the highway modes, where most of the fuel is burned. The Federal Highway Administration (FHWA) publishes total highway fuel-use data based on tax receipts, but any further breakdown can only be a matter of estimation. The truck fuel-use estimates provided herein are based on truck-mile data collected as part of the 1967 and 1972 Truck Inventory and Use Surveys, each of which canvassed some 100 000 trucks of all types nationwide, and on estimated fuel efficiency of trucks by fuel, by range (local or intercity), and for four weight classes (6). The resulting estimates run lower than those of certain sources. The estimated 1976 total fuel use of trucks, for instance, is 112 million m^3 (706 million bbl), compared to the FHWA estimate—most often quoted—of 136 million m^3 (857 million bbl). It has not been possible to learn, however, just how the FHWA estimate was made.]

In freight transportation, there is a well-known trade-off involving flexibility and level of service on the one hand and energy efficiency on the other. It is a fact that a vehicle that can carry more commodities more places faster on a more accommodating schedule burns more fuel. Listed in order of flexibility and in reverse order of efficiency, the four major freight modes are trucks, rail, marine, and pipeline. (Since air freight, other than belly freight, in passenger aircraft uses less than 1 percent of freight transport energy, it is omitted from consideration here.)

Trucks are not only the least efficient of the four modes but are the predominant users of fuel and energy. In 1976, they used 69 percent of the liquid fuel and 57 percent of the energy devoted to freight movement (Table 1, 5). If intercity trucking is weighed against trains and ships, it is seen to use half the energy but to carry only 30 percent of the ton-kilometers, resulting in an average energy intensiveness of about 2000 mm/s^2 (2800 Btu/ton-mile). This compares to about 500 mm/s^2 (700 Btu/ton-mile) for rail movements (7). Tables 2 (5) and 3 (8) reflect this relation between freight movement and energy use. Table 4, which notes trends in intercity truck and rail freight energy intensiveness, is derived from data in Tables 2 and 3. The method used to calculate energy intensiveness is noted below.

[The customary unit of energy intensiveness, J/kg•km (=kJ/t•km), is equivalent to a unit of acceleration, mm/s^2. The letter "t" is used herein as an abbreviation for the metric ton. In the English system, 1000 Btu/ton-mile is equivalent to 0.07369 ft/s^2. The energy intensiveness of a vehicle in fact represents the amount of constant acceleration it would deliver to its cargo if all of its energy were used to achieve acceleration. To get the energy required for a trip, multiply this acceleration (mm/s^2) by the mass moved (kg) and the distance covered (km); the result is in joules ($mm \cdot km \cdot kg/s^2 = kg \cdot m^2/s^2 = J$). It is also possible to use another method to obtain this result. Multiply the acceleration (energy intensiveness) in ft/s^2 by the mass in slugs and the distance in feet to get the energy use in foot-pounds.]

To be sure, the comparisons in the tables, text, and other sources are unfair to trucks because trucks carry materials of relatively low density. Yet it has been estimated (7) that even when carrying high-density materials, trucks operate at about 1350 mm/s^2 (1860 Btu/ton-mile). It is clear that the flexibility and speed of truck transport exact a substantial energy premium.

A comparison of rail and truck transport illustrates how speed and flexibility can cost energy. The steel rails that limit the extent of rail service reduce rolling friction. They permit freight cars to be pulled in long consists, which reduces air drag but necessitates time-consuming switching operations. The segregation of rail traffic on its own network also reduces the energy-consumptive stopping and starting to which vehicles on the highway are subjected. The sheer size of trains, compared to trucks, provides economy of scale with respect to energy use but simultaneously makes the rail system more sluggish and less flexible. Finally, the ability to control operating conditions on the rails permits the traction engines to be designed for a fairly narrow range of conditions. Highway vehicles must negotiate a greater range of inclines and must deliver a much greater range of torques and acceleration rates. One can build this kind of flexibility into an engine only by sacrificing efficiency.

The energy characteristics of water transport depend on which of the four classes of water carriers is at issue. These classes are lakewise shipping, which carries mainly iron ore, iron, and steel; coastal traffic, dominated by tankers and tanker-barges; and river and international shipping, each of which moves a variety of products. Due to the relatively high density and viscosity of water, ships and barges are not inherently more-efficient transportation devices than trains or even trucks. They use less energy per ton-kilometer because of a substantial economy of scale and because they move slowly. Lakes, oceans, and navigable rivers are big and float the biggest transport vehicles in existence. Big ships are more efficient principally because their surface area exposed to water drag is smaller per unit of cargo volume. A ship's energy intensiveness varies roughly with the square of its speed so that, as a rule of thumb, a 10 percent reduction in speed effects a 20 percent reduction in energy use (9). It happens that the economics and engineering of shipping have resulted in operating speeds that, in combination with economy of scale, make water shipping more efficient than rail shipping. Rose (7) estimates that energy intensiveness averages about 270 mm/s^2 (380 Btu/ton-mile) for coastal shipping, 370 mm/s^2 (510 Btu/ton-mile) for lakewise shipping, and 350 mm/s^2 (480 Btu/ton-mile) for inland shipping, compared to about 500 mm/s^2 (700 Btu/ton-mile) for rail shipping. (No reliable estimates for international water movements are available.) The energy advantage of inland water transport is offset, however, by the fact that rivers are crooked. A correction for circuity can be made by comparing energy use per ton per great-circle kilometer. Measured in this way, rail's energy intensiveness (7) is about 650 mm/s^2 (900 Btu/ton-mile), whereas the corresponding number for inland water transport is 670 mm/s^2 (920 Btu/ton-mile). It should be borne in mind, of course, that these numbers are only rough averages; transport efficiency varies enormously for different commodities and over different routes.

Pipeline transport is unique in that its vehicle is stationary. This and a substantial economy of scale enjoyed by large-diameter pipelines make them the most-efficient movers of oil and oil products. No reliable data for the nation as a whole exist, but pipeline movements of oil products from the U.S. Gulf Coast to the Atlantic seaboard achieve an energy intensiveness of some 200 mm/s^2 (270 Btu/ton-mile), compared to a minimum of 350 mm/s^2 (480 Btu/ton-mile) for competing coastal tankers (10). The greater circuity of the water route compounds even this advantage. The penalty for such efficiency, of course, is the inflexibility of pipeline transport. The routes are fixed when the pipe is buried, and the flow must remain near capacity for profitable operation. Pipelines are also suitable for only a very small class of commodities, albeit the class is growing with the development of various types of slurry pipelines (11). As for gas pipelines, they are considerably less efficient than oil lines but have no serious competitor for overland transport. Gas lines consume about 3 percent of the heating value of their cargo per 1000 km of movement, compared to less than 1 percent in case of oil lines, and they consume nationwide about three times as much energy as oil pipelines. The energy intensiveness of a pipeline is highly sensitive to the flow velocity and the pipe diameter, however. It varies roughly with the square of the flow velocity, and a rule of thumb, valid at least for oil pipelines, is that energy intensiveness is more or less inversely proportional to the diameter. [This assumes that flow velocity is independent of diameter, whereas oil tends to move somewhat more rapidly in large pipes. A study whose aim is to quantify the energy use and efficiency of oil pipelines more accurately is under way at Oak Ridge National Laboratory (12).]

I will not discuss pipelines further in this paper for two reasons. One is that pipelines consume relatively little oil. Three-quarters of pipeline energy is supplied by natural gas and nearly all the rest by electricity. Since 18 percent of electricity is generated by burning oil at roughly 30 percent efficiency (13), pipelines use indirectly about 0.6 million m^3 (4 million bbl) of oil per year, or only about 0.5 percent of that consumed directly for freight transport. The other reason for neglecting pipelines is that the allocation of fuel in an emergency will require maximum flexibility on the part of pipelines. Indeed, the ability of pipelines and other transporters of energy to implement a given allocation plan is too seldom weighed. In any case, the urgency of routing fuel to where it is needed would override any desire to conserve energy in its transport.

The obvious lesson to be learned from the foregoing is that any proposed scheme for saving fuel in an emergency

Table 1. Types of fuel and energy used by commercial freight transport modes, 1976.

	Gasoline (m^3 000 000s)		Diesel Fuel (m^3 000 000s)		Residual Oil (m^3 000 000s)		Liquid Propane Gas (m^3 000 000s)		Jet Fuel (m^3 000 000s)		Electricity (kW·h 000 000 000s)		Natural Gas (m^3 000 000 000s)	
Mode	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
Truck[b]	47.3	100	36.3	68	0		1.0	100	0		0		0	
Marine[c]	0		4.5	8	18.7	95	0		0		0		0	
Pipeline	0		0		0		0		0		11.3	100	15.5	100
Rail	0		12.4	23	0.9	4	0		0		0		0	
Air[e]	0		0		0		0		0.6	100	0		0	
All modes	47.3	100	53.3	100	19.6	100	1.0	100	0.6	100	11.3	100	15.5	100

[a]Assumes 38.49 billion J/m^3 (138 100 Btu/gal).
[b]Excludes government-owned trucks and all trucks used primarily for personal transportation.
[c]Includes fuel purchased in the United States for both domestic and international shipping.
[d]No breakdown by fuel is available.
[e]Includes only freight aircraft operated by U.S. certificated air carriers; fuel used to transport belly freight in passenger craft is excluded.

Table 2. Trends in commercial freight transport energy use by mode, 1967-1976.

	Energy Use (PJ)										
Mode	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
All modes	4251	4422	4584	4808	4914	5190	5484	5243	5066	5318	NA
Truck[a]											
Local	1398	1439	1474	1486	1513	1567	1589	1468	1434	1452	NA
Intercity	853	943	1034	1089	1201	1329	1488	1451	1424	1526	NA
Marine[b]	642	693	670	716	651	653	778	756	802	954	1061
Pipeline	840	856	901	1001	1028	1053	1006	943	846	803	791
Rail	517	491	504	515	522	588	624	625	561	584	595

Note: 1 J = 0.001 384 Btu; NA = not available.

[a]Local trucking is that mostly in the local area (in or around the city and suburbs, or within a short distance of the farm, factory, mine, or place where the vehicle is stationed). The rest is classified as intercity. Estimates are based on interpolation and extrapolation of the percentages of each fuel type used for local and for intercity trucking in 1967 and 1972.
[b]Military shipping excluded.

Table 3. Trends in commercial freight movement by mode, 1970-1977.

	Movements (t·km 000 000 000 000s)							
Item	1970	1971	1972	1973	1974	1975	1976	1977
Intercity trucks[a]	601	628	687	736	723	664	745	803
Rail[b]	1121	1086	1141	1255	1243	1107	1153	1199
Inland waterways[c]	465	460	496	521	517	501	546	541

Note: 1 t · km = 0.684 ton-mile.

[a]Includes movements between cities and between rural and urban areas. Rural-to-rural movements and city deliveries are omitted.
[b]Revenue movements.
[c]Excludes coastwise and intercoastal movements.

Table 4. Trends in intercity truck and rail freight energy intensiveness, 1970-1977.

	Average Energy Intensiveness (kJ/t · km = mm/s^2)							
Intercity Mode	1970	1971	1972	1973	1974	1975	1976	1977
Truck[a]	1810	1910	1940	2020	2010	2150	2050	NA
Rail[b]	459	481	514	497	502	507	507	496

Note: NA = not available.

[a]Calculated by dividing energy use in Table 2 by movements in Table 3. The fact that the Table 3 figures do not account for long-distance movements from one rural area to another, while the energy use estimates do, makes the above estimates of energy intensiveness slightly high. Also, the energy intensiveness of an average loaded truck would be somewhat lower because the energy-use estimates in Table 2 cover the fuel used to drive empty trucks. The above figures are appropriate, however, for assessing the efficiency of truck transport as a system. Yet they should be interpreted with caution due to the difficulty of obtaining reliable estimates of energy use and movements.
[b]Calculated by dividing energy use in Table 2 by movements in Table 3. The energy intensiveness of an average loaded train would be somewhat lower because Table 2 covers energy use for switching and hauling empty trains, and Table 3 covers only revenue ton-kilometers shipped. The above numbers are appropriate, however, for assessing the efficiency of the rail system as a whole.

should be scrutinized for a corresponding degradation in service.

MODAL SHIFTS

The greater energy efficiency of the rail and water modes described earlier suggests that a quick transfer of shipping from truck to these modes could stretch fuel supplies. This suggestion is strengthened by results of the Transportation System Center's Freight Energy Model (14), evidently the most comprehensive and detailed effort to account for the behavior of freight transport. This model incorporates a somewhat aggregated representation of the U.S. freight network, including access points and transfer points. It takes into account the cost of movement over each link, travel and transfer times, costs of loading and transfer, link capacities and congestion, the effect of congestion on energy use, the effects of long-term contracts, and a number of other factors. One particular run of the model directed each shipper to choose modes so as to minimize the energy required to deliver cargo, regardless of cost. This policy was to be in effect through 1990. During this period, no technological or system improvements were allowed. A base case run of the model set up similar conditions but directed shippers to minimize costs, and it too ran to 1990. Not surprisingly, rail and marine's share of freight movement increases substantially when shippers are directed to minimize energy use.

The model indicated that the total intercity freight energy requirement drops by one-third when shippers do their best to save energy. This can be taken as an absolute upper bound on the saving that could be achieved in an

Total Liquid Fuel (m^3 000 000s)		Total Energy (PJ)		Crude Oil Equivalent[a] (m^3 000/day)
Amount	%	Amount	%	Amount
81.8	69	2977	57	212
23.2	19	954	18	68
0.1[d]	0	726	14	52
13.3	11	584	11	42
0.6	1	23	0	1.6
119.0	100	5264	100	375

emergency through modal shifts. In other words, the available fuel could be cut 31 percent, at an absolute maximum, without a reduction in the ton-kilometers shipped. Degradation of service does occur. Bronzini's figures imply that the ton-weighted average transit time for the portion of cargo shifted from truck to train would rise from 0.8 days to 6.8 days, assuming that the shifted freight gets average rail treatment. The heavy use of expedited trailers on flatcars (TOFC) would improve service for this freight, but it should be realized that TOFC transport is not as efficient as customary rail transport.

There are several reasons why modal shifts would not obtain anything like the 31 percent maximum fuel saving. One is that those who make the choice of mode, unlike the carriers themselves, would not ordinarily have an immediate incentive to conserve fuel during a crisis. Their object is to ship their freight quickly and cheaply. Consequently, any shift away from trucking would be that occasioned either by prohibitive rates (in instances where regulations would permit tariffs to reflect exorbitant fuel costs) or simply by the unavailability of trucks with fuel in the tank. The high cost of fuel would presumably have little effect on the modal choice of firms served by their own private carriers because an idle fleet of trucks could be economically disastrous for a firm. Similarly, many patrons of common carriers would pay dearly rather than subject their freight to railroad delays. Delays not only can spoil merchandise and alienate customers, but they can necessitate more warehouse space than is available or affordable. The surest motivation for a shift would be dry fuel tanks aboard a fair portion of the nation's trucks. Demand for rail transport under such unprecedented circumstances is inextricably bound up with the way a fuel crisis would alter demand for freight transport in general. Its prediction would be a herculean task, one that to my knowledge no one has undertaken in a serious way.

Another factor limiting modal shifts away from trucks during a crisis is the capacity of railroads to absorb their share of the diverted freight. Industry sources tend to be optimistic about the ability of the railroads to accommodate sudden influxes of new business and point to the rapid escalation of coal shipping over rail in the West after the 1973 embargo. But this optimism is not universal. The only general consensus regarding rail capacity is that it would be limited much more by the availability of cars and locomotives (in the short term) than by congestion, except in such bottleneck areas as high-volume seaports. Bronzini's model in fact indicated that the increase in traffic described above would not, generally speaking, cause problems of congestion. (The increase in ton-kilometers does not fairly represent the magnitude of the demand for new rail capacity because the new cargo is relatively less dense.) It is difficult to gauge, however, the ability of rolling stock to accommodate higher demand.

The ability of new freight to find a place on the rails would depend in part on whether it happens to be so routed that it could fill some of the rolling empties. Opportunities to boost quickly the number of available cars are limited. Sources at the Association of American Railroads indicate that the railroads are retiring cars earlier than in the past and would have the option of refurbishing these old cars rather than junking them. Such a move would be cost-ineffective in the long run but would be useful for supplying cars in the short run. As for new cars, there is already a backlog of orders for them.

Even if car space were found, it would probably be more difficult to find locomotives. It is difficult to obtain firm data on this point, but it appears that locomotives are used close to their capacity now. Lead time for ordering a new locomotive is at least six months, and a rise in demand would, of course, lengthen the delay. In the event of a fuel crisis, many railroaders would undoubtedly clamor for relief from regulations requiring branchline service. Besides making things more profitable for the railroads, this would free locomotives to pull longer consists on main lines and, as a bonus, would upgrade energy efficiency. But a reduction in branchline service would not only turn away some of the business for which room is being made, but it would of course necessitate an increase in truck service to the cut-off areas, potentially defeating the purpose of expanding railroad capacity. The new truck service would not only use more fuel but, if fuel supplies are very short, it may simply be unavailable. Thus, it appears unwise to count on the ability of railroads to provide a large immediate increase in freight service. If they accommodate a massive shift from trucks, it would be at the expense of service already provided.

There are yet other obstacles to a sudden shift in modes: limited waterway capacity (at least in the short run), long-term contracts with carriers, and so on. The foregoing observations do not prove that modal shifts cannot help significantly during a fuel crisis. But they do, I maintain, shift the burden of proof to one who would contend otherwise.

TRUCKS

A glance at Table 3 reveals what is happening to intercity trucking. It is booming. Table 2 shows that the resultant increase in energy consumption by intercity trucking accounts for two-thirds of the 1967-1976 increase in total freight transport energy use. (The reader is reminded that these are not firm data, because the fraction of the annual consumption of each fuel type that is attributed to intercity trucking is an interpolation or extrapolation of fractions derived from 1967 and 1972 data. It is certain, however, that intercity truck fuel use rose substantially between 1967 and 1972, by an amount close to that indicated in Table 2.) Table 4 documents the consequences for the efficiency of freight movement. The average energy intensiveness for overload transport (except pipeline) increased from about 900 mm/s^2 in 1970 to about 1100 mm/s^2 in 1976 (1300-1550 Btu/ton-mile). The energy intensiveness of intercity trucking itself appears to have been increasing up to the time of the 1973 embargo. These facts corroborate the popular observation that our economy is tending more and more to emphasize high-value, low-density goods—goods economically suited for energy-intensive truck transport. This trend does not bode well for our ability to weather another oil shutoff, except to the extent that these light goods are inessential gadgets we can well do without for a while.

But let us first examine whether, in a pinch, the trucking industry can move the same goods with less fuel. I will first discuss three proposed ways to reduce intercity fuel consumption: (a) slow down, (b) load the empties, and (c) use mechanical devices.

Slow Down

The energy advantage of slowing down is hotly debated, but it has been firmly established to exist (8). To begin with, the resistance to a typical [i.e., gross vehicle weight (loaded) = 27 700 kg (61 000 lb); frontal area = 8.9 m^2 (96 ft^2); normal road surface] truck's motion on a straight, level road in still air falls 16 percent when its speed drops from 105 to 90 km/h (65 to 56 mph). So, if air and road resistance were the only variables, fuel use per mile would be some 16 percent less for a typical truck at 90 km/h than at 105 km/h. The fact that diesel engines generally run more efficiently at low rpm tends to increase the saving, and the fact that lower speeds often require lower gears tends to decrease the saving. On-the-road tests put the saving at about 15 percent (15,16). In the well-publicized 55-mph road tests, staged by the Voluntary Truck and Bus Fuel Economy Program, 32 randomly picked truckers used an average of 9.3 percent less fuel at 55 mph than at an average higher speed of 62.3 mph on a level track (17). After examining driver reports of rpm and gear choices, as well as manufacturers' specifications for the tractors, analysts claimed that this 9.3 percent advantage could have been 13.9 percent if the drivers had shifted correctly. Some drivers, they said, used unnaturally low gear ratios at 55 mph. If they are right, a straight-line extrapolation would put the advantage of 105 over 90 km/h at about 17 percent.

The effect of slowing down seems to show up in the national data. Table 4 shows the energy intensiveness of intercity truck transport increasing until about the time the national 55-mph limit was imposed. Although the margin of error in these figures is of the same order of magnitude as the annual variations, it is difficult to believe that this distinctive pattern in the data is the result of random error. One might argue that, since average truck speed on rural highways, according to an FHWA study, fell only from 91.1 to 88.2 km/h (56.6 to 54.8 mph) between 1973 and 1975, speed reductions could not explain an improvement in fleet fuel efficiency. But the variance of the distribution of speeds appears to have narrowed considerably. In 1973, 31 percent of highway vehicles clocked was moving at least 8 km/h (5 mph) faster than the average speed, while in 1975 only 21 percent was moving at least 7 km/h (4 mph) faster than the average speed; average speed (18) had dropped from 97.0 to 89.8 km/h (60.3 to 55.8 mph). These latter data were unfortunately not collected for trucks in particular, but it is reasonable to assume the variance of truck speeds likewise decreased. This reduction in the variation of speeds would, due to the nonlinear relation between speed and fuel use, tend to improve efficiency. A narrower range of speeds also implies less acceleration and deceleration, and this would also contribute to higher overall efficiency. It appears, then, that speeds may have changed enough to account for the apparent leveling of truck energy intensiveness.

Although no one knows exactly the effects of speed on fuel efficiency under everyday driving conditions, it is difficult to deny that many truckers could cut fuel use 10 or 15 percent with a modest, perhaps proportional, reduction in speed. To be sure, such a reduction would probably cost money in ordinary circumstances because fuel costs represent only some 6 percent of a motor carrier's costs (19). The question is whether short fuel supplies would provide the incentive for a speed reduction. Insofar as a trucking firm or private carrier can control the speed of its drivers, the aggregate fuel saving of reducing speed would provide strong incentive for doing it. The cost of traveling 10 or 15 percent fewer miles due to lack of fuel can only outweigh the costs of a reduction in speed. (If every reduction in speed causes a certain loss of business, then the optimal solution would be an intermediate one in which speed and miles traveled are reduced a certain amount; solution of a nonlinear program would indicate how much.) The larger motor carriers claim, however, that their trucks already travel under 55 mph (although it is often unclear whether it is only the average of a rather wide distribution of speeds that is under 55 mph) because the cost of fuel has already made it economical to do so. If it is true that the large motor carrier fleets stay close to 55 mph already, it is unclear to what extent further speed reductions would improve their fuel efficiency. Because of the sensitivity of fuel consumption to terrain, equipment, and the driver at these speeds, there is no reliable estimate of the average savings of slowing down to, say, 45 or 50 mph. As for owner-operators, everyone says they drive fast, but the incentive to slow down imposed by a fuel shortage is less clear in their case. The 10, 15, or 20 percent saving of reduced speed would not often make the difference between making a run and not making it, and it can be argued that independent truckers, who cannot accumulate small savings as can trucking firms, would view the matter one trip at a time.

Load the Empties

Much has been made of the fact that a fair portion of trucks on the road is empty. An Interstate Commerce Commission (ICC) survey of 13 000 trucks on Interstate highways found in 1976 that about 20.4 percent of truck miles is empty truck miles (20). Table 5 shows the results of the survey in further detail. The fraction of truck fuel burned to propel these empty trucks depends on the distribution of truck speeds. A rough lower bound on the fraction can be had by calculating that some 60 percent of the resistance encountered by an average truck moving at 50 km/h (31 mph) is due to factors other than the weight of the cargo. An average truck is taken here to be one having the average tare weight and carrying the average cargo weight among trucks sampled in the ICC survey—12 500 kg (27 000 lb) and 13 600 kg (30 000 lb), respectively. If 20.4 percent of truck miles is empty, this suggests that at least 12 percent of intercity truck fuel is used to haul empties. This is a lower bound because the presence of cargo weight is a less important factor at speeds over 50 km/h and because drive-train resistance (not estimated above) reduces further the relative contribution of cargo weight to fuel use.

How many of the empty truck-miles can be eliminated? The ICC study (20) found that most empty haulage is necessary due to specialized equipment and commodity flow imbalances. Nonetheless, a fair portion of empty trucks drive past one another in opposite directions. Some 17 percent of these empty trucks (a) consisted of the same basic type of equipment, (b) normally carried compatible commodities, and (c) could have avoided at least 25 percent of their combined travel distance and at least 50 miles had they found an opportunity to exchange loads. This number may fail to take into account all the equipment barriers to exchanging loads, but, on the other hand, it does not reflect potential savings involving trucks using different routes. If 17 percent of empty truck miles were eliminated, the intercity truck fuel savings, conservatively estimated, would be about 2 percent.

Use Mechanical Devices

Most technological improvements in fuel efficiency cannot be extensively installed or adopted under the pressure of an emergency. Two that can be put to use in a matter of months are rpm governors and aerodynamic aids. Governors are already widely installed among truck fleets, and many firms order trucks with engines that are rated to limit fuel injection and, hence, power output. It is agreed that no governor is tamper proof, and various devices designed to disable governors are sold at truck stops. But no one seems to want to deny that governors can slow down a fleet. As discussed earlier, however, it is questionable to what extent existing governor settings would or should be changed in the event of a fuel crisis.

Air drag is particularly bothersome for trucks because of their high speed and their shape. Boxlike trailers and bluff cabs, smashed flat to make room for longer trailers within legal limits, generate about 50 percent of a truck's moving resistance at 105 km/h (65 mph) in still air. Crosswinds can worsen drag considerably because they set up turbulence on the lee side of the truck (21). Several add-on devices have been designed to smooth out some of the worst of the turbulence. Aside from the popular cab-top deflectors, there are nose cones for trailers, vanes for directing air around corners, and flexible gap fillers for reducing the eddies between the tractor and trailer. Manufacturers' claims for fuel-use reduction with such devices range as follows (22): deflectors, 6-33 percent; vanes, 3-27 percent; and gap fillers, 6-13 percent. Practical experience suggests that fuel economy improvements are more on the order of 3-5 percent for such devices (6,8,23). Many trucks already bear an aerodynamic appliance, however, and the fuel savings of two or more devices on the same truck are not additive. Furthermore, a stymied crisis economy can make and deliver a limited, if perhaps substantial, number of these appliances in the space of a few months. It is unlikely, then, that aerodynamic devices can be of significant help during a fuel crisis.

All in all, it appears that the most effective way to cut intercity truck fuel use in a crisis, short of reducing service, is to slow down. However, reduced speed itself degrades service and, when trucks are used to capacity, can reduce the ton-kilometers shipped. Since yet untapped fuel savings to be had from slowing down appear to be significant but not large, the dominant response of the intercity trucking business to a severe fuel shortage would be to curtail the number of miles driven. The number of ton-kilometers carried would not fall proportionately because many of the least-productive runs would be cut first. This is not meant to suggest that the scene would be one of orderly optimization. Disruption of deliveries in one sector can have repercussions along an entire chain of production and delivery so that a carrier's most-productive routes might dry up overnight. Yet insofar as a carrier's customers remain predictable, it can pick and choose among them—within the limits of law and contract, of course—so as to make better use of its fuel. Can the extent of service reduction be quantified in advance? Here again, any attempt to forecast economic behavior in such a volatile situation, it seems, must assimilate so many of the details of the economy and the freight transport system as to be hopeless.

It would be unwise to ignore local trucking, which consumes nearly as much fuel as intercity trucking. Table 6 (5) and the data below (5) provide insights to fuel and energy use by commercial trucking:

Fuel Type	Local Trucking	Intercity Trucking	Total
Gasoline (m^3 000 000s)	33.8	10.7	44.5
Diesel (m^3 000 000s)	6.5	29.8	36.3
Liquid propane gas (m^3 000 000s)	1.0	0	1.0
Total energy (PJ)	1450	1530	2980

There is potential for saving some of this fuel in the intelligent choice of delivery routes and consolidation of delivery runs. About half of local trucking fuel is burned by pickups, panel trucks, beverage trucks, and garbage trucks (Table 7, 5), and a good many of these trucks make fairly regular pickup, delivery, or service calls. The largest operators claim that their routes are optimally chosen already, due to the clear economic incentive to do so. They insist that any reduction in fuel means a reduction in service. This is probably not the case, however, with respect to the multitude of smaller operators. The problem of optimal routing is theoretically quite difficult, but algorithms that produce a good, if perhaps suboptimal, routing can be applied by experts. The general impression of persons in operations research is that few firms have cared to sustain the expense of hiring a consultant for this purpose, even though it is common for an optimizing of routes to result in a 10 or 15 percent savings in expense and distance traveled.

In any case, even if optimization of routes would help little, there appears to be a good deal of flexibility in local trucking. By cutting the frequency of runs so as to raise load factors, consolidating pickup-truck errands, and so on, fuel use could be reduced significantly, albeit service and convenience would undoubtedly suffer. This is not to say that a firm should cut out delivery or pickup altogether, however, since customers may consume even more fuel as they come by to pick up or deliver goods. These matters could be quantified, but extensive and expensive surveys of local trucking would appear to be necessary to obtain reliable estimates of the possibilities for fuel conservation during a crisis.

RAIL

Railroad consumption of energy is already low. Railroads use about 11 percent of the energy consumed for freight transport, less than any other freight mode except air

Table 5. Survey results of empty truck miles on Interstate highways, 1976.

Category	No. of Trucks Sampled	Empty Truck Miles (%)
All trucks	13 165	20.4
Van	6 645	18.1
Refrigerated van	2 164	14.8
Flat or lowboy	2 304	18.9
Tank	1 073	38.0
Bulk	410	39.3
Other	487	30.7
ICC authorized	7 243	16.2
Exempt	1 403	21.2
Private	4 458	27.3
Intrastate	2 547	32.9
Interstate	10 572	17.6
Not owner-operator	10 058	21.5
Owner-operator		
Long-term lease (>30 days)	2 471	18.1
Short-term lease	312	7.6

Table 6. Percentage of commercial truck fuel and energy use by fuel, range, and weight, 1976.

Weight Class[a] (lb)	Local Trucking: Gasoline	Diesel	LPG	Total Energy	Intercity Trucking: Gasoline	Diesel	Total Energy	Total: Gasoline	Diesel	LPG	Total Energy
0-10 000	27	0	68	39	49	0	12	47	0	68	25
10 000-20 000	29	6	13	25	21	1	6	27	2	13	15
20 000-26 000	7	2	5	6	6	0	2	7	0	5	4
>26 000	17	92	14	3	24	99	81	19	98	14	56

Note: 1 kg = 2.2 lb.

[a]Based on extrapolation to 1976 of percentages derived from 1967 and 1972 data; percentages may not add to 100 due to rounding.

Table 7. Local and intercity truck energy use by body type, 1976.

Body Type	Percentage Consumption[a] Local Trucking	Intercity Trucking	Total
Pickup or panel truck	46.2	12.9	29.1
Platform truck	15.1	21.2	18.2
Cattle rack	3.5	3.2	3.3
Insulated van	1.0	5.6	3.4
Refrigerated van	1.8	11.6	6.8
Furniture van	1.7	5.8	3.8
Open-top van	0.4	1.1	0.8
Other enclosed van	8.3	26.3	17.6
Beverage truck	1.0	0.9	0.9
Utility truck	6.1	7.9	7.0
Garbage truck	1.4	1.4	1.4
Winch or crane	1.3	2.1	1.7
Wrecker	1.2	1.3	1.3
Pole or logging truck	1.2	2.6	1.9
Automobile-transport truck	0.2	2.3	1.3
Dump truck	9.4	12.1	10.8
Tank truck (liquids)	3.9	10.7	7.4
Tank truck (dry bulk)	0.5	2.7	1.6
Concrete mixer	1.6	1.5	1.5
Other	0.0	0.2	0.1

[a]Based on extrapolations of percentages derived from 1967 and 1972 data.

freight. Still, there is some potential for improving fuel efficiency in the rail system.

A few months of fuel shortage do not provide time for any appreciable technological improvements so that operational improvements must carry the day. Several have been suggested. One is to impose a speed limit, perhaps 65 km/h (40 mph), as has been done by the Soo Line (24). It is true that the resistance to the motion of a typical 100-car train is about 12 percent less at 65 km/h (40 mph) than at 75 km/h (47 mph). But it is unclear how much time freight trains spend moving at speeds above 65 km/h, and fuel saving depends as much on the manner in which the train is accelerated and braked as on the speed it attains. Partly for these reasons, there are no good estimates of the potential fuel saving that a speed limit would effect. Yet, in combination with a policy of closely matching traction horsepower to the consist and the track conditions, speed reductions can pay off. The Union Pacific Railroad achieved an 8 percent reduction in fuel use in its first year under such a policy and more in subsequent years (24).

One advantage of this or any fuel conservation policy is that it induces more careful accounting of fuel use. As things are, fuel is not ordinarily metered as it is pumped into a locomotive, and, by one estimate, some 4 percent of railroad fuel is lost through spillage (24). Although this is an obvious area for improvement, it is unclear that all of this fuel is actually spilled; some may be stolen, for instance. Also, spilled fuel is commonly caught in pans and sold for heating or salvage, or occasionally recycled for railroad use.

One railroad practice that has raised eyebrows is the extensive idling of locomotives. Two estimates of idling time are 40 percent (19) and two-thirds (24) of total operating time. The resulting energy use estimates are 2.4 percent and 4 percent, respectively, of railroad energy use. But the reasons for allowing a locomotive to idle are many. Coolant tends to leak past seals when the engine is shut down, requiring a time-consuming inspection before startup, and coolant will freeze if the weather is cold. Batteries are unreliable, and the time and separate labor required for recharging is expensive. Some railroads have adopted a policy of shutting down a locomotive in mild weather rather than let it idle for several hours, others have installed heaters to prevent freezing, and still others have installed a low-idle setting for long idle periods. The upshot is that the gradual installation of new technology can make a dent in idle fuel use, but emergency measures probably cannot.

Another possibility is heavier loading of cars. In 1977 (25), 26.2 billion loaded car-km (16.3 billion car-miles) of movements carried 1441 billion t-km (987 billion ton-miles) of freight, so that the distance-weighted average load per car was 54.9 t (60.6 tons). Since the average car capacity in 1977 was 68.5 t (75.5 tons), the average loaded car was filled to about 80 percent of its weight capacity. It has been estimated that there is space in these cars for about 5 percent more weight than they now carry (26). If heavier loading were to cut car-miles by 5 percent, an estimated 3 percent fuel saving would ensue. It is often difficult to arrange for a capacity loading, however, and heavier cars increase wear on the tracks. The heavy loading would be temporary, but it has been noted that six months of this could do significant damage. Yet little harm is done in bringing the lighter cars up to the average, and this could effect a marginal fuel saving.

Rail cars are sometimes delivered via a longer route than necessary, and this wastes a certain amount of fuel. A railroad can sometimes increase its share of the revenue to be collected for hauling a certain car by moving the car to its destination in a roundabout way rather than turning the car over to another railroad that offers a shorter route. Shippers sometimes specify circuitous routings to get better service from a particular railroad or to obtain some free storage in transit while a warehouse at the destination is being cleared out (24). It is impossible to estimate the extent of circuitous routing, however, unless a detailed flow analysis of the railroad network is carried out, an expensive job requiring more data than the railroads now provide.

Table 8 (7) estimates the ratio of empty to loaded ton-kilometers for different commodity classes--the ratio most relevant to energy use. The average ratio, weighted by the energy used in transporting each class, is 0.36. So, if all empties were eliminated, about 26 percent of ton-kilometers would be eliminated. This means that about one-quarter of rail energy is tied up in moving empties. (This assumes the locomotive requires no energy for its own propulsion—an assumption that tends to result in an overestimate—but it also assumes that the resistance provided by a car is proportional to its weight, which tends to result in an underestimate.) A good deal of empty traffic is the inevitable result of specialization in cars, however, and the ratio of empty to loaded movements has correlated highly with the relative number of specialized cars in operation (27). Yet, 46 percent of railroad energy was used to move boxcars in 1976, and the energy-weighted ratio of empty to loaded boxcar movements was even higher, 0.38. Elimination of empty boxcars, then, would reduce energy use about 13 percent, and elimination of empty boxcars without special equipment (about 65 percent of the fleet) would bring an 8 percent reduction in energy use.

If equipment imposed the only constraint, then, from 8 to 13 percent of rail energy could be saved by getting rid of empties. But imbalances of flow also constrain the matter. Traditionally, more rail freight has moved east and north than west and south, and the empties must be returned. A nationwide coordination of rail car use designed to reduce empty movements would do so at the expense of causing car shortages in the exporting areas. Conversely, enforcement of an ICC regulation requiring that empties depart the Northeast within 48 hours of arrival has eased shortages in the South and West but has increased empty-car movements (24). It is impossible to say, then, just how much the movement of empties can be cut without upsetting the distribution of cars. The railroads generally insist that the system is trimmed to the bone already due to the many costs of tying up cars in backhauls. But the most efficient use of cars requires cooperation among railroads, and competition often obstructs cooperation that, other things being equal, would benefit everyone. A tenable estimate of unnecessary backhaul movements would require a network study of the sort needed to measure circuity that can be eliminated. The Association of American Railroads is now studying freight car use, and some useful conclusions regarding empty movements may ensue.

Table 8. Rail freight load factors by commodity.

Commodity Class	1972 Ratio of Empty to Loaded: Car-Kilometers	1972 Ratio of Empty to Loaded: Ton-Kilometers	1976 Ton-Kilometers in Boxcars (%)
Coal	0.91	0.22	0
Food and kindred products	0.84	0.35	31
Chemicals and allied products	0.95	0.30	23
Farm products (mostly grain)	0.87	0.30	27
Lumber and wood, except furniture	0.74	0.31	68
Pulp, paper, and allied products	0.95	0.41	92
Nonmetallic minerals, except fuels	0.91	0.26	17
Stone, clay, and glass	0.82	0.30	48
Primary metal products	0.78	0.27	37
Transportation equipment	0.69	0.42	46
Metallic ores	0.93	0.26	5
Petroleum and coal products	1.02	0.38	12
Miscellaneous mixed shipments[a]	0.70	0.41	100
Freight and forwarding traffic[a]	0.70	0.42	100
Fabricated metal products	0.76	0.38	49
Machinery, except electrical	0.69	0.42	27
Electrical machinery	0.70	0.47	79
Rubber and miscellaneous plastic products	0.70	0.45	90
Basic textiles	0.69	0.44	81

Note: 1 km = 0.6 mile; 1 t·km = 0.684 ton-mile.

[a]All shipments assumed to be in boxcars.

WATERWAYS

It is difficult to estimate how much fuel is consumed by the different branches of waterborne commerce, but data on the amount of commerce carried provide some idea. In 1976, domestic movements accounted for 47 percent of the 1665 million t (1835 million tons) involved in U.S. trade. Of the 864 billion t-km (592 billion ton-miles) shipped domestically, 55 percent was coastwise, 12 percent lakewise, and 33 percent internal (28). The fuel purchased in the United States for these operations comprised some 19 percent of 1976 freight transport fuel use in this country.

The fuel efficiency of waterborne transport can most readily be improved by slowing down the boats, and the potential saving is substantial. It was mentioned earlier that the energy intensiveness of a ship varies with the square of its speed so that a 10 percent drop in speed brings roughly a 20 percent saving in fuel (29). It is true, of course, that reduced speed not only degrades service but limits capacity. Yet, even in the worst case, in which capacity decreases proportionately with speed, a limited fuel supply goes furthest when the speed is reduced. It is easy to derive that, in these circumstances, the optimal speed, as well as the resulting distance covered, varies with the cubic root of the quantity of fuel available. That is, a 30 percent fuel shortage would dictate at least a 10 percent reduction in speed, which would result in at most a 10 percent reduction in the distance traveled. So the potential for fuel conservation, at least on oceans and lakes, is considerable. The situation on rivers is slightly less clear because speed reductions entail a smaller separation between barge tows and congestion and collisions could result. Yet, it should be a straightforward matter to predict the effects of reduced speed on traffic, given current flows.

Speed reductions can undoubtedly dull the competitive edge of the water mode, resulting in financial trouble for the industry as well as discouraging use of an energy-efficient mode of transport. One can assume that the difficulty of securing transport during a fuel crisis would at least partially offset this disincentive, but foretelling the behavior of shippers with any accuracy would suffer the same difficulties that beset crisis economics in general.

Another, but related, possible strategy for fuel conservation, at least in maritime shipping, is rationalization. This ill-chosen term refers to the pooling of vessels from different lines in such a way as to move the same freight more efficiently. The most-often proposed strategy is to coordinate routings so that each port is served by fewer ships rather than permitting ships from a large number of lines to compete for business in each port. This would raise load factors and allow ships to travel shorter distances because they no longer would make the rounds of several ports looking for cargo. As a result, fewer ships could be operated, or the same ships could be operated at lower speeds, without a reduction in tons shipped. Such an arrangement certainly has drawbacks. Shippers at a given port would have fewer competing lines to choose from, and departures, at least at the smaller ports, would be more widely spaced. Despite these drawbacks, the formation of such pools is far from infeasible. Following the 1973 embargo, the Federal Maritime Commission requested rationalization proposals and received several. The seven carriers operating on the North Atlantic submitted the most elaborate plan, and an examination of their situation provides a good illustration of the fuel saving possible through rationalization. A scheduling and routing of these 33 vessels worked out for the National Maritime Research Center accommodates current commodity flows while reducing speed and fuel use (30). On this hypothetical pooling, average speed would be reduced from 39 to 28 km/h (21 to 15 knots), and fuel use would shrink from 855 to 447 L/20-ft container equivalent (from 5.38 to 2.81 bbl/ton-equivalent unit)—a saving of nearly 50 percent.

Rationalization may be undesirable in the long run because it precludes competition. But the long-run evils of a lack of competition would not be an objection to a temporary rationalization agreement arranged solely in order to weather a fuel crisis. It can be presumed that a fuel shortage affecting the United States would probably involve other nations sufficiently to ensure a bilateral incentive to set up such a pool. On the other hand, the North Atlantic agreement was slow and tedious in its formulation due to disagreement over the fraction of revenues to be allotted each line. It is possible that such pooling agreements would not be arranged quickly enough to do much good in an emergency. But there is no reason a contingency pooling could not be worked out in advance, ready to go into operation whenever the participants agree the situation warrants it.

COMMENT

In closing, it should be noted that it is evidently possible to gauge the ability of our freight transport system to adapt to a temporary fuel shortage. The assessment can be difficult and expensive, especially in the highway and rail modes where it would require a detailed network-flow analysis and extensive surveys. But there is no reason to believe it cannot be done.

It should also be noted that it is probably impossible to forecast what freight carriers and shippers would do with this sytem if a fuel crisis happened, even once regulations binding them have been specified. It is impossible because their behavior depends on both the logisitics and the economics of freight transport during a crisis and, worse, because the logistics and economics depend on each other.

Logistics has to do with where the freight is, where it is to go, how it can get there, and who has the fuel. Without this information one can only estimate what freight carriers could do with a given amount of fuel; a carrier cannot predict what would happen unless it was known how much freight there is to be moved and how much fuel there is to be burned. U.S. industry is complex and a disruption of fuel supplies upsets, among other things, the customary location of freight and demand for its movement. The location of the fuel needed to move it would be subject to similar disturbances. To trace the effects of this disruption would require two kinds of knowledge, neither of which exist. It would require detailed knowledge, all coherently assembled in one place, of the physical operation of industry and the role of transportation in it. It would also require a superhuman grasp of the economic forces that would influence this operation during a crisis.

It is even more difficult to master the economics than the logistics. Economic models ordinarily presuppose some kind of equilibrium in the marketplace, traditionally a price equilibrium. The advantage of this presupposition is similar to that of assuming a steady state in physics and engineering—it permits one to overlook a great deal of detail as to how the system moves from one state to another. But during a crisis it is unlikely that economic equilibrium would be achieved. The exchange of goods would be a direct function of where the goods are and whether they exist as well as their price. In other words, the price of a commodity would come to encode less information about its availability. Under these conditions, steady-state economics would be even less valid than it is ordinarily. The dynamics of the mechanisms whereby prices tend to equilibrium would need to be analyzed. Since this analysis would require that the logistics of supply and transport be taken into account, economics would depend on logistics and vice versa. Also, there is the additional wrinkle that consumers behave differently in a crisis than in ordinary situations. Economists, who find the prediction of equilibrated prices hard enough already, have made little progress in these more-difficult areas.

We cannot foretell, then, just what would happen during a fuel crisis, but this does not mean we cannot prepare for it. The best preparation, of course, is one that has already begun among many freight carriers: Cut fuel consumption now through programs that are too long to implement during an emergency.

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Issues in Developing Contingency Plans for Intercity Freight

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Inherent in any understanding of the relation between trucking and energy must be an awareness of the impact of the truck industry on the U.S. economy. We live in a complex and highly advanced society. In our transportation system, trucks offer source-to-market speed and versatility to serve our needs. A special study by the U.S. Bureau of the Census revealed the importance of trucks. Consider that trucks move 83 percent of all fresh and frozen meats; 73 percent of all radios, televisions, phonographs, and records; 84 percent of all clothing; 92 percent of all ice cream and frozen desserts; 84 percent of all office and accounting machines; and 83 percent of all carpets and rugs. In fact, trucks move three out of every four tons of urban and intercity freight and generate over 100 billion dollars in revenue. Most important, all this movement depends on the availability of petroleum. Ironically, although the job done by trucking is big, the amount of petroleum needed by commercial trucks is small—only about 20 billion gal of diesel fuel and gasoline a year. This is about 7 percent of the total energy supply consumed by transportation.

The problems encountered by the trucking industry with DOE's contingency plans are twofold: (a) DOE fails to recognize the critical position motor carriers have in the nation's economy, and (b) DOE fails to recognize the variety of fuel-purchasing patterns.

I have already touched briefly on the first problem. Needless to say, it would appear that most contingency plans approach trucks per se as "overgrown" cars. The ultimate contingency plan, i.e., DOE's gasoline-rationing plan, proposed to base truck fuel coupons on an index of what the average automobile used and the truck's gross vehicle weight. Neither of these criteria recognize how and where trucks are used.

A more recent example is DOE's Special Rule 9. Under this rule, DOE allocated diesel fuel to agricultural production at 100 percent of current need. Production was not defined to include distribution. As a result, farmers were allowed the diesel fuel they needed to produce food, but trucks could not get the fuel to haul it. Later, DOE amended the regulations to include distribution. However, DOE so narrowly defined distribution as to make it meaningless. Trucks had to have the cargo already loaded. Specifically excluded were trucks on their way to pick up agricultural products. Ironically, these same amendments expanded the 100 percent allocation level to other categories, including the exploration and production of oil and natural gas. Again, DOE excluded distribution. Apparently, the rationale was that gasoline could be produced but not distributed to the local retail outlet.

FUEL-PURCHASING PATTERNS

The second shortcoming is equally disturbing. Most contingency plans cannot handle the diversity of fuel-purchasing patterns. As a result, there is no equity. Consider that trucks use more than 20 billion gal of fuel per year. About 11.7 billion gal is diesel fuel; the rest is gasoline. Many carriers use both fuels. Also, not all carriers purchase fuel in bulk. In fact, we have no idea of the percentage purchased in bulk, and neither does DOE. We do know, however, that many carriers buy exclusively in bulk quantities, others buy all fuel retail, and still others buy both ways.

As a result, some carriers find themselves falling under four sets of contingency plans: (a) diesel fuel purchased wholesale, (b) diesel fuel purchased retail, (c) gasoline purchased wholesale, and (d) gasoline purchased retail.

Diesel Fuel Purchased Wholesale

Diesel fuel purchased wholesale is currently under no allocation plan. All middle distillates were decontrolled in 1976. However, in January 1979, DOE's Economic Regulatory Administration published Standby Product Allocation and Price Regulations and Imposed Allocation Fractions. These regulations allow cargo, freight, and mail carriers 100 percent of current requirements (reduced by an allocation fraction). This is the second priority level. Base period is no longer the month of 1972 corresponding to the current month, but a period defined inadequately as "the month or quarter corresponding to the current month or quarter in the 12-month period ending with the second full month prior to the month which (DOE/ERA) issues an order...."

Although this is DOE's standby or contingency plan in case of a diesel fuel shortage, DOE did not insitute it during the diesel fuel crisis of May and June 1979. Instead, it instituted Special Rule 9, which gave 100 percent of current need to agricultural production. The trucking industry was not prepared for this action.

Fuel oil distributors were also ill prepared. Some could not even meet the demands of farm customers and cut off all other diesel users. Almost overnight, diesel fuel all but dried up in the Midwest. Apparently, the nation's farmers defined "current need" as something called "future perceived need". There were even some instances of farmers selling their "current need" to motor carriers and railroads.

Currently, motor carriers buying diesel fuel in bulk are at the mercy of the distributors. Depending on the commitment the oil company has to home-heating oil customers, motor carriers in 1979 had allocations as low as 40 percent of 1978 levels. Base periods, however, are not uniform and can be anything the oil company determines. Carriers with allocation levels below their current needs can do one of four things:

1. Seek other suppliers willing to take on new customers,
2. Purchase diesel fuel on the spot market,
3. Purchase fuel at the retail pump, or