India's Transportation Energy Problem

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The transportation sector is the largest and fastest-growing imported oil consuming sector in India. This paper reviews the growth of the sector in recent decades and characterizes its current demand, supply, and energy consumption. Two analyses, one of the social, political, and physical infrastructure constraints on the sector and the other of the government's policies, plans, and five-year budget are summarized. The paper concludes that without good planning the transportation sector may hinder rather than support the country's development, not only because the cost of imported transportation fuels reduces the ability to import other goods needed for development but because the sector could become insufficient for the required internal distribution. Several suggestions for planning and research projects are presented.

The study of transportation in India is a study of contrasts: jumbo jets landing on handmade but smooth runways, a subway under construction in Calcutta, bullock-carts mixed in with motorized traffic on city streets and rural highways, vehicles produced by only two automobile and two highway truck manufacturers (each company with only one model), nearly 8000 steam railway locomotives in service, and 314 000 towns and villages not served by any road. Laborers sometime load coal from head baskets into railway hopper cars, yet India launches communication satellites that one day may replace some travel with telecommunications.

India has a population of nearly 700 million, three times that of the United States in 40 percent of the land area. Although only about 23 percent of the population is now urban, by 2000 the urban population is expected to increase by 85 percent and the rural population by 29 percent, assuming that the government's population-control program works reasonably well. All Indian resources appear to be limited in some way. For example, coal reserves are abundant but the coal is not efficiently extracted, distributed, or used and it has very high ash and moisture content. Labor is abundant and is used instead of machines as a matter of government policy but is becoming more organized, which results in many protracted strikes. The country is now feeding itself and in recent years even exporting grain. Lack of capital is the main drag on development.

Recent trends in fuel and energy use in India are shown in Table 1 (1). India now faces an energy crisis, the primary component of which is its reliance on imported oil; the Indian subcontinent imports two-thirds of the petroleum it uses. The problem is one of foreign exchange: India's imported oil bill is 85 percent of its export earnings. Although the percentage of oil demand met by imports remained stable during the 1970s (61-71 percent), both the oil-import bill as a percentage of export earnings and the amount of product imported have increased dramatically (tenand six-fold, respectively) (1). Because India is on the front side of its industrial revolution, it increases its commercial energy consumption 1.8 percent for every 1.0 percent increase in gross domestic product (GDP). For most Western countries this elasticity is less than 1 (2). The transportation sector consumes a third of India's commercial energy. It is the largest and fastest-growing consumer of petroleum-based fuels, mainly diesel fuel. This sector therefore is key in any long-term solution to India's energy crisis. No short-term solution seems possible.

OVERVIEW OF INDIAN TRANSPORTATION

India's demands on its transportation system are more like those of the United States than Europe, even though Indian transportation technology has an inherited European flavor. In Europe, cities are close together and the rail system is extremely well developed. In the United States and India, however, distances between activity centers are large (except in the northeastern United States). Even though the analogy to the United States holds better for freight shipments than for passenger travel, the historical trends of U.S. transportation, especially the trend toward highway transportation, are being replayed in India.

The Indian transportation system should be evaluated in terms of its ability to meet the country's current and future transportation needs, but there is no consensus among Indian transportation experts regarding the adequacy of the system. Transportation plays a critical role in the development of a nation like India. It links industry to its sources and markets and permits imports and exports. It carries fertilizer to the farmers and produce to the hungry. Advances in passenger transportation change the social fabric of the country because more people can interact more easily. Transportation brings the medicines and the agricultural extension workers to the villages. A rural road allows a once isolated, marginally self-sufficient village to participate in and, with irrigation water and fertilizer, contribute to the Indian economy.

Over a decade ago, Wilfred Owen wrote the following (3):

> In India a key factor in economic development is the rapid growth of the transport burden with rising levels of economic activity. Every increase in national product is accompanied by two to three times as great an increase in the movement of materials.

India's transportation system has no spare capacity as it is currently operated. Any increase in capacity created by more efficient operation would quickly be filled by passengers and goods. Indian business people today use trucks at an average cost six times the rail tariff to increase reliability and reduce inventories. People hang on the sides of buses and commuter trains and often sit on the roofs of intercity trains. Waiting in line to obtain a first-class booking on a train can take hours and must often be done days in advance for a chance for a seat. The national highways are obstacle courses for motorized vehicles, especially in towns that are seas of pedestrians, carts, and bicycles, with an inevitable one-lane bridge in the middle of each town. Trucks are small, not maintained, and apt to fail. Vehicles on the same road move at many different speeds. Sometimes 140 people have been counted in a bus designed for 50.

The Indian transportation engineer is well aware of all the operational techniques to increase energy efficiency: proper tire pressure, vehicle maintenance, channelized intersections, contraflow bus lanes, etc. (4). The Indian automotive engineer has studied Western advancements in vehicle technology, engines, transmission, and fuels. But the transportation problems of Indian are far different than those of the West.

Consider that Indian engine and vehicle technology is 15-20 years behind that in the West, and the engines wear rapidly because they are run on

Table 1. Distribution of energy consumption in India by fuel type.

	Coal Replacement (t 000 000s)						
	Commercial			Noncommercial (or traditional)			
Fiscal Year[a]	Coal[b]	Oil[b]	Electricity	Firewood	Animal Dung	Agricultural Waste	Total
1960-1961	40.4	43.9	16.9	94.6	21.8	29.1	246.7
1965-1966	51.8	64.6	30.6	103.8	23.9	31.9	306.6
1970-1971	51.4	97.2	48.7	122.0	25.8	34.4	369.5
1975-1976	70.1	115.7	66.0	126.5	29.2	38.9	446.4
1980-1981	72.3	159.6	90.9[c]	-[d]	-[d]	-[d]	-

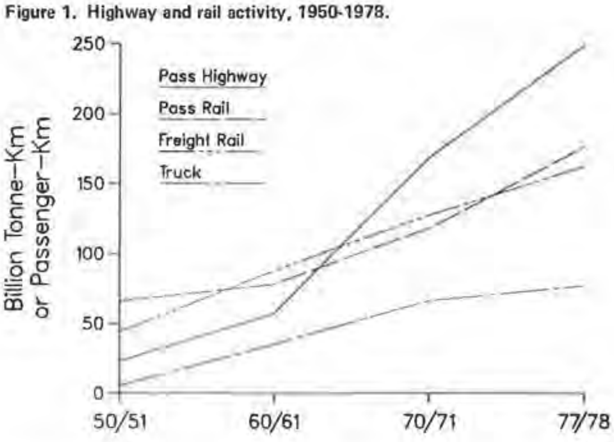
[a]Indian fiscal year begins April 1.
[b]Excludes electric power generation.
[c]Estimated electric power generation.
[d]No estimate given.

Table 2. Growth in Indian vehicle stocks.

	Growth by Fiscal Year (000s)				
Vehicle	1950-1951	1960-1961	1970-1971	1977-1978	Increase[a] (%)
Railway					
Locomotive					
Steam	8.1	10.3	9.3	8.2	-[b]
Diesel	0.02	0.2	1.2	2.0	990
Electric	0.07	0.1	0.6	0.9	118.6
Suburban electric multiple-unit coach	0.5	0.8	1.7	2.3	36
Conventional coach[c]	13.1	20.2	24.7	26.6	10.3
Freight car	205.6	307.9	384	400	94.6
Highway					
Car, jeep, and taxi	159	309	-[d]	846	423
Bus	34	57	-[d]	117	244
Truck	82	168	-[d]	368	349
Two- and three-wheelers	27	95	-[d]	1509	5489

[a]Covers period 1950-1951 to 1977-1978.
[b]None built after 1971.
[c]Excludes baggage and mail cars.
[d]Not reported in available sources.

Figure 1. Highway and rail activity, 1950-1978.



high-sulfur fuel (maximum allowable sulfur content is about four times the U.S. standard). In general, roads can barely be repaired with existing funds, much less improved. The pavement is not thick enough to carry today's loads. Because of low tire quality and overloads, truck tires last only 30 000 km. The side walls fail long before all the tread is used, and rubber is not cheap in terms of either rupees or energy.

Three historical trends are important to note. First, per capita use of transportation, especially passenger transportation, has increased tremendously since India's independence from the United Kingdom in 1947. As Figure 1 shows, highway transportation growth has outstripped rail transportation growth, and more passengers now travel by highway than by rail (5). This shift away from rail is consequential and is recognized as such by the government (5,6).

Second, India imported its first electric and diesel-electric locomotives; now it exports locomotives and coaches (and has stopped building steam locomotives). This is a good transportation example of the government's policy of self-sufficiency. All vehicles are now made in India. Table 2 (5,7) summarizes the growth in vehicle stocks. Although the number of railroad cars doubled between 1950-1951 and 1977-1978, the number of highway vehicles skyrocketed, especially the stock of small two- and three-wheeled vehicles.

Third, the direct correlation between investment in transportation and the economic growth of India is high. A regression analysis of gross capital formation in the transportation sector and GDP time-series data shows R^2 goodness-of-fit indicators of 0.95 or more (5).

CURRENT STATUS OF TRANSPORTATION

Concerning the railways, the Sixth Five-Year Plan (6) laments that, recently, "there have been frequent bottlenecks when even important commodities, particularly coal, fertilizers, cement, etc., have not moved adequately." These bottlenecks often have been due to shifts in traffic patterns; commodities once imported are now exported and traffic demands have shifted as different areas have developed various industries. The railways, however, are the fourth largest in the world (based on kilometers of track) and with 1.6 million employees may be the largest employer in the world (7).

Highway freight transportation and ports suffer from undercapacity. The supply of trucks is insufficient when rail cannot meet demands. Long waiting times at ports, particularly at Bombay, are common on many commodities. Traffic at ports has quadrupled since 1950-1951, and the government has developed minor ports to handle important commodities.

Inland-waterway transportation is limited by the small number of navigable rivers. Approximately 550 km of navigable inland waterways carry only about 10 million tons of goods each year (8). The Sixth Five-Year Plan sees the growth potential in this energy-efficient mode; it also notes the potential of coastal shipping, which is now plagued by port congestion and high transshipment costs and thus poor reliability.

There are an estimated 80 million work animals and 13 million bullock-carts in the country. Animal power is estimated to provide 10 billion t-km of freight transportation annually (6).

Of prime importance is the transportation of coal, India's main domestic source of commercial energy. The Indian transportation system carried 69.26 million t of coal an average distance of 673 km/t in 1977-1978. Of that, 92.2 percent moved an average of 691 km by rail and the rest moved an average of 408 km by truck. Coastal shipping carried 670 000 t of coal that year, but the average distance carried is not reported (5).

India, like the United States, has one dedicated unit-train system where the track, locomotives, and cars are owned and operated by a power company. Both of these systems are closed to all other traffic and not part of a local railroad. In the Indian system, 1 car/min, moving at about 1 km/h, is loaded from a pneumatic system in a silo. Bottom-discharge hopper cars are used; 40 percent of the bottom area opens electropneumatically. Each car carries about 60 t and the power plant is about 50 km from the mine. Trains are 30-40 cars long.

The normal rail shipment of coal is much different. Side-opening hopper cars and regular boxcars are used in nondedicated service (i.e., they also carry other commodities at other times). Loading and unloading methods are mechanical or manual. The cars can be shipped on regular freight trains in small groups or arrangements can be made to ship full train loads to avoid many switching delays. The latter arrangement, called a block train, is not a unit train since it is not made up of dedicated equipment and because some marshalling yards are not by-passed.

The public mass transportation modes are required to carry the masses because the per capita number of private motor vehicles is quite small, possibly about 0.01. Urban population was 44.15 million in 1951, is estimated at 150 million today, and is projected to be 278 million by 2001. Consider that Bombay's population during the 1970s increased by 2.5 million. The mass transit systems are extremely overcrowded and, except in Madras, Delhi, Bombay, and Calcutta, consist entirely of buses. These four cities have commuter rail systems that use mostly electric, multiple-coach trains.

The mass transit systems are most crowded during rush hours, when people literally hang onto the sides of the buses and commuter trains. Three-wheel auto-rickshaws (essentially motor scooters built like rickshaws) and automobile taxis are prevalent in most cities, but fares have been increasing regularly and ridership has declined. Table 3 (5) presents statistics on urban travel in India's four largest cities. A 16.4-km underground railway (subway), India's first, is being constructed in Calcutta.

Intercity passenger transportation is also quite crowded. Intercity trains offer few amenities. Ordinary second-class railway compartments have wooden walls and wooden seats. Fares for first-class accommodations, some of which are air-conditioned, are an order of magnitude higher than for second-class travel but cheap by Western standards. Domestic air transportation carries less than 1 percent of the passenger kilometers.

ENERGY CONSUMPTION

The Indian transportation system, especially the highway mode, is quite energy inefficient, primarily because of congestion, outdated engine technology, poor vehicle maintenance, vehicle underutilization, poor intermodal coordination, and limited infrastructure. Traffic congestion causes many accelerations, which are the most energy-intensive part of transportation. The effect on energy consumption of poorly maintained and outdated vehicles is obvious. Vehicles are underutilized because of delays due to congestion as well as ineffective system operation. This underutilization causes additional capital requirements for vehicles and facilities (since more are needed to perform the same tasks) and the concommitant energy expenditure to build the additional vehicles and facilities. There is a lack of intermodalism and thus a failure to conserve enrgy by using better combinations of modes to transport goods and passengers between origins and destinations. In freight, the lack of intermodalism stems mainly from the public and private split of the modes and the inability of the more energy-efficient railways to carry international containers and semitrailers. Infrastructure limitations, such as severe load limits on highways, constrain the use of larger, more energy-efficient trucks.

India's National Transportation Policy Committee has studied energy intensity and consumption by mode and submode. Table 4 (5) summarizes its findings. The relatively good efficiency of rail transportation is quite apparent from the table, and the electrification of more routes will decrease dependence on imported fuels. India is in an enviable transportation and energy position relative to the rest of the world, developing and industrialized countries alike, because it has a very large rail system. Clearly, the railways are central to any plan to conserve energy in the Indian transportation sector.

A recent major study of energy prospects for developing countries made the following observation (9):

> There is some evidence that energy intensity of freight (transport) varies with stage of economic development. At times of rapid industrializa-

Table 3. Indian urban transportation statistics.

Mode and Vehicle Use	Calcutta	Bombay	Delhi	Madras
Total daily trips[a]				
No. of trips (000 000s)	7.0	9.4	5.0	3.6
By mass transit (%)	80.0	75.0	43.5	65.0
Daily mass transit trips[a] (%)				
By rail	25.5	53.0	4.0	20.0
By bus	74.5[b]	47.0	96.0	80.0
Vehicles[c] (000s)				
Cars and jeeps	80.8	137.4	105.2	27.8
Two-wheelers	33.9	62.7	282.3	40.8
Auto-rickshaws[d]	–	0.7	17.9	1.5
Taxis	7.1	23.7	5.6	2.5
Urban buses[e]	4.1	3.5	6.9	1.8
Trucks[f]	25.8	35.5	31.1	5.9

[a] 1976-1977 estimate.
[b] Includes trams (36 percent of bus trips).
[c] 1978.
[d] Three-wheelers used as small delivery vehicles and taxis.
[e] Standard, school, and mini buses.
[f] Private-public carrier, tractor-trailers, and tempos-delivery vans (tempos are three-wheeled trucks with a capacity of about 0.5 t).

Table 4. Average energy intensities of various Indian submodes.

Submode	Energy Intensity (Btu/vehicle km)		Average Total Energy Intensity[a,b]	
	Propulsion (direct)	Total[a]	Btu per Passenger km	Btu per t-km
Rail[c]				
Diesel	121 055	129 820	160.2	255.5[d]
Steam	776 840	785 605	1460.8	3576.9
Electric	41 595	50 360		84.6
Suburban electric	21 935	30 700	64.6[e]	-
Bus				
Urban, diesel	9 178[f]	10 638	307.7	-
Regional, diesel	8 410	9 870	NA	-
Petrol	15 135	16 595	555.5	-
Petrol automobile	3 817[g]	5 512	NA	-
Scooter	625	865	NA	-
Barge	NA	NA	-	328.0
Pipeline	NA	NA	-	281.7
Coastal shipping[h]	NA	NA	-	155.0
Truck	NA	NA	-	1587.3

Notes: Btu = British thermal unit.
NA = not available.
[a]Includes indirect energy spent in maintenance, construction, and vehicle manufacture.
[b]Although it is not clear from the source how all these numbers were derived, and some must be estimates, at least for the railways it is the ratio of the net passenger kilometers or metric ton kilometers to fuel consumed over the three-year period 1974-1975 to 1976-1977.
[c]Main line rail, except suburban electric.
[d]Or about 374 Btu/ton mile; the U.S. value for 1977 was 670 Btu/ton mile.
[e]Average for electric rail and suburban electric rail.
[f]Or about 8.4 miles/gal, a typical value for a U.S. 40-ft urban bus is 3.7 miles/gal.
[g]Or about 20 miles/gal, which seems reasonable given the light weight of the cars.
[h]About 14 400 dead-weight-tonnage ship.

Table 5. Modal distribution of India's commercial energy, 1978-1979.

Source	Consumption (Btu trillions)				
	Railway	Highway	Air	Ship	Total
Coal	42.3	0	0	0	42.3
Oil	27.0	205.8	30.7	3.4	266.9
Electricity	8.9	0	0	0	8.9
Total	78.2	205.8	30.7	3.4	318.1

Note: About 4.5 percent of the energy used in transportation is animal power.

tion, the number of ton-miles relative to GDP increases; indeed at some point this figure may become greater in developing than in industrial countries, whose typically more regionally balanced economic structures lead to even declining freight transport.

This observation does not bode well for India. Regional imbalances have plagued the Indian freight transportation system. The trend toward the more energy-intensive truck exacerbates the regional energy-intensity effect.

Table 5 (10) gives the distribution of commercial energy demand by energy type and mode. In short, transportation is dependent on diesel fuel (since there are relatively few cars) and thus susceptible to world oil prices and potential oil shortages. Although India is attempting to make itself more energy independent by using more domestic coal and oil, oil importation will continue for the foreseeable future, especially importation of middle distillates. Gasoline is highly taxed, as are automobiles, because automobile ownership and use are considered luxuries. Diesel is sold at about cost.

TARIFFS

All modes of transportation are subsidized in India; airports, ports, railway cars and facilities, and roads are built by the government. Urban mass transit is subsidized. The freight rates on some commodities are set to cross-subsidize the shipment of other commodities, and passengers who travel in the higher classes (e.g., intercity first-class air-conditioned rail) subsidize those in lower classes of accommodation. Because noncommuter rail passenger traffic accounts for only 50 percent of the total rail passenger trips and 80 percent of the total passenger miles (but 90 percent of the total passenger earnings), the intercity traveler is subsidizing the commuter (8).

A major scheme for cross-subsidization is freight equalization. Here short hauls subsidize long hauls of certain basic commodities through a pool to the extent that the charge for shipping the commodity between any two points in the country is the same. The rationale for the scheme was that location in the country should not be a factor for discrimination and that balanced regional growth would occur because of equalization.

Another scheme used in goods shipment involves telescoping rates. Here the cost for the first increment of distance is relatively high, the second increment costs less, the third even less, and so on. Like freight equalization, this scheme covers the total cost of all shipments of the commodity, but short hauls subsidize long hauls. The real cost of shipping is tapered with distance due to some fixed and initial switching costs, but not tapered as much as in telescoping rates (5,11).

CONSTRAINTS TO CHANGE

This section addresses constraints on the Indian transportation system that prevent rapid change, since a key question about India's transportation system is whether it is constraining the nation's economic and social development and whether its growth can at least match that of other sectors. The potential for a systematic evolution is there, but the constraints or barriers are substantial. They include national policy, continued shifts in demand patterns, capital availability, infrastructure inadequacies, management resistance, spatial location of industries, a decentralized population, size of vehicles, age of vehicle technology, lack of sufficient planning information, and energy availability and cost. Further research would undoubtedly uncover more. Some of this has already been mentioned and the most significant are discussed below.

Two national policies define the types of change that can take place in India; these policies state that all undertakings should be as labor intensive as possible and that all goods used in India should be made in India. Exceptions to these policies are possible but rare. Sophisticated electronic instrumentation may, for example, be imported. On the other hand, the railway managers are proud that almost every component of their diesel and electric locomotives is now made in their shops. The goal of self-sufficiency limits the types of technology that can be used in the transportation sector. Indian vehicles are simple and will remain simple. There is no infrastructure to maintain complex vehicles. The impact of the labor-intensiveness policy on the transportation sector is best seen in facility construction. Roads and runways are built by hand.

Since India gained independence, the demands placed on the transportation system have shifted continually; this situation also constrains the development of the system. Commodities once imported are now exported. New major industries have sprung up that require the shipment of new commodities, sometimes over long distances. Many of the resources of the transportation system, especially the railways, have been devoted to an attempt to meet this dynamic demand. As a result, attention to growth often has been distracted by the need to fix the latest bottleneck.

One of the major constraints on change in the transportation sector is lack of capital. The government, with its limited budget, must carefully choose its priorities. During the time since independence, feeding its people has been of prime importance to India, and it still is not an easy task. Irrigation projects therefore receive great emphasis. However, the transportation sector has not been neglected and its importance in development has been recognized. Now energy is a problem and the Sixth Five-Year Plan focuses on coal, conservation, and the large users of petroleum. The emphasis on the railways and the electrification of the railways is strong. Yet sufficient capital to move the railways ahead quickly is not forthcoming.

The social and political infrastructure of the transportation system often hinders change. The nine zonal railways act independently, which cuts into efficiency. The structure of the government of India, with its various bureaucracies, hinders intermodalism. The Railway Board is independent of the government. Most highway decisions are made at the state and local level. The government owns the railways; therefore no private investment can be attracted to stimulate growth. Trucks are privately owned.

The physical infrastructure is also a problem. The two-axle highway trucks are designed to haul 9-12 t with a 25 percent overload, but overloads beyond that are common. The highway network is limited both in the quality of the roads and the extent of coverage. Low weight capacity on bridges limits use of many routes. Only 29.3 percent of the villages are connected by all-weather roads, another 16.1 percent are connected only by fair-weather roads, and the remainder are not linked by any road. Clearances and overhead structures severely limit the size of railway shipments; this limitation is a critical problem on the narrow gauge and only slightly less of a problem on the meter gauge. The inability to carry international size containers (about the size of the box of a common U.S. semitruck trailer) causes much loading and unloading of containers at ports (12). Since there are two main track gauges and some narrow gauge, high cost transshipments also occur within the railway system.

The tariff structure often hinders transportation efficiency. Certain commodities and passengers do not cover their shipment cost. For example, firms tend to locate farther from their input sources because of freight equalization and too steep a taper on the telescoping rates, which generate extra ton kilometers.

INDIAN TRANSPORTATION POLICY

India's transportation policy, which is spelled out in Chapter 17 of the Sixth Five-Year Plan, addresses energy directly (6):

> As a long term goal, efforts will have to be made for the railways to develop the capacity to clear (i) all train load traffic for long, medium and short distances, and (ii) all nontrain load traffic (i.e., piecemeal traffic) for long and medium distances (except for certain commodities). This would broadly leave all short distance piecemeal traffic for the road transport. While capacity will need to be developed by the railways to do so, and while fiscal measures would be in keeping with the above objectives, the choice of transport mode will, to a great extent, be conditioned by the consumers preferences as a regulatory or legal measures will be difficult to implement, and could lead to misuse of the regulatory processes.

Some of the action items are to (a) accelerate the pace of railway electrification; (b) improve the fuel efficiency of diesel-based road vehicles through vigorous methods, including improved vehicle design and road conditions, speed control devices, and truck-trailer combinations on selected stretches of national highways; and (c) encourage other energy-efficient modes, including coastal and inland-waterway shipping, pipeline, bicycles, bullock-carts, and public transportation (including electrified commuter rail and trolley buses).

Like most plans, the Sixth Plan seems too ambitious in light of the available funds. The Sixth Plan budget shows transportation receiving 12.4 percent of the $115 billion plan. Although the emphasis of the plan's text is that the rail and water modes require renewed support for energy reasons, the budget does not appear to reflect this. Historically, the railways received an average of 51.4 percent of the national transportation expenditures for each five-year period. In the Sixth Plan they are targeted for 42.2 percent. Historically, the highways received a 38.4 percent average share; this plan pegs them at exactly that average, up from 33.5 percent in the Fifth Plan. In dollars, the highway mode will receive much more emphasis than the railways because of private investment in vehicles, repair facilities, and other infrastructure. The historical average budget share for the water modes is 5.4 percent, as compared with 6.9 percent in the Sixth Plan.

Owen (3) gives an interesting perspective as an observer of India in the late 1960s. The new technology with the potential of removing the isolation of most of India's population, of moving its goods, and of making the cities operate was the highway mode. From his perspective, development would get a great push from the modern car, truck, and bus on surfaced highways. The government's expenditure on highways as a percentage of transportation expenditure during the Fourth Plan (1969-1974) was 15.7 percentage points higher than under the Third Plan (1961-1966).

Then came the energy crisis of the mid to late 1970s, when a developing country could ill afford to pay the steeply rising cost of imported oil. Instead of being a springboard of development, the thirsty highway diesels became a drag on foreign exchange.

Although the Sixth Plan forecasts vigorous measures to improve the fuel efficiency of the highway mode, significant improvements seem impossible. Even if the 15-year-old engine technology could be immediately updated and other new vehicle improvements implemented, the fleet has a long average life and many older vehicles would remain in service for years to come. Reducing congestion on the Indian highways to a reasonable level will remain a dream, at least in this century, and congestion wastes energy. Maintaining vehicles also seems impossible, given the present vehicle-service infrastructure, the little real control the government seems to have over truckers and taxi drivers, and the quality of the maintenance of government-owned buses.

If there is any lesson India can learn from the United States, it is that every dollar spent on road, automobile, and truck improvements will reduce user cost relative to the user cost of trains and urban buses. The modal shift so apparent in the Indian transportation data will be fostered by the government's highway expenditures.

The average lead for trucks is too long, based on purely economic trade-offs between shipping a commodity via truck or rail (5). (Truck has the economic advantage for shorter distances, rail for longer. Currently, truck traffic goes far beyond the break-even point for most commodities.) As diesel fuel price increases, the break-even point moves toward shorter truck leads. Because trucks haul beyond the break-even point, "the diseconomies of moving goods by road beyond the economical distances are being borne by society, in fact, through increased oil import bills" (10). The "catch-22" is that the rail system has insufficient capacity growing at an insufficient rate. The only way for the economy to expand is to let trucking grow.

CONCLUSIONS

My discussions with transportation professionals throughout India have convinced me that much of what can generically be called systems analysis is required to rationally guide the Indian transportation system toward energy efficiency while making it a more effective tool of India's development. Systems analysis here means constructing alternative plans and evaluating each plan on several criteria, including at least total energy consumption and type of energy consumption, economic and political feasibility, and improvement in mobility.

The Indian transportation system offers many areas for research and analysis. The trade-offs between building synthetic liquid-fuel plants and improving transportation system energy efficiency to lower future demand should be examined. Research is needed to improve vehicle and vehicle-component testing techniques to increase reliability and life. Methods to improve engine efficiency and reduce the wear caused by the high-sulfur diesel fuel--such as lubricant additives, different engine materials, and different combustion chamber or fuel-injection configurations--should be explored. Many optimization studies of subsystem operations come to mind, as do cost-effectiveness and environmental impact studies. Since the Indian transportation system is so vulnerable to reduction or cut off of imported middle distillates, contingency planning to cope with shortfalls seems necessary.

Other studies should investigate better methods of direct combustion of coal in railroad locomotives. Because coal is India's main domestic commercial fuel, systems analysis aimed at increasing the economic and energy efficiency of coal distribution is quite important.

Although high technology has little place in Indian transportation, the potential substitution of telecommunications for travel deserves at least an initial appraisal. Even though much can be done to reduce lead imports by improving vehicle-starting batteries, the market potential and technical feasibility of battery-powered electric vehicles deserve study.

The Indian transportation infrastructure needs rationalization, a task that will require much planning. Intermodalism is an obvious energy-conservation measure, but strong arguments based on careful study are needed to bring about the required infrastructure changes. The transportation system should be moving processed and manufactured products the long distance to market and the raw (more weight-intensive) materials as little distance as possible. The current situation is far from this optimum. Rationalized tariffs will help, but a rigorous exercise in location theory would identify energy-saving opportunities.

India needs these and many other studies to provide a basis for internalizing the real cost of transportation and energy into individual and government decisionmaking. This real cost includes the full social and resource cost. Economic incentives and disincentives (taxes and subsidies) are often needed to accomplish this internalization for individuals.

Both long-term transportation energy system planning and subsystem analysis will be required to allow India's transportation system to keep pace with and fully support the nation's growth and development. For every barrel of diesel fuel India imports it cannot import something else needed for development. The challenge is great.

ACKNOWLEDGMENT

The paper summarizes the analysis and field work performed for the U.S. Agency for International Development during the summer of 1981. The purpose was to design Indo-U.S. transportation energy projects for the agency. I acknowledge their support and direction. It was in traveling through India, observing its transportation system and talking to its transportation professionals, that I learned the meaning of India's transportation problems and plans. I greatly appreciate the assistance of the Indians who gave me their time and insights and hope this paper does some justice to what they tried to teach me.

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Publication of this paper sponsored by Committee on Transportation and Land Development.