Revised per John Zumerchik note of July 14, 2000

3927 words of text

ENERGY USE IN RAIL PASSENGER TRANSPORT

Travelers usually have a choice among several transportation alternatives, most prominent being automobile, bus, airplane and railway. Rail was the preferred means of travel in the mid-19th century and continuing until the 1920s, but began to decline afterwards because it could not compete with the greater mobility of the automobile and the greater speed of air travel. Despite this decline, rail passenger service may yet find a new role where its potential to be more fuel-flexible, environmentally friendly and energy efficient can be realized. Moreover it has the flexibility to avoid the congestion delays of air and roadway traffic that is likely to only worsen.

Box One shows that around sixty percent of transport energy in the U.S. is used for passenger transport, almost entirely by autos, light trucks and aviation. In fact, rail passenger services in the U.S. carry only around 2 percent of total passenger-kilometers (a passenger-km is one passenger moved one kilometer), with the remainder carried by auto, air and bus. In other countries, the rail role is larger, ranging from six to ten percent of passenger-km in many European countries to about 20 percent in India and as high as 34 percent of passenger-km in Japan. Depending on the country, energy in transport could be saved by making rail passenger services more energy efficient (not so important in the U.S. but much more so in Europe, India and Japan) or, probably more important, in getting passengers to switch from less energy efficient modes to potentially more efficient modes such as rail passenger service.

Rail passenger service offers many alternatives, with different characteristics and customers. In urban areas, slow (50 Km/Hr), frequent-stop trolleys ("streetcars") have long operated in many cities, often in the same right-of-way where autos and buses drive. There are "Light Rail Trains" (LRT), midway in speed (up to about 80 Km/Hr) and capacity between trolleys and traditional subways, operating in a number of large metropolises. "Heavy rail" metros (up to 110 Km/Hr) form the heart of the transport network in many of the world's largest cities. Many cities supplement their Metros with longer range, higher speed (up to 140 Km/Hr) suburban rail services, and some have mixtures of all of these (Cairo, for example, or Moscow).

In the intercity market there are glamorous high speed trains (between 200 and 300 Km/hr) such as the Japanese Shinkansen and the French TGV (and Amtrak's Metroliner) and these trains do carry enormous numbers of passengers in Japan (almost 300 million per year), France (about 65 million), and Germany (over 20 million). These trains provide high-quality, city-center to city-center passenger service in competition with air (below 500 Km or so) and auto (over 150 Km or so). Though they are important, only rarely do these high speed trains actually carry a sizeable percentage of the country's total rail passengers.

The workhorse of most rail passenger systems is ordinary passenger trains operating between 70 and 160 Km/hr. Box two shows the rail passenger traffic carried by most of the world's railways. The top three railways account for over half of the world's passenger services, and the top six account for over two-thirds. Box two demonstrates another important point: the **entire** developed world only accounts for 30 percent of rail passenger transport. North American, European and Japanese experience are not representative of the vast bulk of the world's rail passengers.

ENERGY USE BY RAIL PASSENGER TRAINS

Rail passenger energy efficiency depends on many variables, and a complete analysis would consume volumes of argument. In large part, though, an analysis of energy consumption in passenger transport begins with four basic factors: surface contact friction (rolling wheels), air drag (wind resistance), mass and weight (which influence acceleration/deceleration requirements and contact friction), and load factor (the percentage of occupied seats or space).

Surface friction is a source of rail's advantages in transport energy efficiency. Under similar conditions, steel wheels on steel rail generate only about 20 to 30 percent of the rolling friction that rubber wheels on pavement generate (see Box three), both because rails are much smoother than pavement and because steel wheels are much more rigid than rubber tires so they deform much less at the point of contact with the ground. Each rail wheel has only about 0.3 square inches of surface in contact with the rail whereas an automobile tire can have 20 to 30 square inches of rubber in contact with the pavement. The greater rubber tire deformation takes energy that is wasted as heat in the tread, and the lower the pressure the greater the deformation. Slightly offsetting this difference is the friction of the rail wheel flange which keeps the train on the track.

Air drag is minimal at very low speeds, but it rises rapidly with increasing speed. In fact, drag is related to speed squared and the power required to overcome drag is related to speed cubed, and it affects all vehicles. With good design of rolling bearings, rolling friction does not increase as rapidly with speed as does air drag so, in most cases, air drag begins to exceed rolling friction at speeds above 60 to 100 Km/Hr in rail passenger vehicles, and it dominates energy requirements at speeds above about 150 Km/Hr. Streamlining can reduce air drag for any vehicle, but rail again has an inherent advantage because, for the same number of passengers, trains can be longer and thinner than buses or airplanes, and the "thinness" of the form affects air drag significantly..

Mass affects energy consumption because it takes energy to accelerate the vehicle and its passengers, and most of this energy is subsequently wasted as heat in the braking system when the vehicle slows. Weight also increases rolling friction. Surprisingly, rail passenger vehicles are relatively heavy. A fully loaded five passenger automobile will have a gross weight of no more than 800 pounds per occupant and a bus slightly less, whereas a fully loaded rail passenger coach will have a gross weight of between 2000 and 3000 pounds per occupant, and the average train, including locomotives, diners and sleeping cars, can average 4000 pounds or more per passenger.

Engineering models of tractive effort calculation derive from a basic model, generally called the "Davis Formula" (after its initial formulator, W.J. Davis). The Davis formula calculates the resistance (Rt, in pounds per ton of weight being pulled) as:

$Rt = (1.3 + 29/w + bV + CAV^2/wn)/wn$

Where: w is the weight in tons per axle

b is a coefficient of flange friction (.03 for passenger cars)

V is the speed in miles per hour

C is the air drag coefficient (.0017 for locomotives, .00034 for trailing passenger cars)

A is the cross sectional area of locomotives and cars (120 square feet for locomotives, 110 square feet for passenger cars)

The coefficients shown for the formula are examples: they would differ with changing designs of freight and passenger rolling stock and are specific to each train. The purpose here is to show the form of the relationship, not the exact values.

The influence of these variables is displayed in Boxes four to seven. Box four shows the energy consumption for full autos of various sizes and speeds. Box five shows energy consumption on a full bus at various speeds. Box six displays energy consumption on various full passenger trains over a range of speeds. Box seven contains comparable information for a number of fully loaded passenger aircraft depending on trip length and the type of aircraft used.

Box three shows that rolling friction in highway vehicles ensures that a given weight of cargo, even at very slow speeds, will take more force to pull on rubber tires than on steel wheels. In Boxes four through six, energy consumption rises rapidly with speed -- and the energy consumed by the highly streamlined TGV or Swedish X2000 is far less than the energy consumed by the boxy Metroliner. In Box four, the influence of vehicle weight is clear, with large autos significantly less efficient than small cars.

These Boxes leave out another important determinant of energy efficiency **– load factor**. Roughly speaking, a half-empty vehicle consumes twice as much energy per passenger-kilometer (P-Km) as a full vehicle, and a one-fourth full vehicle four times as much. No matter what the potential energy advantages might be, empty trains waste energy, and full autos can be highly efficient. Unless modes are compared while operating at the appropriate load factor, the energy efficiency conclusions reached can be seriously flawed – and it is not necessarily valid to assume the same load factor for all modes. Indeed, the annual average load factor for Amtrak in the U.S. is only 46 percent while the average load factor for U.S. airlines is 65 percent. Commuter trains do run full (or more than full) in the loaded direction during rush hour, but they often run nearly empty in the outbound direction, and during mid-day, and actually average less than 35 percent load factor.

Even after the readily quantifiable engineering and operating issues are argued, the picture is still incomplete. Energy consumption in passenger transport is also affected by a large number of less predictable, real world factors. Hilly countries, for example, cause reduced railway efficiency because railways cannot climb steep grades (the downside of reduced rolling friction), so railway lines usually have to be thirty to fifty percent longer than highways between the same two endpoints in mountainous terrain. Bad maintenance practices and older equipment can severely reduce energy efficiency **and** increase pollution. These factors, and others such as driver expertise, can easily dominate the engineering and operating factors which can be readily measured.

Taking all these factors into account, well calibrated computer models show that U.S. freight trains of various types could theoretically operate at energy consumption rates of 75 to 140 Kilo Joules per ton-km (Kj/T-Km) of cargo depending on the type of train, with low speed, heavy coal trains being the most efficient and high speed, high drag, double-stack container trains being the most energy consuming. In 1997, the actual rail industry average of 250 Kj/T-Km was nearly twice the theoretical upper bound of 140 Kj/T-Km, reflecting the running of partially empty trains, wagon switching, and locomotive idling practices, among other factors. Though the technology is effectively the same, average energy consumption in Kenya Railways freight traffic is over 1000 Kj/T-Km as a result of far less than optimum operating and maintenance practices.

Similar variations occur in reported cases of rail passenger service where engineering models show trains potentially operating at 200 to 400 Kj/P-Km. In practice, though, passenger trains are rarely full, and some trains, such as many long haul Amtrak trains, carry sleepers and diners which add significantly to the weight of the train but do not add many passenger seats. Commuter trains do not usually carry diners, of course, but they often operate essentially empty on their mid-day trips or trips against the flow of rush hour traffic. Thus, the theoretically high rail passenger energy efficiency gets transmuted into an Amtrak system-wide average of 1,610 Kj/P-Km and an average for all US commuter railways of 2,131 Kj/P-Km Because of the effect of actual practices, the optimal efficiency from the engineering model is, in practice, actually a factor of four to eight better than what is actually experienced.

In trying to take all of the issues into account, the best that can be done is to show ranges that reflect the actual outcomes experienced. Box eight summarizes both theory and practice. Box eight shows the range of energy efficiencies of the various modes with the bottom of the range showing full vehicles operating under optimum conditions, and the top of the range showing what has actually been reported by operating agencies in real-world conditions.

In general, the range of reported experience supports the conventional wisdom. Rail **is** the potentially the most efficient method of motorized passenger travel; but bus is almost the equal of rail. Motorcycles are also quite efficient (and this assumes only the driver -- motorcycles with passengers are the most energy efficient vehicles of all). Automobiles and airlines do typically consume more energy per P-Km than rail.

More important, though, is the fact that there are significant overlaps in the energy consumption ranges depending on the factors discussed above. While rail and bus are generally a toss-up, there are conditions in which a fully loaded Boeing 747-400 can be more energy efficient than a partially loaded Amtrak Metroliner. A fully loaded automobile can well be a better energy and environmental choice than empty buses or trains. There is no single answer, and actual conditions are very important.

Though only partly energy related, passenger trains have additional features that deserve highlighting, such as the potential for electrification, the efficient use of land, and impact on urban form.

Electrification. Because their travel path is well defined, where train traffic is dense it can be economically feasible to construct either overhead electric power supply wires (the “catenary” system) or ground level electric supply systems (usually called the “third rail”) which permit trains to be powered directly by electric traction motors. Though there are a few cities which have electric trolley buses, the cost of building and operating a system to supply electricity to buses, autos and trucks is normally so high as to restrict road travel to use of fossil fuels, though advances in battery technology or hydrogen fuels may eventually reduce this dependence.

Electric traction power in railways offers three significant advantages – diversity of fuels, easier control of pollution, and high tractive effort per unit of train weight. Because electricity can be generated by a wide range of fossil fuels such as coal or natural gas, electric trains are not solely dependent on petroleum products for their operation. In fact, hydroelectric or nuclear power uses no fossil fuels at all (though each has its own environmental implications) and some countries, such as Switzerland, can use hydropower to drive almost all of their passenger and freight trains. Even when the electricity used by trains is generated by fossil fuels, the pollution is far more easily controlled from a single electric power station than from thousands of cars and buses, and the pollution and engine noise will be emitted at the power station and not in the city centers.

Because it takes time for an electric motor to overheat when exposed to high power currents, properly designed electric motors have the capability of operating for limited periods of time at power ratings as much as twice the level at which they can operate continuously. This means that electric motors can deliver short bursts of acceleration which requires power well beyond the power needed for cruising. Diesels, by contrast, are limited by the power of the engine, and cannot exceed this rating even for short periods of time. In addition, in the diesel-electric system, which almost all diesel trains use, the diesel engine drives a generator which in turn feeds electric traction motors which drive the train: this involves extra weight so that diesel systems are heavier than all-electric systems. As a result, electric traction has advantages where high acceleration is required, or where (as in high speed trains) the weight of the train must be controlled in order to reduce the forces which the train exerts on the track. Offsetting the performance advantages of electric traction is the added cost of the catenary or third rail and transformers needed to feed the train with electricity.

Most urban rail passenger systems are electrically operated because electric power permits high acceleration and thus closer spacing of trains. Most high speed trains are electrically driven because diesel engines of the high power required are too heavy (and damage the track), and gas turbines do not handle acceleration well because they are not energy efficient at speeds other than the optimum speed for which the turbine is designed. Ordinary, longer haul passenger trains are a mix of diesel and electric traction: diesel traction is far cheaper on light density lines and high acceleration and light weight are not so important on slower trains.

Because railway electric motors can be made to slow a train as well as drive it, the energy of braking can be regenerated on-board and put back into the catenary or third rail for use by other trains. Regeneration has not been prevalent in railways because of the complexity and weight of the on-board equipment involved, and regeneration has generally not been economically feasible where the catenary is providing AC traction current because of the difficulty of matching the frequency and phase of the regenerated power to the power in the catenary. Technology is changing in this respect, and AC regeneration is emerging as a possibility where train traffic is dense enough to support the added investment.

Railway electric traction systems use either alternating current (AC) or direct current. (DC). Third rail systems operate on DC at 600 to 700 Volts. Overhead systems can be found with either 1500 or 3000 Volts DC, or using AC at a range of voltages (from 11,000 to 50,000) and frequencies (16 2/3 cycles per second, or Hertz, to 60 Hertz). The modern standard for overhead catenary systems is usually 25,000 Volts and either 50 or 60 Hertz depending on the industrial standard for the country (50 Hertz for most of Europe, 60 Hertz for the U.S. and Japan).

The total energy efficiency of a diesel system is not much different from an electrically driven system – a point which many energy comparisons neglect. The percentage of the energy in diesel fuel that is actually translated into tractive effort seems low, around 26 percent, in comparison with electric drive trains that convert 90 percent of the power received from the wire or third rail into traction. However, the percentage of the fuel consumed in a power plant that is converted into electric energy is only around 40 percent (slightly higher in modern, compound cycle plants), and electric systems lose energy due to resistance in the transmission lines and transformers. Measured by the percentage of the initial fuel's energy that is actually translated to tractive effort on the train, there is not a great deal of difference between diesel at about 26 percent efficiency and electric traction systems which deliver about 28 percent of the initial fuel energy into tractive effort at the rail.

Space efficiency. The land area required for a double track railway (a minimum right-of-way approximately 44 feet wide) is less than that required for a four lane highway (a at least 50 feet wide at an absolute minimum, and usually much more). Depending on assumptions about load factors, a double track railway can carry between 20,000 and 50,000 passengers in rush hour in each direction, about twice to four times the peak loading of a four lane highway (2,200 vehicles per lane per hour). Putting a double track railway underground is also much cheaper than the equivalent capacity by highway because rail tunnels are smaller and require much less ventilation. Overall, high density railways can carry between three and eight times the amount of traffic a highway can carry per unit of land area used, and they can do so with limited and controlled environmental impact.

Urban form. Because of their ability to handle massive numbers of people effectively, using little space and emitting little or no pollution (in the urban area, at least), railways can support the functioning of much denser urban areas than auto-based urban sprawl: in fact, the term “subway” was invented to describe the underground railway which consumes almost no surface space. Where urban congestion is important (in Bangkok there have been estimates that traffic congestion lowers the Gross Domestic Product of Thailand by several percentage points), various rail options can have a high payoff in moving people effectively. In densely populated countries, as in most of Europe and

Japan, longer haul rail passenger service plays a similar function of moving people with minimum burden on land space and overloaded highway and air transport facilities.

Technology in transport is also on the move. Automobiles have seen advances in engine design (reducing energy and pollution), body design (reducing air drag), radial tires and tread design (reducing rolling friction) and replacement of steel with plastics and aluminum (reducing weight). As a result, auto energy mileage per gallon of fuel, which was about 13.5 miles per gallon in the US in 1970 has improved to about 21.5 miles per gallon in 1997 (a 37 percent improvement), and there are vehicles now available that can produce 50 to 70 miles per gallon. Diesel engine technology has improved in parallel, as has vehicle design for both rail and bus vehicles, yielding roughly a 46 percent improvement in rail efficiency since 1970. Advances in aircraft design and size, along with improved engines have kept pace with the surface modes. Since the basic technology in engine, air drag and vehicle frame weight management is similar, and available to all modes, there is reason to believe that all modes will (or could) improve, but no convincing basis for arguing that any of the modes will dramatically improve its energy efficiency relative to the others.

CONCLUSIONS

The energy/transport relationship is complex and resists easy generalization. Against this backdrop, what are the useful conclusions to be drawn about the role of passenger rail services in saving energy or reducing environmental impacts from transport?

In the urban arena, energy efficient rail passenger services **can** reduce air pollution and help manage urban congestion. Rail passenger services can be vital to the form and function of large cities by putting large movements of people underground or overhead without consuming undue space. This potential cannot be reached, however, unless rail services are carefully planned and managed so that they operate where needed and at high load factors. Rail's effects are likely to be localized, though, and the potential will be limited if competitive modes are not fully charged for the congestion and pollution they cause. Urban rail probably does not offer much to the effort to control greenhouse gas emission, both because of the relatively small amounts of energy involved and because of urban rail's inherently low load factors.

Rail's contribution in the intercity passenger arena is less clear. Where population density is high and travel distances short, and especially where fuel prices and tolls are high and airline travel expensive, there is a need for rail passenger which can operate efficiently. This describes conditions in Japan, and parts of Western Europe and possibly the Northeast Corridor in the United States, where high density and high speed rail services do exist. But, with rail passenger services carrying less than two percent of the intercity traffic in the U.S., the contribution of this traffic to energy efficiency objectives is probably minimal. Where populations are high and extremely poor, and where rail tariffs are kept low, there is also a significant demand for rail passenger services, as in India, China, the CIS countries and Egypt. It is possible that rail passenger service in these countries is making a contribution to the reduction of energy consumption and thus to control of CO_2 emissions. In the "middle" countries, including the U.S. and Canada (outside a few dense urban corridors), which have long distances and low population densities, it seems doubtful if rail passenger services can make a measurable contribution to energy efficiency and CO_2 reduction. In all countries, it is unlikely that intercity rail passenger services will be useful in reducing localized urban air pollution.

Louis S. Thompson

Railways Adviser

The World Bank

BIBLIOGRAPHY

Association of American Railroads. 1997. *Railroad Facts*. Economics and Finance Department, Washington, DC

Archondo-Callao, Rodrigo and A. Faiz. 1992. "*Free Flow Vehicle Operating Costs*." [Highway Design and Maintenance Standards Series.] Infrastructure Department, World Bank, Washington, D.C.

Anderson, David and D. Mattoon. 1993. *Train Operation and Energy Simulator(TOES) Technical Manual*. Association of American Railroads, Research and Test Department, Chicago.

Anderson, David, D. Mattoon and S. Singh. 1992. *Revenue Service Validation of Train Operation and Energy Simulator (TOES), Version 2.0.* Association of American Railroads, Research and Test Department, Chicago.

Association of American Railroads. 1990. *Locomotive Improvement Program, Eleventh Research Phase Final Report*. Washington, D.C.

Chan, Lit-Mian and C. Weaver. 1994. *"Motorcycle Emission Standards and Emission Control Technology*." Departmental Papers Series, No 7. World Bank, Asia Technical Department, Washington, D.C.

Chester, Andrew and R. Harrison. 1987. *Vehicle Operating Costs: Evidence from Developing Countries.* The Highway Design and Maintenance Standard Series. Baltimore: The Johns Hopkins University

BIBLIOGRAPHY

Press.

Commission of the European Communities. 1992. *Green paper on the Impact of Transport on the Environment: A Community Strategy for Sustainable Mobility*. Brussels.

Ibid, 1996. *White Paper: A Strategy for Revitalizing the Community's Railways*. Brussels.

Davis, Stacy C., 1999. *Transportation Energy Data Book*, Edition 19 of ORNL-6958. U.S. Department of Energy, Washington, D.C.

DeCicco, John and M. Ross. 1994. "Improving Automotive Efficiency." *Scientific American*, December 1994: 52-57.

Drish, William F. and S. Singh. 1992. *Train Energy Model Validation using Revenue Service Mixed Intermodal Train Data.* Association of American Railroads, Research and Test Department, Chicago.

Faiz, Asif, Christopher S. Weaver and Michael P. Walsh, 1996, *Air Pollution from Motor Vehicles,* World Bank, Washington, DC.

Gordon, Deborah. 1991. *Steering a New Course: Transportation, Energy and the Environment.* Washington, D.C.: Island Press.

BIBLIOGRAPHY

Hay, William W., 1961, *An Introduction to Transportation Engineering*, John Wiley & Sons, New York, New York

Heierli, Urs. 1993. *Environmental Limits to Motorization Non-Motorized Transport in Developed and Developing Countries*. St. Gallen, Switzerland: SKAT, Swiss Centre for Development Cooperation in Technology and Management.

Imran, Mudassar and P. Barnes. 1990. *"Energy Demand in the Developing Countries: Prospects for the Future."* World Bank Staff Commodity Working Paper No 23. World Bank, Washington D.C.

Ishiguro, Masayasu and T. Akiyama. 1995. *Energy Demand in Five Major Asian Developing Countries.* World Bank Discussion Paper 277. World Bank, Washington, D.C.

Levine, Mark D. et al. 1991. *Energy Efficiency, Developing Nations, and Eastern Europe*. A Report to the U.S. Working Group on Global Energy Efficiency.

Martin, D.J. and Michaelis. 1992. *Research and Technology Strategy to Help Overcome the Environmental Problems in Relation to Transport: Global Pollution Study.* Luxembourg: EEC.

Noll, Scott A. 1982. *Transportation and Energy Conservation in Developing Countries.* Washington, D.C.: Resources for the Future.

BIBLIOGRAPHY

Organization for Economic Cooperation and Development. 1985. *Energy Savings and Road Traffic Management.* Paris: OECD.

Redsell, M., G. Lucas, and N. Ashford. 1988. *Comparison of on-road Fuel Consumption for Diesel and Petrol Cars.* Transport and Road Research Laboratory. Berkshire.

Rose, A.B. 1979. *Energy Intensity and Related Parameters of Selected Transportation Modes: Passenger Movement*. U.S Department of Energy. Oak Ridge, Tenn: Oak Ridge National Laboratory.

Schipper, Lee and S. Meyers. 1992. *Energy Efficiency and Human Activity: Past Trends, Future Prospects.* Cambridge University Press.

Schipper, Lee and Celine Marie-Lilliu, 1998, *Transportation and CO2 Emissions: Flexing the Link*, World Bank Global Environment Division, World Bank, Washington, DC

Thompson, Louis S., and Julia Fraser, 1995. *Energy Use in the Transport Sector,* World Bank Draft Paper, Transport, Water and Urban Department.

United Nations. Economic Commission for Europe. 1983. *An Efficient Energy Future: Prospect for Europe & North America.* Boston: United Nations Economic Commission for Europe: Butterworths.

BIBLIOGRAPHY

U.S. Congress, Office of Technology Assessment. 1991. *Improving Automobile Fuel Economy: New Standards and Approaches.* OTA-E-504. Washington, D.C: U.S. Government Printing Office.

U.S. Department of Transportation. 1990. *Compendium of National Urban Mass Transportation Statistics from the 1987 Section 15 Report.* Urban Mass Transportation Administration, Washington, D.C.

------. 1973. *The Effect of Speed on Automobile Gasoline Consumption Rates*. Federal Highway Administration, Office of Highway Planning, Highway Statistics Department, Washington, D.C.

------. 1993. *Transportation Implications of Telecommuting*. Washington, D.C.

------. 1997. *National Transport Statistics*. Bureau of Transportation Statistics, Washington, D.C.

------. 1991. *Rail vs Truck Efficiency: The Relative Fuel Efficiency of Truck Competitive Rail Freight and Truck Operations Compared in a Range of Corridors*. Federal Railway Administration, Washington, D.C.

Wagner, Frederick A. and Institute of Transportation Engineers. 1980. *Energy Impacts of Urban Transportation Improvements.* Washington, D.C.: The Institute.

World Bank. 1993a. *Energy Efficiency and Conservation in the Developing World*. World Bank Policy Paper. Washington, D.C.

BIBLIOGRAPHY

------. 1988. *Road Deterioration in Developing Countries: Causes and Remedies.* World Bank Policy Study. Washington, D.C.

------. 1996. *Sustainable Transport: Priorities for Policy Reform,* World Bank Development in Practice Series.

Box one

(Percent of total Kilojoules of energy consumed)

Mode	Passenger	Freight	Total
Automobiles	34.8		34.8
Motorcycles	0.1		0.1
Buses	0.7		0.7
Light Trucks*	16.5	8.1	24.6
Heavy Trucks		16.2	16.2
Off Highway Trucks		2.9	2.9
Air**	8.3	0.9	9.2
Water	1.2	4.0	5.2
Pipeline		3.9	3.9
Rail:			-
freight		2.0	2.0
passenger:			-
Transit	0.2		0.2
Commuter	0.1		0.1
Intercity	0.1		0.1
Total	62.0	38.0	100.0

* assumes that 2/3 of light truck usage is passenger transport related and 1/3 is used to haul cargo

** assumes that 10 percent of air transport fuel energy is consumed as a result of cargo and 90 percent is passenger and luggage related.

Source: Davis, Stacy C., **Transportation Energy Data Book**, Oak Ridge National Laboratory, ORNL 6958 Edition 19, Table 2.6, page 2-7

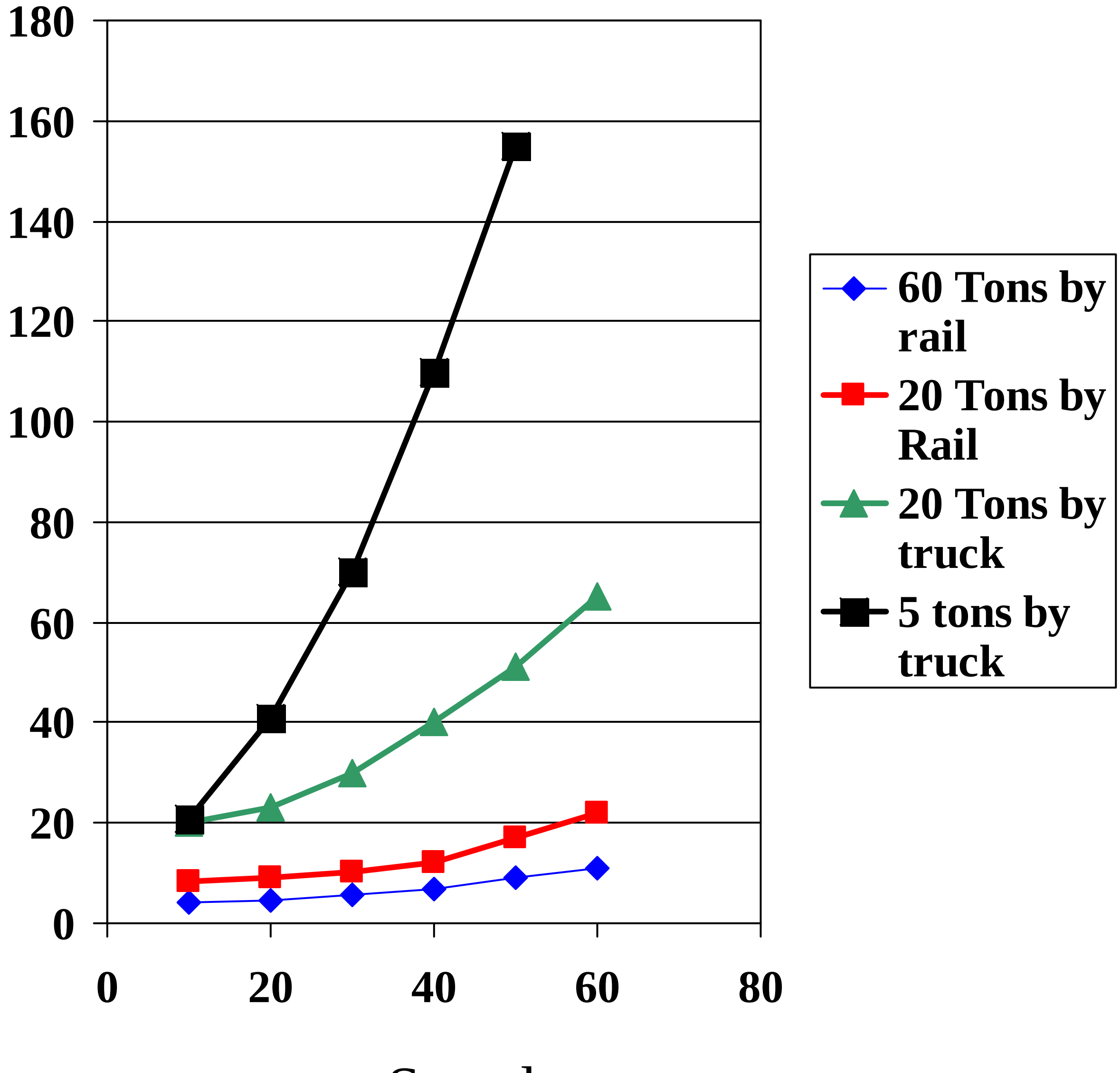
Box two

The World's Rail Passenger Traffic

	Passenger-Kilometers (000,000)	Percent of Passenger-Kilometers	
India	357,013	20.1	
China	354,261	19.9	
Japan	248,993	14.0	
Russia	168,679	9.5	
Rest of W. Europe	68,107	3.8	
Ukraine	63,752	3.6	
Germany	60,514	3.4	
France	55,311	3.1	
Egypt	52,406	2.9	
Italy	49,700	2.8	
Rest of dev.Asia	42,849	2.4	
Republic of Korea	29,292	1.6	
United Kingdom	28,656	1.6	
Rest of CEE	27,963	1.6	
Poland	20,960	1.2	
Kazakhstan	20,507	1.2	
Pakistan	19,100	1.1	
Romania	18,355	1.0	
Rest of Middle East	17,803	1.0	0.5
Latin America	17,204	1.0	0.6
Rest of CIS	16,079	0.9	0.1
All of Africa	14,242	0.8	
US Commuter	11,135	0.6	
Amtrak	8,314	0.5	
Australia	4,904	0.3	
Canada VIA	1,341	0.1	
World Total	1,777,440	100.0	
Percent in Developing Countries		69.8	
Percent in Developed Countries		30.2	

Box three

Force (Pounds/ton) to pull various loads by rail and by truck at various speeds

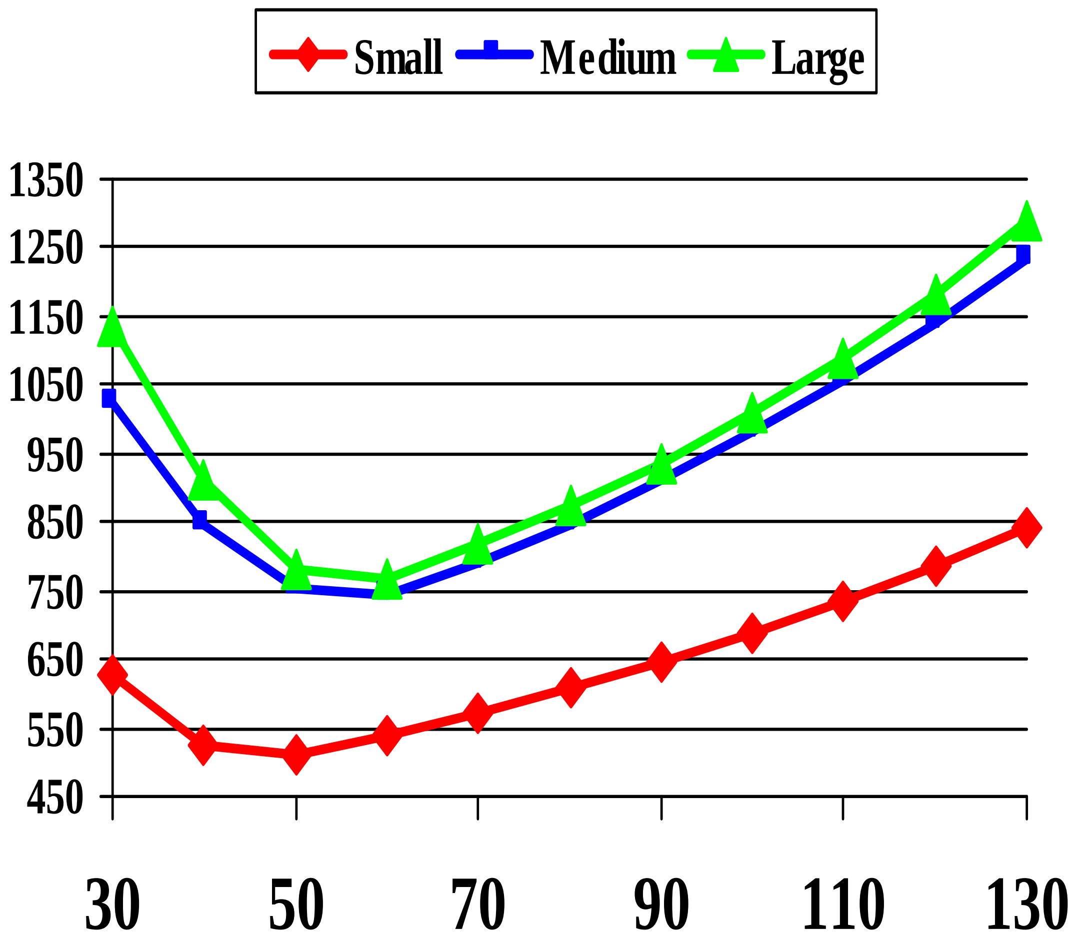


Source: Hay, page 190

Box four

Auto Fuel Consumption at Various Speeds

(KJ/P-Km for full autos)



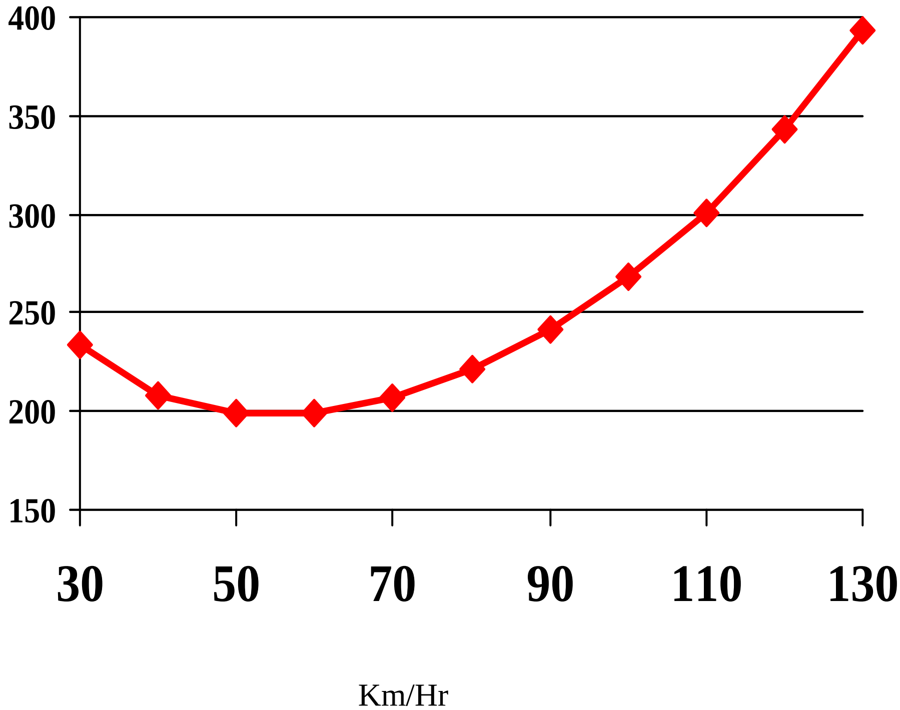
Km/Hr

Source: World Bank HDM Model

Box five

Bus Fuel Consumption at Various Speeds

(KJ/P-Km for full bus)

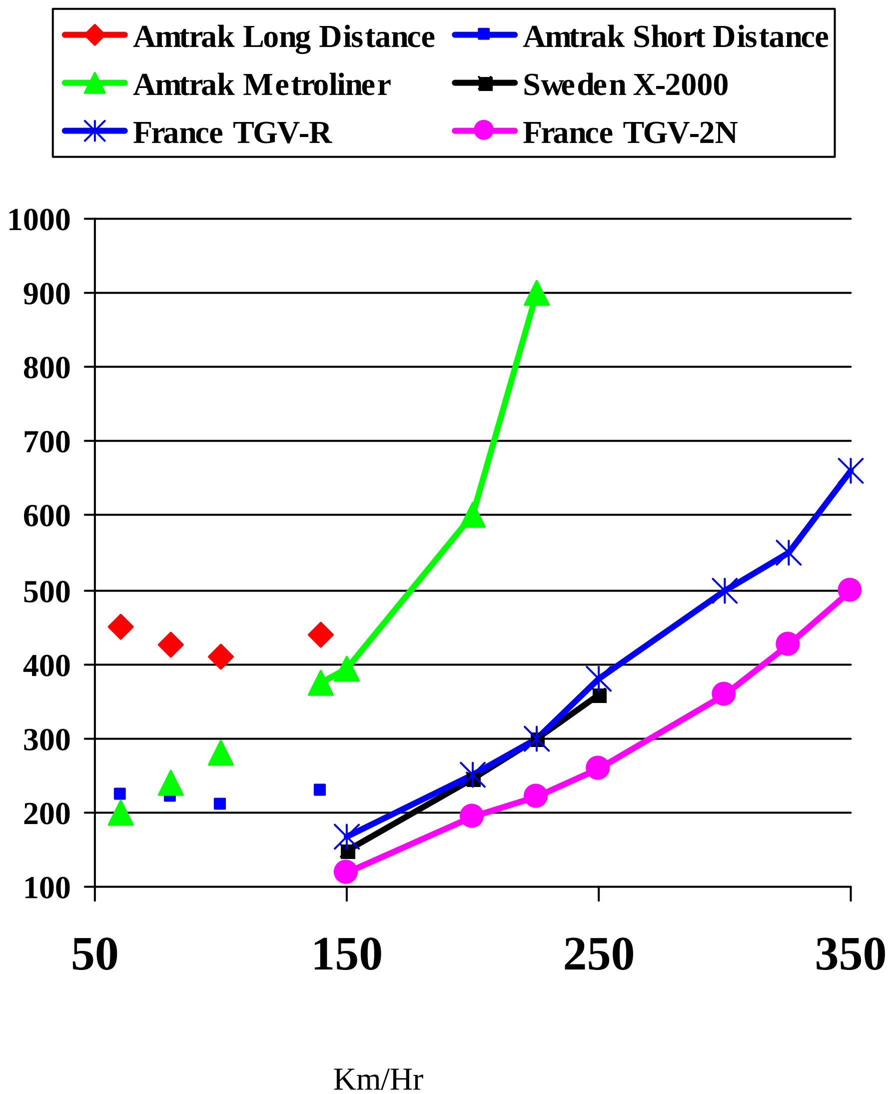


Source: World Bank, HDM Model

Box six

Rail Passenger Fuel Consumption at Various Speeds

(KJ/P-Km for full trains)

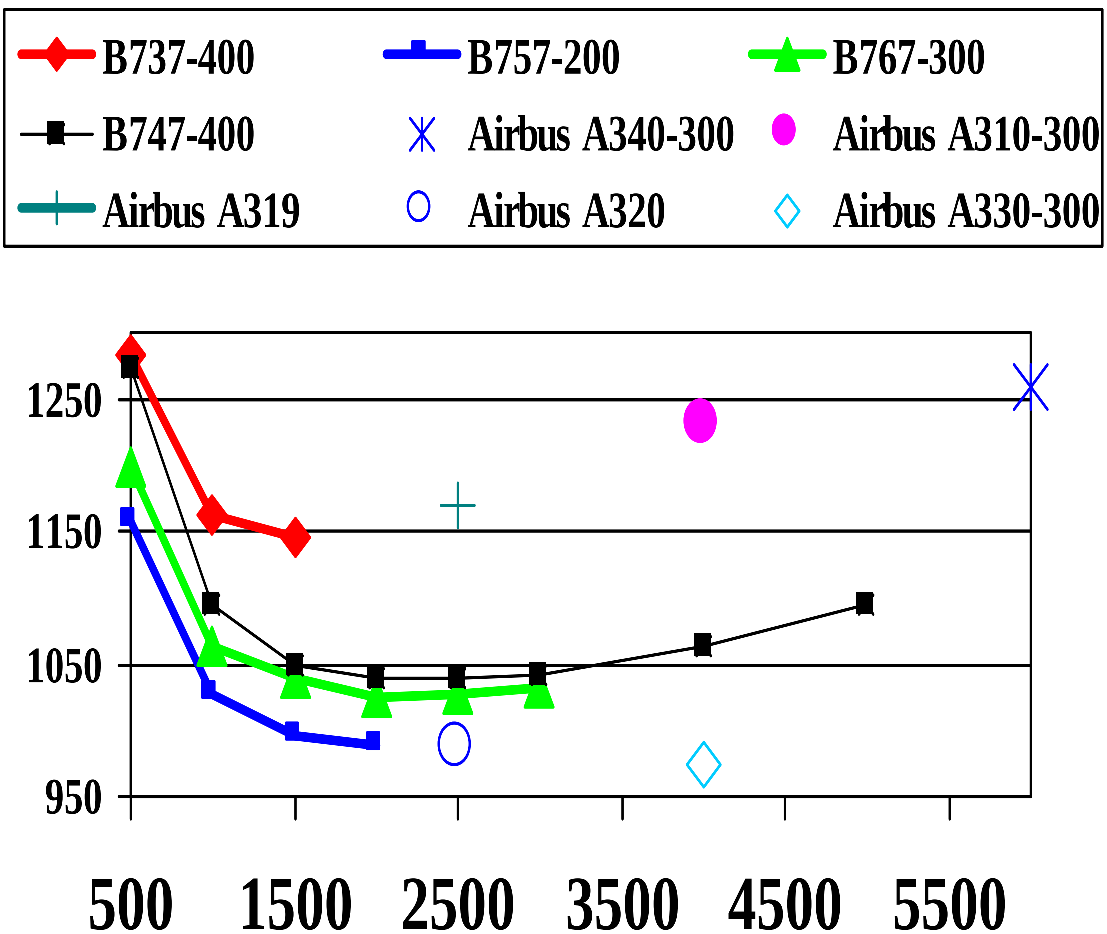


Source: World Bank Research

Box seven

Aircraft Fuel Consumption at Various Stage Lengths

(KJ/P-Km for full aircraft)



Note: The Concorde consumes 6260 KJ/P-Km for a 4,150 NM Trip
A Cessna Citation consumes 7,594 KJ/P-Km for a 2,100 NM Trip

Source: The Boeing Company, Airbus Industrie, The Cessna Company

Box eight

Energy Consumption Ranges in Passenger Transport