ENERGY EFFICIENCY IN MASS TRANSIT SYSTEMS

Clark W. Gellings
Electric Power Research Institute (EPRI), USA

Kelly E. Parmenter
Global Energy Partners, LLC, USA

Keywords: passenger transportation, mass transit, energy efficiency, air, bus, light rail, transit rail, railway, intercity rail

Contents

1. Introduction
2. Air
3. Bus
4. Transit Rail
5. Intercity Rail
6. Energy Efficiency Opportunities
6.1. Reduce Demand
6.2. Increase Load Factor
6.3. Shift to More Efficient Mode
6.4. Improve Vehicle Efficiency
6.5. Operate with Highest Efficiency
6.6. Invoke Progress through Intervention and Technological Innovation
Glossary
Bibliography
Biographical Sketches

Summary

Though they consume less transportation energy than personal passenger vehicles, mass transit systems are responsible for considerable energy use. Therefore, efforts to improve their energy efficiency can yield appreciable reductions in worldwide energy use.

In addition, shifting a portion of passenger travel from more energy intensive modes, such as personal transport vehicles, to mass transit modes has the potential to decrease overall transportation energy use, as well as reduce pollution and alleviate congestion. This article describes trends in passenger travel and energy consumption for the principal mass transit modes: air, bus, transit rail, and intercity rail.

It further presents energy efficiency measures for mass transit systems as they pertain to six general strategies for improving efficiency, namely 1) reduce demand, 2) increase load factor, 3) shift to more efficient mode, 4) improve vehicle efficiency, 5) operate with highest efficiency, and 6) invoke progress through intervention and technological innovation.

1. Introduction

There are several types of transportation mode used for passenger travel. The primary modes include passenger cars (including light trucks, vans, and sport utility vehicles (SUVs)), buses, aircraft, light rail vehicles (e.g., trams and metros), and heavy trains. Other modes include boats, motorcycles, bicycles, scooters, skates, skateboards, and even feet.

The primary modes are responsible for the largest quantities of passenger travel, as measured in units of passenger-kilometer. They also use the most energy.

Figures 1 through 4 show the breakdowns of passenger travel by primary transportation mode for the United States, European Union Countries (EU 15, which comprises Austria, Belgium, Germany, Denmark, Spain, Greece, France, Finland, Italy, Ireland, Luxembourg, the Netherlands, Portugal, Sweden, and the United Kingdom), Canada, and Japan, respectively.

For each of the areas, the dominant passenger transportation mode is the passenger car. In the United States, the passenger car represents the largest share of passenger travel compared with the other countries evaluated; indeed, passenger cars accounted for about 86% of passenger kilometers in 1998.

Passenger cars in Canada and the EU 15 also represented significant portions of passenger travel, with shares of 82% and 79%, respectively. Passenger cars in Japan accounted for 55% of passenger travel in 1998, and are therefore of relatively less importance than are passenger cars in other areas.

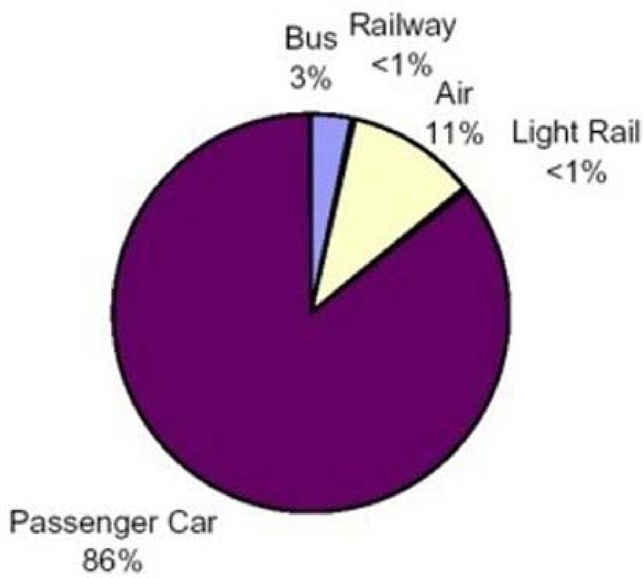

Figure 1. Passenger travel by mode, 1998 (United States). Total for modes shown = 7267×10^9 passenger-kilometer. Source: Data compiled from Europa, European Union. (2001). *Energy and Transport in Figures*, 3.1.13 – Comparison EU 15-World: Passenger and Freight Transport, <www.europa.eu.int/comm/energy_transport/etif/>

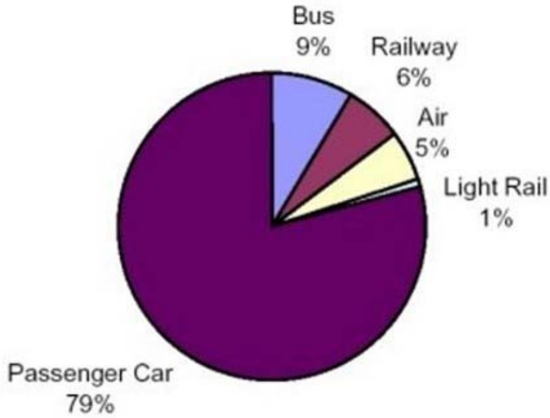

Figure 2. Passenger travel by mode, 1998 (EU 15). Total for modes shown = 4650×10^9 passenger-kilometer. Source: Data compiled from Europa, European Union. (2001). *Energy and Transport in Figures*, 3.5.2 – Performance by Mode of Transport EU 15, <www.europa.eu.int/comm/energy_transport/etif/>

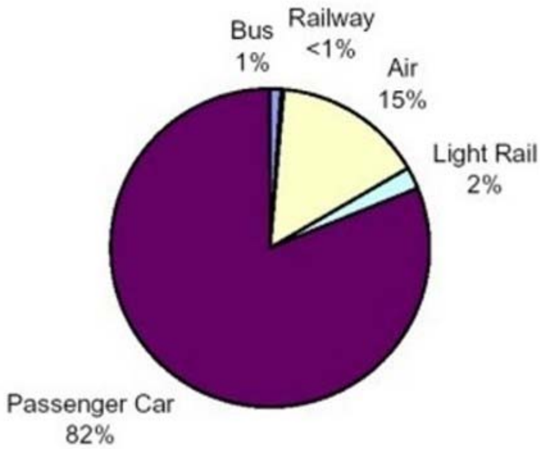

Figure 3. Passenger travel by mode, 1995 (Canada). Total for modes shown = 472.9×10^9 passenger-kilometer. Source: Data compiled from Consumer Policy Institute, *Passenger Travel by Motorized Modes*, Canada, 1970–1995, <www.nextcity.com/cpi/trans/transpo.html>

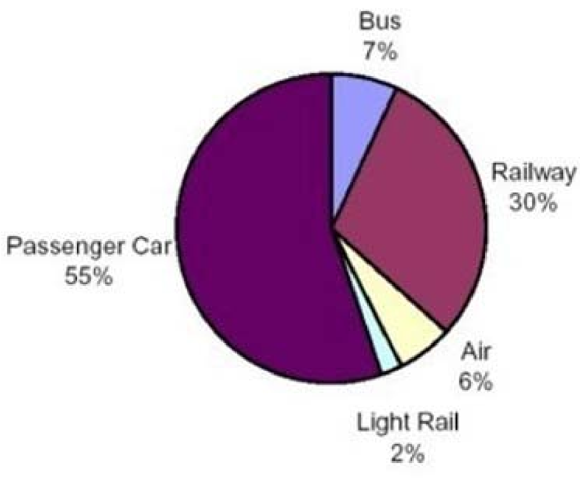

Figure 4. Passenger travel by mode, 1998 (Japan). Total for modes shown = 1309×10^9 passenger-kilometer. Source: Data compiled from Europa, European Union. (2001). *Energy and Transport in Figures*, 3.1.13 – Comparison EU 15-World: Passenger and Freight Transport, <www.europa.eu.int/comm/energy_transport/etif/>

Further examination of Figure 1 shows that air travel was responsible for the second largest share of passenger travel in the United States during 1998, accounting for 11%. Air travel was followed by bus transport (3%), and then by railway and light rail transport (each representing less than 1%). The breakdown is somewhat different in Figure 2. For the EU 15, bus transport was the second largest passenger mode (9%) in 1998, followed by railway (6%), air (5%), and then by light rail (1%).

Figure 3 illustrates that in Canada, as in the United States, air travel was the second largest passenger mode in 1995, followed by light rail (2%), bus (1%), and railway (less than 1%). In Japan, railway was the second largest passenger travel mode in 1998, accounting for a significant 30%. Railway transport was followed by bus (7%), air (6%), and then light rail (2%).

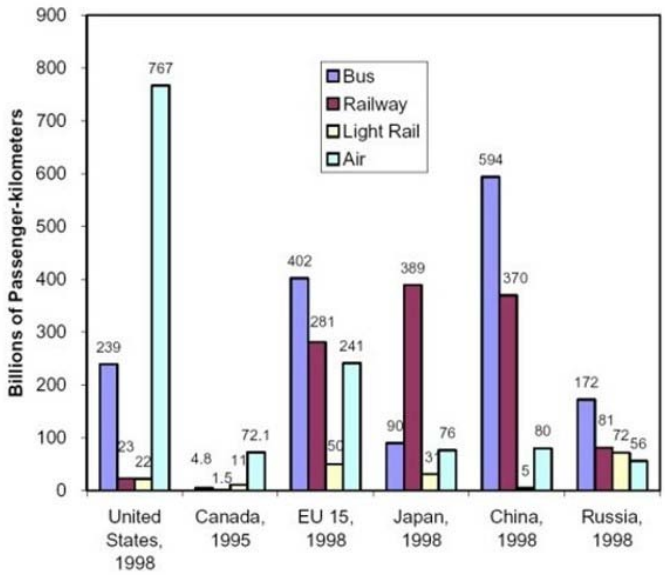

Figure 5. Mass transit passenger travel by mode (selected countries) (passenger-kilometer $\times 10^9$). Source: data compiled from Europa, European Union. (2001). *Energy and Transport in Figures*, 3.1.13 and 3.5.2, <www.europa.eu.int/comm/energy_transport/etif/> and Consumer Policy Institute, *Passenger Travel by Motorized Modes*, Canada, 1970–1995, <www.nextcity.com/cpi/trans/transpo.html>

The current article focuses on mass transit modes of passenger travel. Therefore passenger cars (including light trucks, vans, and SUVs) are not treated here in any more detail. Rather, they are discussed separately in *Energy Efficiency in Passenger Cars and Light Trucks*. In keeping with the emphasis of the current article, Figure 5 depicts the modal quantities of passenger travel in the mid-to-late 1990s by just the mass transit modes of bus, railway, light rail, and air for the United States, Canada, the EU 15, Japan, China, and Russia. The largest quantity of mass transit was attributable to air travel in the United States (767 × 10^9 passenger-kilometers). The second largest was bus travel in China (594 × 10^{69} passenger-kilometers), and the third largest was bus travel in the EU 15 (402 × 10^9 passenger-kilometers). Each of the geographical areas evaluated is characterized by a different breakdown of mass transit modes.

Air travel is the predominant mass transit mode in the United States and Canada, while bus travel dominates in the EU 15, China, and Russia, and railway is the leader is Japan. One common trend is that light rail is responsible for some of the smallest shares of mass transit. Figure 6 plots the energy intensities, as determined from four references, for each of the main mass transit modes in the United States during the mid-to-late 1990s. Before the figure is discussed, it should be emphasized that the data are for the United States alone, and energy intensity values for other countries differ based on many factors, including vehicle efficiency and passenger load factors. It should also be mentioned that at least some of the data for air travel in Figure 6 include energy consumed for both passenger and all-cargo transport. Therefore, the energy intensities are slightly higher than would be found if all-cargo flight were excluded. In addition, at least some of the transit and intercity rail data do not include electric power and distribution losses.

Inclusion of these losses would have the effect of raising the energy intensity values by roughly 20% for intercity transport and by roughly one-third for transit rail. Moreover, as can be seen from examination of the figures, there are subtle discrepancies between energy intensity values.These discrepancies arise from the fact that energy intensity values are strongly dependent on how a mass transit mode is defined. Furthermore, one must use caution when comparing energy intensities among modes, as the different modes are suited for different types and lengths of mass transit.

Nevertheless, thoughtful comparisons among the modes are useful for determining the most energy-efficient means of travel for a given application.

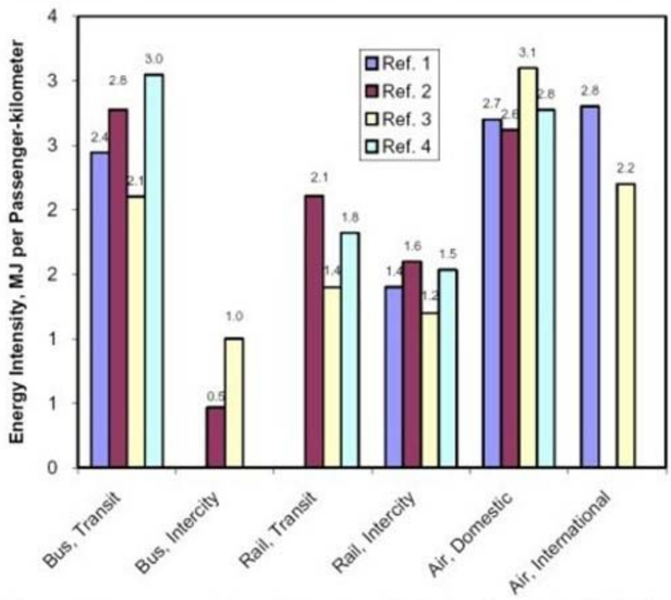

Figure 6. Energy intensities of mass transit modes, mid-to-late 1990s (United States): approximations from four sources (MJ per passenger-kilometer). Sources: data compiled from: 1) US Department of Transportation, Bureau of Transportation Statistics. (2001). *National Transportation Statistics 2000*, BTS01-01. Table 4-20. Washington, DC, USA: US Government Printing Office. 2) Oak Ridge National Laboratory (Stacy C. Davis), Office of Transportation Technologies, US DOE. (2000). *Transportation Energy Data Book: Edition 20*. Washington D.C., USA: US DOE. 3) Victoria Transport Policy Institute. (Ongoing). *Energy Conservation and Emission Reduction Strategies*. Online TDM Encyclopedia <www.vtpi.org/tdm/tdm59.htm> 4) The Public Purpose, *Urban Transport Fact Book*, US Transport Fuel Efficiency: 1995, <www.publicpurpose.com/ut-en-95.htm>

Figure 7 shows the variation in energy consumption in the United States between 1960 and 1998 for the main mass transit modes. The energy consumed by air travel increased dramatically during this period—from 279×10^{12} kJ to 1976×10^{12} kJ. Energy consumption changes for bus, transit rail, and Amtrak rail were less notable during this period. Bus consumption was 153×10^{12} kJ in 1998, compared with 121×10^{12} kJ in 1960. Transit rail rose slowly from 66×10^{12} kJ to 113×10^{12} kJ during the same period. Amtrak energy consumption remained relatively constant during the period of 1975 to 1988, at values fluctuating between 11×10^{12} kJ and 13×10^{12} kJ.

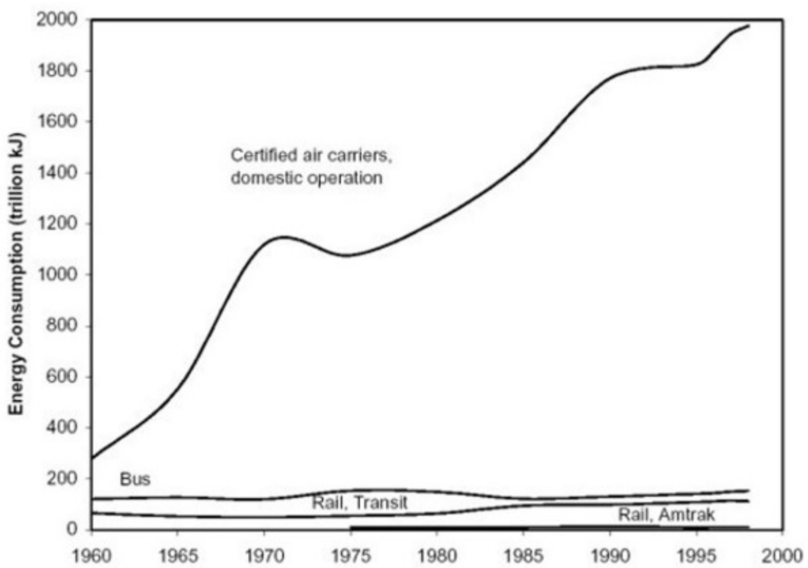

Figure 7. Energy consumption by mass transit mode, 1960–1998 (United States). Source: Data compiled from US Department of Transportation, Bureau of Transportation Statistics. (2001). *National Transportation Statistics 2000*, BTS01-01. Table 4-6. Washington, DC, USA: US Government Printing Office.

Figure 8 shows the variation in energy intensity for mass transit modes in the United States between 1970 and 1998. The energy intensity of air travel by certified air carriers dropped substantially during this period (from 6.78 to 2.62 MJ per passenger-kilometer). Overall decreases in intercity rail travel (2.41 to 1.61 MJ per passenger-kilometer) and intercity bus travel (0.69 to 0.47 MJ per passenger-kilometer) were less notable during similar periods. In contrast, the energy intensities actually increased for transit rail travel

(1.61 to 2.11 MJ per passenger-kilometer) and transit bus travel (1.62 to 2.78 MJ per passenger-kilometer), in large part because of lessened load factors. Because of its poor success in the United States, the financial and energy benefits of public transit by bus and rail are under debate. Public transit is currently heavily subsidized to encourage passenger travel; however, efforts have had relatively little success to date. In other countries, public transit is quite successful and yields obvious energy efficiency advantages.

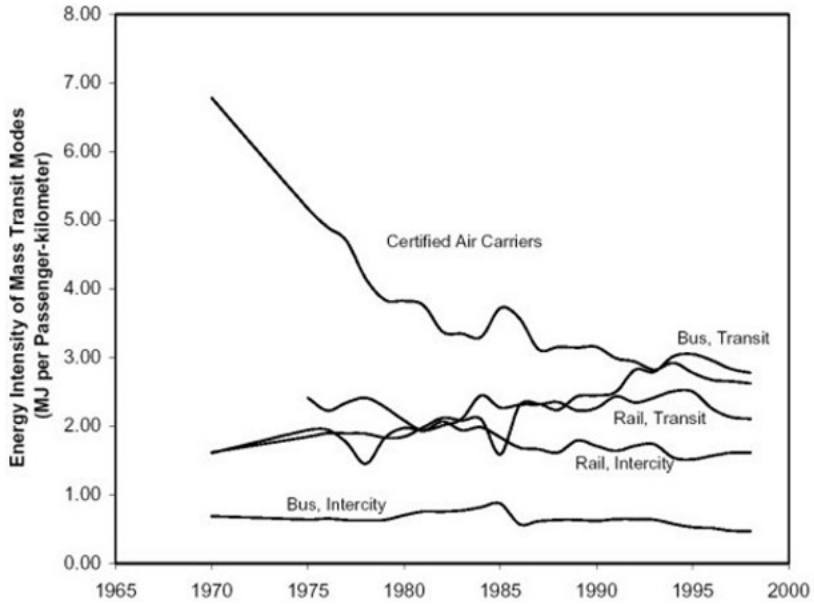

Figure 8. Energy intensity of mass transit modes 1970–1998 (United States) (MJ per passenger-kilometer). Source: Data compiled from Oak Ridge National Laboratory (Stacy C. Davis), Office of Transportation Technologies, United States DOE. (2000). *Transportation Energy Data Book: Edition 20*, Table 2.12. Washington D.C., USA: US DOE. (Also available online at <www.cta.ornl.gov/data>)

Sections 2 though 5 discuss the mass transit modes of air, bus, transit rail, and intercity rail, respectively, in more detail. Emphasis is placed on energy-use characteristics, as well as trends in passenger travel and modal share, for each mode. Section 6 summarizes the main opportunities for improving the energy efficiency of mass transit systems

-
-
-

.

Bibliography

Oak Ridge National Laboratory (Stacy C. Davis), Office of Transportation Technologies, United States Department of the Environment (US DOE). (2000). *Transportation Energy Data Book: Edition 20*. Washington, D.C.: US DOE. (Also available online at <www.cta.ornl.gov/data>) [This reference contains numerous data tables and figures related to transportation energy use in the United States.]

United Nations, Department for Development Support and Management Services, Energy Branch. (1993). *Energy Efficiency in Transportation: Alternatives for the Future*, 107 pp. New York: United Nations. [This report examines worldwide trends in transportation energy use and efficiency. It further presents case studies of conservation efforts in various developing countries, and explores the use of alternative transportation fuels. Particular emphasis is placed on natural gas vehicles.]

US Congress, Office of Technology Assessment. (1994). *Saving Energy in US Transportation*, OTA-ETI-589. Washington, D.C.: US Government Printing Office. [This report discusses energy usage patterns in the US transportation system, and compares the patterns with those of Europe. It also summarizes potential efficiency measures and policy options to reduce transport energy use.]

Victoria Transport Policy Institute. (Ongoing). *Energy Conservation and Emission Reduction Strategies*. Online TDM Encyclopedia. <www.vtpi.org/tdm/tdm59.htm> [This chapter describes measures to improve energy efficiency and reduce emissions in transport. It is part of an ongoing encyclopedia on transport demand management (TDM).]

Biographical Sketches

Clark W. Gellings' 30-year career in energy spans from hands-on wiring in factories and homes, to the design of lighting and energy systems, to his invention of "demand-side management" (DSM). Mr. Gellings coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in EPRI, an organization that is second in the world only to the US Department of Energy (in dollars) in the development of energy efficiency technologies. Mr. Gellings has demonstrated a unique ability to understand what energy customers want and need and then implement systems to develop and deliver a set of R&D programs to meet the challenge. Among Mr. Gellings' most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage R&D dollars for the maximum benefit. Mr. Gellings has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow in the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the Association of Energy Engineers for having invented DSM. He has served as an advisor to the US Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.

Kelly E. Parmenter, Ph.D., is a mechanical engineer with expertise in thermodynamics, heat transfer, fluid mechanics, and advanced materials. She has 14 years of experience in the energy sector as an engineering consultant. During that time she has conducted energy audits and developed energy management programs for industrial, commercial, and educational facilities in the United States and in England. Recently, Dr. Parmenter has evaluated several new technologies for industrial applications, including methods to control microbial contamination in metalworking fluids, and air pollution control technologies. She also has 12 years of experience in the academic sector, conducting experimental research projects in a variety of areas, such as mechanical and thermal properties of novel insulation and ablative materials, thermal contact resistance of pressed metal contacts, and drag reducing effects of dilute polymer solutions in pipeflow. Dr. Parmenter's areas of expertise include energy efficiency, project management, research and analysis, heat transfer, and mechanical and thermal properties of materials.