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Author
Lave, Charles A.

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Charles A. Lave

School of Social Sciences and
Institute of Transportation Studies
University of California, Irvine

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It has always seemed obvious that substantial energy savings could be realized by diverting commuters from cars onto rail transit. In fact, the wisdom of this idea has appeared so self-evident, to so many people, that is has been little examined. The only direct analysis (1), calculated the energy-cost of various kinds of transit construction and concluded that the United States could save energy by diverting investment from highways to rail transit.

Those conclusions were based on three implicit assumptions, but a reasonable modification of those assumptions produces a directly opposite conclusion. Their unstated assumptions were: 1. that Congress often acts as if the expenditure of construction money were an end in itself (while I will assume that the expenditure should be evaluated in terms of the passenger-services it produces); 2. that engineering capacity measures are appropriate for estimating patronage (while I will use observed behavioral data because there is little evidence to support the continued hope that the public's demonstrated dislike of "public transit" can be altered to any significant degree (2)); 3. that modern

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rail systems would have similar energy characteristics to existing rail systems (but data which became available after their article make it clear that modern systems are actually much less efficient (3)).

My analysis uses data from the San Francisco Bay Area Rapid Transit system (BART), and evidence is presented to show that BART is typical of modern rail systems. I shall first concentrate on the construction-energy relationship and will show that for a standarized measure of services, passenger-miles, freeway construction is much more energy efficient than rail transit construction. I will then show that viewed as a total system--looking at the energy involved in propulsion, building automobiles and other transit vehicles, and right-of-way construction--BART should never have been built in the first place if energy saving was the only goal.

Relative Construction-Energy of Highways and Rail Transit

Constructing the right-of-way for either transit or highways involves a large investment of energy. Either investment yields passenger-miles of travel as its benefit, and so it seems reasonable to use passenger-miles per construction-dollar (PM/$) as an evaluation criterion. BART carries 130,000 passengers per day, with an average trip length of 13.0 miles, and cost $2.28 billion (in constant, 1974 dollars) to build; and I shall assume 260 commuting days per year (4). Putting these figures together yields, on a yearly basis, 0.193 PM/$ of BART construction. For a typical freeway (carrying the high volumes that would result if it were in a travel corridor with enough traffic to support rail transit), the corresponding figures would be 18,000 cars per lane-mile per day, with 1.4 persons per car, and a construction cost (in constant, 1974 dollars)

of \$932,000 per lane-mile (<u>5</u>). Putting these figures together yields, on a yearly basis, 7.03 PM/\$ of highway construction. Thus, for comparable situations, a freeway will yield 36.4 times more passenger-miles per construction-dollar than this rail system.

However, a dollar's worth of freeway construction uses more energy than a dollar's worth of rail transit construction; so I modify the above figures to take account of the different Btu/\$ ratios (<u>6</u>), thus converting the evaluation criterion into passenger-miles per Btu:

$$\frac{7.03 \text{ PM/\$}}{11.2 \times 10^4 \text{ Btu/\$}} = 6.28 \text{ PM/Btu } (10^5) \text{ for freeways}$$

$$\frac{0.193 \text{ PM/\$}}{7.76 \times 10^4 \text{ Btu/\$}} = 0.249 \text{ PM/Btu } (10^5) \text{ for BART}$$

Comparing these ratios, <u>I conclude that freeway construction produces 25.2 times more passenger-miles per Btu than rail transit construction.</u> In other words, it would require a twenty-fold increase in BART's patronage to make its construction-investment as energy efficient as the highways it was to replace.

This is a surprising result, and it raises two further questions: first, would a broader consideration of energy impacts, taking account of more than construction energy, produce a similar conclusion? I take up this question in the next section. Second, is BART a reasonable example? Is it typical of modern rail systems? I chose BART because it is the only operational, complete, new-generation rail system, and hence has real, measured data rather than engineering projections.

This is quite important: BART cost twice as much, carries only half as many passengers, and uses double the propulsion energy as was

forecast (4). Hence it is obvious that we must be very careful about comparisons between the actual characteristics of BART and the projected characteristics of other systems. Fortunately, we do not need to compare the systems along many dimensions. The 25.2 : 1 efficiency ratio is primarily dependent upon, and sentitive to, just two statistics: 1. construction cost per mile, and 2. total patronage. It is easy to show that BART is typical on the first of these, and there is some evidence which suggests that it is also typical on the second. Using constant, 1974 dollars, BART's construction cost $32.1 million per system mile; the projected cost for three other rail systems now under construction is $34.4 million per system mile (4, p.163). Hence if BART is at all atypical on this criterion, it is atypically efficient. Total patronage is harder to compare since none of the other new systems has yet been proven. There is, however, good reason to believe that the others will do no better than BART: the average proportion of work trips, via bus and rail transit, across Boston, Chicago, Cleveland, Philadelphia, and Washington is 18.8%; in San Francisco this proportion is 25.1% (7). The unusually high proportion of work trips make via transit systems and the relatively high-volume traffic corridors caused by the geographic constraints of the Bay Area combine to make BART's patronage higher than might be experienced in other cities. Hence, again, if BART is atypical, it is atypical in a way favorable to BART's efficiency.

System-Wide Effects

While there is no evidence to indicate that my calculations are based on an atypical example, they may still be misleading because they

do not look at the effects of BART on the entire transportation system. Even though rail transit systems involve a much greater investment of energy than highways, they may compensate for this through their broader effects once in operation: by diverting people from cars and buses, rail transit reduces the energy investment needed to build cars, buses, and highways; and it also reduces the operating energy needed to transport people.

From the previous figures we can calculate that it required 16.4 x 10^{13} Btu to build BART, and I have estimated (8) that this figure must be reduced by 3% to take account of the reduced need for highways; hence there is a net 15.8 x 10^{13} Btu invested in the system. Now, allowing for both the energy to build vehicles and to operate them, each BART passenger uses 680 Btu/PM less than he would have used on the combination of buses and cars from which BART's passengers are diverted (8). This operating energy saving is so small, relative to its construction energy, that it will take 535 years for BART to repay the energy invested in building the system. Furthermore, even this figure overstates BART's energy advantage since it is based on an assumed auto efficiency of 14 MPG. Congress has already mandated a fuel average of 27.5 MPG by 1985, and such a car would be 15% more efficient than BART. Hence the rail system actually loses energy with every trip, and it would save energy to shut it down.

Since this is also a surprising result, it should again be asked if these figures are typical of modern rail transit. The three critical parameters are the relatively high energy consumption of rail, the low proportion of passengers diverted from cars, and the relatively low energy consumption of buses. From the limited data available on other modern

rail systems, it appears that BART is either typical, or even more efficient than the average: the Philadelphia-Lindenwold High Speed Line consumes 2% more energy than BART, and diverts 6% fewer auto users (9). The South Boston extension of the MBTA diverts 17% fewer auto users than BART (4, pp. 136-37).

Furthermore, the 535 year energy payback period is a very robust result. Even an extremely optimistic set of projections about future patronage does not alter it substantially: if we assume that BART's patronage will double; that the percentage of people diverted from cars will increase from 46% to 75%; and that the load factor will increase from 28% to 50%; then the payback period is still 168 years (8).

CONCLUSION

Contrary to previously published results, highways are far more energy-efficient than modern rail transit. When we standardize by a measure of service delivered, passenger-miles, we find that rail transit uses 25.2 times more construction energy than highways. Furthermore, this enormous energy investment is not repaid by greater operating efficiency. For a typical rail system (which attracts most of its patronage from energy-efficient buses), the operating energy per passenger-mile is about the same as that of the combination of modes it replaces. And as Congressionally mandated increases in auto MPG occur over the next few years, the comparative energy efficiency will actually turn substantially against rail systems.

Rail transit is an energy waster. If we want to improve the efficiency of our transportation system, we should emphasize the

development of more efficient automobiles, because that is where most of the energy is now being used; and the development of bus-oriented transit systems, because of their energy efficiency.

Footnotes

1. R. Bezdek and B. Hannon, Science, 185, 669 (1974).

2. G.W. Hilton, Federal Transit Subsidies. American Enterprise Institute, Washington, D.C., 1975, has an exhaustive review of demonstration projects and capital grants by the Urban Mass Transit Administration (over the past 11 years and 3 billion dollars) which concludes that they have been almost uniformly unsuccessful in attracting passengers from cars. See also C. Lave, Transportation and Energy: Some Current Myths, Institute of Transportation Studies, University of California, Irvine, September, 1976.

3. To make the new rail systems more attractive to potential riders, they were given higher speed (hence higher acceleration), and the trains and stations were air-conditioned and heated.

4. R. Ellis and A. Sherret, Transportation and Travel Impacts of BART: Interim Service Findings, Report No. FR 6-3-75, Peat, Marwick, Mitchell & Co., April 1976, pp. 71, 163, 165.

5. The figure for persons per car comes from the National Personal Transportation Survey of the 1970 U.S. Census, and was also observed on the San Francisco-Oakland Bay Bridge in October 1975 (4). The construction cost figure is the average of urban-central-city and urban-suburban figures computed for California by T. Keeler, et al., The Full Costs of Urban Transport, Part III, Institute of Regional Development, University of California, Berkeley, 1975, p.28. The figure for cars per lane-mile is from Robert Kabel of the California Department of Transportation.

6. T. Healy and D. Dick, Total Energy Requirement of the Bay Area

   Rapid Transit (BART) System. Civil Engineering, University of

   Santa Clara, 1974, analyze BART energy consumption (classifying

   expenditures by input/output table categories and then use known

   Btu weights for each category) to produce an estimate of 7.76 x

   10^4 Btu/$. This estimate is corroborated by the ratio of aggregate

   U.S. energy consumption to U.S. gross national product, 7.88 x

   10^4 Btu/$, and by an independent estimate by E. Hirst, Energy

   Consumption for Transportation in the U.S., Oak Ridge National

   Laboratory ORNL-NSF-EP-15, 1972, of 7.2 x 10^4 Btu/$. The com-

   parable figure for highway construction is 11.2 x 10^4 Btu/$

   (1, p. 670).

7. D. Kulash, The Washington Area Metro Rail System. Report prepared

   by Jack Faucett Associates for Congressional Research Service,

   Library of Congress, January 1976, p. 32; 4, p. 92.

8. C. Lave, Rail Rapid Transit: The Modern Way to Waste Energy.

   Economics Department, University of California, Irvine,

   September 1976.

9. D. Boyce, et al., Impact of a Suburban Rapid Transit Line on Fuel

   Consumption and Cost for the Journey-to-Work. Report to the Office

   of Transportation Policy Research, Federal Energy Administration,

   Washington, D.C., December 1975.