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By

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Introduction

In an attempt to quantify more of the total system costs associated with transportation alternatives, studies are continuing in the area of energy cost per ton mile for alternate freight and transportation modes. In light of the present energy difficulties, energy efficiency is beginning to have a significant economic impact on the various modes. Energy cost per ton mile is also an important parameter in determining the total environmental impact of competing transportation modes. This paper presents results of an energy comparison per ton mile of competing rail freight vs. inland barge freight, including the effects of circuity and the use of probable competing rail lines instead of national average rail data.

The Problem

The basic underlying difficulty is that of constructing an equitable frame of reference for comparing the two modes. Railroads haul some freight along the barge routes and some over the continental divide. They haul in unit trains dedicated to a single commodity (e.g., coal) over a fixed long distance trip (e.g., Louisville, Ky. to New Orleans) and they also haul in mixed trains which stop and switch frequently. Finally, the railroads also compete with the trucking industry and haul freight (in truck trailers) on "piggy-back" systems as well as in the more conventional railcars. The water transportation industry appears to be even more heterogeneous than rail. Domestic water transportation includes:

1) Inland waterways (Mississippi river system and tributaries)

- 2) Gulf and Atlantic intracoastal waterways
- 3) Lakewise or Great Lakes transportation

4) Coastwise or deep sea transportation (New Orleans to New York,

Puerto Rico to New Orleans, etc.)

Even within the inland and intracoastal waterways system there is a large number (1800 on the Mississippi-Gulf system)⁽¹⁾ of barge firms ranging from family owned tugs to large multi-commodity freight haulers.^{*} Barge freight is moved on large capacity, long distance dedicated tows with the power unit waiting for loading and unloading. It is also moved on multi-commodity tows in which the power unit continually moves while shore based tugs connect and disconnect barges and bring supplies. Thus general, widely applicable questions can be answered less precisely than specific ones.

Previous results in this area (2), (3), (4) have been limited to ratios of total domestic fuel use to total domestic ton miles. The present study gives more precise results in that it takes into account two other important variables. The energy intensity per ton mile calculation takes into account the actual energy efficiencies of the most probable rail line competitor of the barges on each particular haul and also includes the relative circuities of the two modes. Circuity (defined as the modal difference in distance travelled for an equivalent haul) is important since a ton moved from New Orleans to Chicago will not travel the same number of miles in both modes.

Methodology

Due to resource limitations, this study was limited to freight traffic on the Gulf Intracoastal Waterway and the Mississippi River with all its tributaries. Using the 1971 actual barge traffic data (5)(6), a list of 290 approximate origin-destination (OD) pairs was compiled. Data on tonnage

In 1971, 6.6% of the domestic ton mile traffic was regulated by the ICC (5).

carried for each OD pair in each of five bulk commodities (agricultural output, lumber, petroleum, coal and chemicals) was also compiled. These OD traffic pairs are approximate since the data in reference (5) is only disaggregated to the regional level. Ports within the regional level were chosen based on relative percents of corresponding traffic handled at the major ports listed in reference (6).

Rail and barge routings were then generated for each OD pair. In the barge case, the shortest routing was used. In the rail case, a balance of minimum distance and minimum number of rail carriers was used in each routing. Mileages in each case were obtained from (7) and (8). OD ton miles (Tm) are given by the product of the tonnage and respective routing length for each OD pair. Rail energy for each OD trip was calculated by summing the product of energy intensity⁽⁹⁾ (Btu/Tm) and mileage for each railroad's portion of the trip. Barge energy for each trip was assumed constant as explained in the next section.

The computer program evaluated the overall intensities (Btu/Tm) for each mode using the following weighted sums:

Rail (Btu/Tm) =
$$\frac{\sum_{i} (Tm_{OD_{i}})(\frac{Btu}{Tm})_{trip_{i}}}{\sum_{i} Tm_{OD_{i}}}$$

Barge (Btu/Tm) =
$$\left(\frac{Btu}{Tm}\right)_{AVG} * \frac{\sum_{i} Barge Tm_{trip_i}}{\sum_{i} Rail Tm_{trip_i}}$$

The circuity weighting factor $\frac{\sum_{i}^{Barge Tm} \text{Trip}_{i}}{\sum_{i}^{Rail Tm} \text{trip}_{i}}$ is also important in its own

right since changes in the estimates of energy efficiency per Ton Mile of either the rail or barge mode can be easily included in the results of this study by simply multiplying the barge efficiency by the above defined circuity factor. The circuity factor will remain stable until either major traffic pattern changes or major rail or waterway construction occurs.

Results

There are two principal results of this study. First, the weighted average energy intensity (EI) of that portion of the rail industry which competes with the barge lines (on the Gulf and Mississippi with tributaries) was found to be 639 or 711 Btu/Tm depending upon whether one includes or not the fuel used for yard switching. Both numbers are included in the comparison since the barge switching and tow makeup is sometimes done on contract (10) (e.g., tugs hitch and unhitch barges while the main tow continues moving). It is therefore unclear how much of the switching and tow makeup fuel is included in the barge direct EI figure quoted in Table 1. The rail EI's are weighted by 1971 waterborne commerce statistics, and include the 1971 actual energy intensities (Btu/Tm) experienced by each pertinent rail line as explained in the previous section. The second basic result is the relative circuity of the rail and barge modes for the 1971 waterway commerce traffic on the Gulf and Mississippi with tributaries. On the average, barge ton miles were 1.38 times as great as the equivalent competing rail ton miles. Accepting for a moment that the comparison of an entire rail line's EI with that of the average barge line is a valid one, the derived rail EI is very accurate due both to the availability of excellent data (9) and the fairly

The actual 1971 waterborne traffic pattern was the basis for comparison between the modes.

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1971 Rail vs. Barge Energy Comparison Parameters

ENERGY INTENSITIES (Btu/ton mi)					
	RAIL	BARGE			
Direct ^(a)	639-711	785			
Total	1330 ^(b)	1633 ^(b)			
RELATIVE CIRCUITY $(\frac{\text{ton mi} - \text{barge}}{\text{ton mi} - \text{rail}})$	1.00	1.38			
SAMPLE SIZE					
Origin Dest. Pairs		290			
Ton Miles Transported		108			
Notes: (a) Includes motive fuel only lowing clarifications:	, subject to	the fol-			
Barge direct = $\frac{\text{fuel con}}{\text{ton min}}$	sumed where	the fuel			
figure is fairly imprecis fuel, some but probably n and no maintenance fuel.	e and includ ot all swite	les hauling ching fuel			
Rail direct = $\frac{fuel cons}{ton mil}$	Rail direct = $\frac{\text{fuel consumed}}{\text{ton miles}}$				
Neither rail figure given fuel, both include freigh The smaller figure exclud while the larger one incl	includes ma t line haul les switching udes all swi	aintenance fuel. g fuel tching fuel			
(b) These figures are subject certainties.	to fairly]	arge un-			

large sample used (290 OD pairs and one hundred million barge Tm transported). Although the circuity figure is subject to some uncertainty due to judgmental decisions in the choice of logical rail route, the large sample involved would tend to reduce such uncertainty.

The above two results are combined with current estimates ⁽¹¹⁾ of barge freight EI in Table 1. The stated (in Table 1) barge EI is the product of Hirst's revised direct EI and the 1.38 circuity explained above. Admittedly the Hirst figure is subject to large uncertainties^{*}, but Table 1 can easily be updated as new barge EI ratios become available. The new Table 1 barge EI would simply equal 1.38 times the new estimate of barge EI. More is said about the barge EI estimate in Appendix A.

With a bit more effort, a fairly imprecise estimate of total (direct and indirect) system energy for both rail and barge can be obtained. The indirect energy includes such things as electricity consumed to make locomotives, track and freight cars as well as the paint for the offices of the respective companies. Using a method explained in Appendix B, one obtains the results listed in Table 1. It must be emphasized that these are only estimates of the total energies involved. They are useful, however, in that they indicate the total energy consumed in providing a ton mile of rail or barge transportation as about twice that consumed by the locomotive or tugboat alone.

Finally, it is worthwhile to return momentarily to the subject of the legitimacy of comparing an entire rail line's EI to the average barge EI

It includes all domestic water transportation (coastwise, lakewise and internal) and is based on the roughest, but best available, fuel consumption estimates. Since barge lines are numerous (1800 on Gulf-Mississippi alone), unregulated for the most part and are exempt from fuel tax, no accurate fuel consumption data exists.

competing with it. Rail sources argue plausibly that, by and large, barge movements are large commodity, long, point to point hauls and therefore should be compared to unit train movement EI, not average rail line EI. The energy intensity of high volume dry bulk cargo is significantly lower than the line average EI, it is argued, since:

- a) The gondola cars have one of the highest net to gross weight ratios of all rail freight cars.
- b) A homogeneous train of gondola cars has a very low air resistance factor when compared to boxcars and especially to piggy back loaded flatcars.
- c) Significantly less switching fuel is needed.
- d) Unit trains generally travel at lower speeds than other freight trains.

Although some unit train EI results have been published⁽¹²⁾ indicating a range of 226^{*} to 359^{**} Btu/ton mile not including circuity but including the emply return trip, much more data needs to be collected before any real comparisons can be made.

Level track.

^{**} Significant grade.

Conclusions

- 1) The 1971 average barge circuity (ratio of barge ton miles to equivalent rail ton miles) on the Gulf-Mississippi system was 1.38.
- 2) 1971 rail EI (energy intensity) in Btu/Tm for lines competing for barge traffic was 639 (excluding switching fuel) and 711 (including all switching fuel). The corresponding national average energy intensity was approximately 700 Btu/Tm.
- 3) The resultant energy intensity comparison including the two above mentioned factors and the best available barge energy intensity per ton mi indicates that rail is from 10 to 23% less energy intensive than barge, but such a factor is inconclusive in view of the large uncertainty associated with the barge fuel consumption data (see Appendix A).
- 4) The important overall question of modal energy efficiency can only be accurately answered if a definitive program of collection of barge fuel consumption data is initiated. In this author's opinion, the data must be gathered in such a way as to permit regional or national weighting by actual traffic carried and by the circuity factors involved. This means following all steps of the procedure used in this paper with the exception of the inclusion of the actual EI of the most probable barge line (or average of barge lines) for each portion of each trip. The data should also accurately reflect that portion of the barge industry associated with high volume, bulk, long distance (over 100 miles) hauling.
 5) The matter of unit train EI should also be resolved for both dry bulk and liquid bulk traffic. To be meaningful in a national average comparison, these data must also be gathered in such a way that the rail line EI's used in this report's calculations could be replaced by the equivalent unit train EI.

REFERENCES

- Kearney: Management Consultants, "Domestic Waterborne Shipping Market Analysis, Executive Summary," prepared for the Maritime Administration of the U.S. Department of Commerce, February 1974, p. 10.
- (2) Eric Hirst, "Energy Intensiveness of Passenger and Freight Transport Modes 1950-1970," Oak Ridge National Laboratory, Report No. ORNL-NSF-EP-44, April 1973.
- (3) Richard A. Rice, "System Energy as a Factor in Considering Future Transportation," presented at the American Society of Mechanical Engineers Annual Meeting, December 1970. By the same author: "System Energy and Future Transportation," MIT Technology Review, January 1972.
- (4) William Mooz, "The Effect of Fuel Price Increases on Energy Intensiveness of Freight Transport," Rand Corporation, Report R-804-NSF, December 1971.
- (5) U.S. Army Corps of Engineers, "Waterborne Commerce of the United States," part 5, 1971.
- (6) U.S. Army Corps of Engineers, "Waterborne Commerce of the United States," part 2, 1971.
- (7) Rail mileages and routes were obtained from <u>Handy Railroad Atlas of</u> the United States (New York: Rand McNally & Co., 1971).
- (8) Barge mileages and routes were obtained from 1972 Interstate Port Handbook (Chicago: Rockwell F. Clancy Co., 1972).
- (9) The energy intensity of each rail line was calculated by dividing the line's total diesel fuel consumption in the freight and yard switching categories (Personal communication with Mr. H. Wolf, U.S. Interstate Commerce Commission, April 1974) by the total revenue ton miles carried by the line (U.S. Interstate Commerce Commission, "Transport Statistics in the United States," part 1, 1971, pp. 142, 168, 194, 220, 246, 272, and 298).
- (10) Telephone conversation with Mr. Harry N. Cook, National Waterways Conference, Inc., April 1974.
- (11) A list of research results in the area is given in Table Al of Appendix A. Dr. Hirst's revised results (Ref. (2), Appendix A) were chosen here since:
 - (a) Dr. Hirst's and Dr. Mooz's research are independent national average estimates of total actual fuel consumption and traffic.
 - (b) Although both used the same fuel consumption estimates,

there appears to be some double counting of barge ton miles in Dr. Mooz's results (see Ref. (2), p. 38).

- (c) Of the two, Dr. Hirst's results are the most recent and apply to the year of this study (1971).
- (12) Telephone conversation with Mr. George Anderson, Western Railroad Traffic Association, Chicago, Illinois, April 1974.
- (13) Letter from Mr. Harry N. Cook, Executive Vice-President, National Waterways Conference, Inc. to Dr. Eric Hirst, FEO, March 7, 1974.

APPENDIX A. Barge Freight Energy Intensity

Without any doubt, the most uncertain piece of data in the entire area of Barge vs. Rail energy efficiencies is that of barge fuel consumption. The research results given in Table Al indicate the uncertainty involved.

The commonly held opinion is that more data must be collected. Although the information in existing data has been fully extracted and been found to be insufficient, gathering new fuel data compatible with a ton mile weighting similar to the approach used in this paper is not a trivial task due to the large number (1800 on the Gulf-Mississippi system) of mostly unregulated barge lines which must be queried.

TABLE A1

RESULTS OF RESEARCH ON WATERWAY ENERGY INTENSITY (Btu/Tm)

Author and Applicable Data Year	Btu/tm
Hirst ⁽¹⁾ , 1970	680
Hirst ⁽²⁾ , 1971	570
Mooz ⁽³⁾ , ca. 1968	500
$Mooz^{(4)}$, 1970	512
Brinegar ⁽⁵⁾ , 1973	462
National Petroleum Council ⁽⁶⁾ , 1973	510
National Waterways Conference, Inc. ⁽⁷⁾ , 1968	415 (Lowest Sample 217 Btu/Tm)

Notes:

- (a) These figures do not include circuity and should be compared with the rail result from Table 1 of the main report (after correction) which is 463 to 515 Btu/Tm.
- (b) The Western Railroad Traffic Association has published ⁽⁸⁾ results of 10,000 net ton coal train movements which range from 164 Btu/Tm (level track) to 260 Btu/Tm (significant grade) after correction for barge circuity. These figures are most logically comparable with the National Waterways Conference data given above.

References--Appendix A

- (1) Oak Ridge National Laboratory, Report No. ORNL-NSF-EP-44. Domestic (including coastwide, barge, and lakewise) national average Fuel source: Ref. (3) Ton mi source: Transportation Association of America, "Transportation Facts and Trends."
- (2) Telephone conversation with Dr. Hirst. Domestic (including coastwise, lakewise and barge) national average Fuel source: James J. Mutch, Rand Corporation Document R1391-NSF, December 1973. Ton mi source: Transportation Association of America, "Transportation Facts and Trends."
- (3) "The Effect of Fuel Price Increases upon the Energy Intensiveness of Freight Transport," Rand Corporation Report R-804-NSF. Domestic (including coastwise, barge and lakewise) Fuel source: U.S. Bureau of Mines, "Minerals Yearbook" and "Mineral Industry Surveys--Crude Petroleum, Petroleum Products and Natural Gas Liquids." Ton mi source: Interstate Commerce Commission and American Waterways Operators, Inc.
- (4) An update of (3) based on 1970 actuals. Letter to J. Feeney from Dr. Wm. E. Mooz, August 8, 1973.
- (5) Statement by Claude S. Brinegar, Secretary of Transportation, Before the House Appropriations Subcommittee on Transportation, March 5, 1974. Includes "Freight Transportation by Water."
 Fuel and ton mi source: Department of Interior estimates.
- (6) "Interim Report Phase I, Transportation Task Group of the National Petroleum Council's Committee on Energy Conservation. Tug and barge operators only. Fuel source: Estimate based on propulsion efficiency, annual HP hours of propulsion and fuel efficiency. Ton mi source: Not given in the interim report.
- (7) "A Waterways Fuel Tax: Measurements of the Menace," Washington, D.C., May 1970. Based on a 32.4 precent sample survey of inland waterway carriers conducted by National Waterways Conference, Inc. in 1969. Includes tug and barge operators only.
- (8) Telephone conversation with Mr. George Anderson, Western Railroad Traffic Association, Chicago, Illinois, April 1974.

APPENDIX B. Derivation of Total Energy Efficiencies

A reasonable way of estimating total energy impacts of transportation is by the use of a Leontief Input Output inverse matrix, whose elements $(I - A)_{ij}^{-1}$ by definition are the total (direct and indirect) output (\$) of industry i needed per dollar of output of industry j. These matrix elements can easily be converted to energy units.

The basic method^{*} and 1963 results for the rail industry are given in reference (1). The same document also extrapolates 1963 data to 1971 but due to a difference in the groundrules of comparison, the 1971 results in Table 1b of (1) are not applicable here. Only the method (Section IIB) is useful.

1971 total rail freight EI, X, can be estimated via the product:

$$X = A \cdot B \cdot C$$

where

- A = locomotive and switching fuel used per ton mi in 1971.
- B = ratio of total refined petroleum used per ton mile in 1963 to the locomotive and switching fuel used per ton mi in 1963.
- C = ratio of direct energy used per ton mi by the railroads in 1963 to the refined petroleum per ton mi used by the railroads in 1963.
- D = ratio of the total (direct and indirect) energy per ton mi used by the railroads in 1963 to the direct energy used by the railroads in 1963.

Backup data for (1) gives the following values:

Including a correction for capital purchases such as rolling stock.

B = 1.084

C = 1.129

Table la of (1) gives the value of D:

D = 1.70

Table 1 of the present report gives the value of A:

A = 711 Btu/ton mi

Therefore, 1971 total rail freight EI is given by

639 Btu/ton mi × 1.084 × 1.129 × 1.70 = 1330 Btu/ton mi

If the same values for B, C, D are assumed valid for the barge case, 1971 total barge freight EI is given by

785 Btu/ton mi \times 1.084 \times 1.129 \times 1.70 = 1663 Btu/ton mi Note that these total energies add nothing to the comparison between rail and barge, they simply estimate how much total energy is spent per ton mi in each case.

References--Appendix B

(1) Anthony Sebald and Robert Herendeen, "The Direct and Indirect Dollar, Energy and Employment Impacts of Air, Rail and Automobile Passenger Transportation," Energy Research Group, Center for Advanced Computation, University of Illinois, Urbana, Illinois, October 1973.

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