Measuring Bulk Product Transportation Fuel Efficiency.
Author(s): C. Phillip Baumel
Source: *Journal of the Transportation Research Forum*, Vol. 50, No. 1 (Spring 2011), pp. 79-88
Published by: Transportation Research Forum
Stable URL: http://www.trforum.org/journal

Measuring Bulk Product Transportation Fuel Efficiency

by C. Phillip Baumel

This paper reviews the literature that compares the fuel efficiencies of bulk commodity transportation modes. Most studies used net-ton-miles per gallon to compare modal fuel efficiencies. Net-ton-miles per gallon have traditionally been estimated from aggregate industry data of total net-ton-miles and total fuel consumed. More recent studies have targeted specific origins, destinations, products hauled, types and sizes of equipment, backhauls, and miles traveled to estimate total fuel consumption. This paper shows that fuel efficiency estimates based only on net-ton-miles per gallon can be erroneous. The paper identifies basic variables and measurement methods that can improve the accuracy of modal fuel efficiency comparisons.

INTRODUCTION

In 1971, the price of imported petroleum was $2.00 per barrel; it peaked at $147 per barrel in July 2008 and fell to $50 in December 2008 (Baumel 2009). At the time of the writing of this article, the price of petroleum fluctuated around $90 per barrel. No one knows the precise future prices of petroleum, but few people expect the long run price to decline.

Major air pollutants from motorized vehicles include hydrocarbons, carbon monoxide, carbon dioxide, nitrogen oxides, and particulate matter. The Environmental Protection Agency estimates emissions of these hazardous air pollutants in grams per vehicle mile traveled (Texas Transportation Institute 2009). Thus, fuel consumption and miles traveled are major factors in estimating air pollution from freight transportation.

Users and operators of the three major modes of bulk product transportation call for major infrastructure upgrading. Bulk products include coal, grains, chemicals, aggregates, and liquid fuels. Increased traffic congestion is evidence of needed highway upgrading. A 2007 study estimated that the U.S. railroad industry would need to invest $147 billion over the next 35 years in infrastructure expansion to meet the U.S. Department of Transportation projected 88% increase in rail freight tonnage by 2035 (Cambridge Systematics Inc. 2007). Barge users and the barge industry have been urging the U.S. public to invest in upgrading America's inland waterway locks and dams to "help keep America green" (Waterways Council Inc. 2010).

Environmental concerns, increasing fuel costs, and needed infrastructure upgrades suggest the need to improve the fuel efficiency of the bulk product transportation system. This objective requires that modal fuel efficiencies should be accurately estimated.

Previous research on measuring bulk product transportation fuel efficiency can be grouped into five categories:

1. Using aggregate data to estimate net-ton miles per gallon (NTMG) by mode
2. Estimating NTMG by river segment or by direction of rail movement
3. Estimating NTMG by operating characteristic
4. Estimating NTMG by product hauled
5. Estimating total fuel consumption using NTMG and miles traveled by mode from specific origins to specific final destinations

A review of the literature in each of these five categories follows.

Using Aggregate Data to Estimate Modal NTMG

The majority of past fuel efficiency studies and reports used total fuel consumed and total net ton miles of freight over thousands of commodities and routes to estimate NTMG. A 1975 U.S. Department of Transportation advisory report on the replacement of Alton Locks and Dam 26 on the Upper Mississippi River summarized the results of 19 energy studies (U.S. Department of Transportation 1975). The 19 studies used aggregate data to estimate rail and/or barge NTMG. The estimated rail fuel efficiencies ranged from 138.5 to 693.5 NTMG. Barge fuel efficiency ranged from 243.3 to 639.2 NTMG.

Eastman (1980) estimated the following NTMG: barge, 514; rail, 202; and truck, 59. The Eastman numbers were frequently used in other reports, i.e., U.S. Department of Transportation (1994) and were still being reported 30 years later (Bernert Barge Lines Inc. 2010).

The Texas Transportation Institute (TTI) estimated the following NTMG: truck, 155; rail, 413; and barge, 576 (Texas Transportation Institute 2009). Some writers and organizations use the TTI estimates to promote barges and short sea shipping as the most fuel efficient modes of bulk product transportation (National Waterways Foundation 2008, Quigley 2009). The Association of American Railroads (2010) reported a 2009 U.S. Class I railroad NTMG of 480.

Most of the above reports used their estimated NTMG as the only basis for comparing the fuel efficiency of the three major modes of freight transportation. TTI assumed that since the miles traveled by each mode were similar, NTMG could be used to define the fuel efficiency of each of the three modes.

Estimating NTMG by River Segment and Rail Direction

Using data from four barge companies, Baumel, Hauser, and Beaulieu (1982) estimated barge NTMG for moving grain from several Mississippi River system origins to New Orleans, Louisiana (NOLA). At a 25% backhaul, NTMG on the Lower Mississippi River from Cairo, Illinois, to NOLA was 525, while barges on the Upper Mississippi and Illinois Rivers averaged about 450 NTMG.

Baumel et al. (1985) used daily fuel measurement data from three barge companies to estimate the NTMG of barges on the Upper Mississippi and Lower Mississippi Rivers. Calibrated steel tape measurements were used to estimate daily fuel consumption. Fuel meters were not possible because when one or more propellers were in reverse, the vibrations caused fuel meters to malfunction. At a 35% backhaul, the NTMG for barges on the Upper Mississippi River was 526, while barges on the Lower Mississippi River obtained 548 NTMG.

Burton (1997) used a Tennessee Valley Authority (TVA) Barge Costing Model to estimate barge NTMG on six rivers. His estimated NTMG was 694 for the Upper/Middle Mississippi River and 917 for the Lower Mississippi River.

Baumel et al. (1985) used fuel meters to estimate NTMG for three 54-car unit grain trains and three 75-car unit trains from Iowa to West Coast ports. Four unit grain trains were shipped from Iowa to NOLA. The four grain trains to NOLA averaged 640 NTMG. This was 46% more than the 437 average NTMG achieved by the six West Coast trains. All West Coast trains had to traverse one or more mountain ranges to and from the West Coast. This explains most of the difference in the average NTMG of the two sets of trips.

Gervais and Baumel (1999) used TVA calculated barge NTMG from three segments of the Mississippi River. The TVA estimated total fuel consumption from actual barge fuel tax collections. The 1995 estimates of NTMG were as follows: Lower Mississippi River, 646: Mouth of the Missouri to the Mouth of the Ohio River, 595; and Minneapolis to the Mouth of the Missouri River, 308. All of the locks and dams are located between Minneapolis and the Mouth of the Missouri River. The weighted average NTMG of the three Mississippi segments was 420 NTMG.

Estimating NTMG by Operating Characteristic

Burton (1997) used TVA data to estimate NTMG for each of 12 railroad companies. The estimated NTMG ranged from 118 to 374. The highest NTMGs were for the four largest railroad companies. Seven of the other eight companies have either merged with the four larger companies, or merged together to form new companies.

Baumel et al. (1985) used data from three barge companies to estimate the impact of the percent backhaul on barge NTMG on the Upper and Lower Mississippi rivers. At zero backhaul, NTMG were estimated to be 420 on the Upper Mississippi and 483 on the Lower Mississippi River. At 50% backhaul, the NTMG gap between the two rivers narrowed to 578 on the Upper Mississippi and 592 on the Lower Mississippi River. At 100% backhaul, there was little difference in the NTMG on the two rivers; those estimates were 756 for the Upper Mississippi and 754 for the Lower Mississippi River.

Gervais and Baumel (1999) used data from computer simulations by two railroad companies to estimate the impact of the type of locomotive and size of rail car on rail NTMG. Three scenarios were analyzed. Two were from Central Iowa to NOLA and to Los Angeles. The third was from western Iowa to Tacoma, Washington. Each trip was simulated with three different locomotives and two sizes of covered hopper cars. The two types of rail cars were 100-ton and 110-ton capacities. The 100-ton cars are now 30-40 years old and are being replaced by new 110-ton cars.

The three locomotives were the SD40 that was introduced in the late 1970s and the newer SD60 and C40-8. Four SD40s are required to pull a 100-car grain train. Only three SD60 or C40-8 locomotives are needed to pull 100-car grain trains. All simulations were at 35 mph.

The SD60s had the highest NTMG and the older SD40s had the lowest. The 110-cars had higher NTMG than the older 100-ton cars. Finally, the NTMG for the trips to NOLA were 30% higher than those to Los Angeles and 22% higher than those to Tacoma. The reason for the higher NTMG to NOLA is that the terrain to NOLA is relatively flat, while each trip to Los Angeles and Tacoma was over one or more mountain ranges on the loaded and empty legs of each trip.

Gervais and Baumel (1999) also reported computer simulations of state-of-the art semi trucks obtaining 131 NTMG at a speed of 60 MPH. NTMG declined 16% to 110 NTMG at a speed of 70 MPH.

Baumel et al. (1985) used fuel consumption data for 254 grain hauling ocean vessels taken from *The Journal of Commerce and Commercial* (February 1, to July 31, 1983) to estimate NTMG for grain carrying ocean vessels. Small vessels (<25,000 deadweight tons--dwt) were estimated to achieve 509 NTMG with no backhauls to 966 NTMG with 100% backhauls. The largest vessels (≥75,000 dwt) achieved 1,011 NTMG with no backhaul and 1,922 NTMG with 100% backhauls. The average overall vessel size was 1,240 NTMG when loaded 100% of the time.

Gervais and Baumel (1999) updated the grain carrying ocean vessel estimates using fuel consumption data for 139 bulk carrying vessel data taken from *The Journal of Commerce and Commercial* (January 1 to July 1998). Smaller vessels (< 35,000 dwt) achieved 1,312 NTMG when loaded 79% of the time. The largest vessels (≥ 75,000 dwt) achieved 3,094 NTMG when loaded 88% of the time. The average NTMG for all vessels was 2,342 with a load factor of 85%. Much of the increase in average NTMG came from the shift from smaller to larger vessels since 1993.

Estimating NTMG by Product Hauled

Abacus Technology Corporation (1991) compared rail and truck fuel efficiency along corridors in which both modes competed in selected commodity markets. The analysis relied on simulations of rail and truck fuel consumption over specific corridors, representative equipment configuration, operations, and route characteristics for the commodity and origin-destination pair being modeled. The study included the first and last legs of intermodal movements that are generally performed by a drayage truck, usually older and less fuel efficient than a long-haul truck, operating in congested conditions.

ICF International (2009) updated the Abacus Technology Corporation (1991) study. ICF International (2009) used computer simulations of rail and truck movements in 23 competitive rail-truck corridors to compare rail and truck fuel efficiencies. Individual rail movements included in the analysis were double stack, covered hopper, tank car, trailers on flat cars (TOFC), and automotive rack trains. Individual truck movements included dry vans, dump, tanker, container, flatbed with sides and auto haulers. The dominant measure of fuel efficiency was NTMG. The fuel efficiency of railroads exceeded that of trucks in each of the 23 movements. However, the difference between rail and truck fuel efficiencies varied widely among the products hauled.

Estimating Total Fuel Consumption Using NTMG and Miles Traveled by Mode from Specific Origins to Final Destinations

Baumel et al. (1985) estimated total fuel consumption in gallons per short ton (GPT) in shipping grain from six origins in Iowa to Yokohama, Japan. GPT was estimated by dividing total miles traveled by each mode by the appropriate NTMG for that mode. The NTMG for railroads were estimated from metered fuel consumption data provided by five railroad companies. The NTMG for barges were calculated from daily fuel measurement data provided by three Mississippi River barge companies. The truck NTMG were calculated from three fuel metered trips hauling grain to barge loading elevators on the Mississippi River. *The Journal of Commerce and Commercial* ship fixture data (February 1-July 31, 1983) on bulk carrier time charters were used to estimate ocean vessel fuel consumption. Fuel consumed by each mode in each intermodal shipment was added to obtain the total GPT for each route. The results for shipments to Japan are ranked below in descending order of total fuel efficiency when similar sized ocean vessels and typical routes are used:

1. Unit trains direct to West Coast ports
2. Unit trains direct to NOLA and the unit train-barge combination with 100% barge backhaul
3. Unit-train-barge combination with less that 100% backhaul
4. Truck-barge combinations

EVALUATION OF THE ABOVE FUEL EFFICIENCY STUDIES

The major characteristic of the above fuel efficiency studies is the conflicting results and conclusions among the many studies. There are at least three reasons for these conflicting results. One is the 50-year span over which these studies were conducted. The earlier studies, based on data from the early 1960s, reported smaller NTMG than those based on late 1990s and 2000 data. Technological improvements and larger vehicle and vessel sizes have greatly increased fuel efficiency and NTMG in all modes of bulk product transportation. Some of these technological improvements are reflected in later study results.

A second reason for the conflicting results is that most of the earlier studies were based on average data over thousands of commodities and routes for the truck and rail industries. Many of the later studies were targeted to specific commodities, specific routes, and even alternative types and sizes of equipment. The Abacus Technology Corporation (1991) and ICF International (2009) studies estimated NTMG on trains and trucks, each hauling only automobiles, manufactured products, and liquid or bulk products. Most of the specific product studies focused on the types and sizes of equipment and miles traveled on routes typically used to transport bulk commodities including grain. These targeted analyses of actual movements generally allowed the studies to focus on larger size shipments such as unit trains and ocean vessels and on specific routes, miles, and direction of shipments that are typical of bulk commodities. These targeted analyses should provide more accurate estimates of fuel consumption than average NTMG estimates averaged over different weights, speeds, transportation equipment, terrain, and distances hauled. Speed is important because aerodynamic resistance of a train increases with the square of the speed (Grervais and Baumel 1999). Ship company executives indicate that, on average, fuel consumption decreases about 20% with each 10% reduction in speed (Baumel et al. 1985).

A third, and perhaps the most important reason for different results, is that some of the later studies have focused on estimating total fuel consumption from specific origins to specific destinations. The TTI (2009) estimated the following NTMG as measures of fuel efficiency:

Truck	155
Rail	413
Barge	576

These NTMG suggest that barges are 39% more fuel efficient than railroads and almost four times more fuel efficient than trucks. However, NTMG alone tells only part of the fuel efficiency story

The following example focuses on grain shipped by railroad and barge from Iowa to export grain elevators in the NOLA area. Almost all grain shipped by barge must be hauled from inland elevators, or from farms, to barge-loading elevators. Grain shipments from elevators direct to a final destination are typically by rail or truck. Usually, no other mode is involved in these transfers. Similar movements also are typical for coal and some chemicals and liquid fuels. To make correct comparisons of total fuel consumption of barge versus rail direct to an export port, fuel consumed by truck or rail to a barge loading facility must be added to the barge fuel consumption. Moreover, NTMG measures only the miles that one ton of freight is moved by one gallon of fuel. It fails to measure the total fuel consumed in moving the freight from an origin to a destination.

Bruton (1997) makes the following argument in his paper (p. 7) prepared for the U.S. Army Corps of Engineers:

> "A majority of barge shipments involve a truck movement at one or both ends of the line-haul move and in some cases, these truck hauls may be of considerable length. Anecdotal evidence suggests that some grain shipments may be trucked as much as 300 miles for trans-loading to barge. Alternately, most rail movements can be made rail direct and where additional truck movements are necessary, they are seldom more than a few miles. Consequently, the appropriate fuel usage comparison is not between line-haul barge and line-haul rail. Rather, this comparison must be made over the entire movement. This often means comparing the fuel efficiency of an all rail movement with that of a truck-barge-truck combination. Quite clearly, such cases tend to diminish the aggregate efficiency advantage otherwise attributable to barge."

Table 1 illustrates the impact of distance travelled on total modal fuel consumption. The table shows the total fuel consumed to move one ton of grain from one Iowa origin to a NOLA destination by rail and by truck-barge. Rail direct versus rail-barge was not evaluated because almost all grain shipped by barge from Iowa is now delivered by trucks to barge loading elevators (Van Der Kamp 2010).

The NTMG listed in Table 1 are those estimated by TTI. The Association of American Railroads (2010) reports that the average NTMG for Class I railroads for 2009 was 480; this is 16% more efficient than the 413 reported in TTI. Nevertheless, Table 1 uses TTI's lower rail NTMG of 413.

St. Charles Parish, Louisiana (SCPL), was selected as the destination for both the rail and barge delivered grain. Three of the 10 grain export elevators in the NOLA area are located in SCPL.

Waterloo, Iowa, located near the center of Black Hawk County, was chosen as the origin of the grain in Table 1. The railroad miles in Table 1 from Waterloo to SCPL are the average miles for typical routes of rail shipments of grain from Black Hawk County, Iowa, to SCPL.

The data in Table 1 show that total fuel consumption per ton of grain shipped by truck-barge combination from Waterloo to SCPL is 6% greater than for the direct rail shipment. If the Association of American Railroads (2010) rail NTMG of 480 was substituted for the TTI (2009) rail NTMG in Table 1 the total truck-barge fuel consumption would be 23% greater than for the direct rail

Table 1: Estimated Total Fuel Consumption to Ship Grain from Waterloo, Iowa, to St. Charles Parish in Gallons per Ton of Grain

Mode of transport	Miles	NTMG[d]	Gallons per ton	Total gallons per ton
Rail direct to St. Charles Parish	1,180[a]	413	2.86	2.86
Truck to Dubuque	91[b]	155	0.59	
Barge (Dubuque to St. Charles Parish)	1,413[c]	576	2.45	
Total truck-barge	1,504			3.04

Sources:
a. Association of American Railroads (2010)
b. MapQuest Driving Directions North America
c. Iowa Department of Transportation and Blue Water Shipping Company
d. Texas Transportation Institute (2009)

shipment. These results are the opposite of the conclusion derived from NTMG alone. The major reasons for the different conclusions are:

1. The truck portion of the barge movement adds almost 0.6 gallons to total truck-barge fuel consumption per ton of grain,
2. The total barge distance from Dubuque to SCPL is 20% longer than the average typical rail distance from Waterloo to SCPL, and
3. The combined truck-barge distance from Waterloo to SCPL is 27% longer than the direct rail shipment from the same origin to the same destination.

The longer barge distance is caused by the meandering of the Mississippi River. Figure 1 illustrates the impact of this meandering on river distances.

All of the NOLA grain export elevators are located within the Baton Rouge-Myrtle Grove section of the river. The river distance between these two points is 167 miles (Blue Water Shipping Company). The MapQuest driving distance between these two points is 107 miles. Thus, the meandering of the river increases the river distance between these two points 56% above the driving distance. The entire Mississippi River meanders in a similar fashion up to its source near Minneapolis.

The total miles to an importing country is even more important for calculating total fuel consumption for grain destined for export. For example, corn exports to Japan typically move in two directions. One is by barge, rail, or truck to Gulf of Mexico ports (including NOLA) for ocean vessel movements through the Panama Canal. The second is by rail to the West Coast and ocean vessel to Japan. The rail movement from Iowa to the West Coast is longer than to NOLA and it is over the Rocky Mountains. This suggests that fuel consumption would decrease if Iowa corn was shipped to NOLA ports for export. However, the ocean distance from NOLA to Japan is more than double the distance from Seattle–almost 6,000 miles longer (Baumel et al. 1985). The net result is that corn shipped by rail from western Iowa to Tacoma and ocean vessel to Japan uses less total fuel than any modal combination through NOLA (Gervais and Baumel 1999).

Barge NTMG are typically calculated by dividing total net-ton miles of freight hauled by all barges on all navigable rivers, by the total number of gallons of fuel consumed. The Lower Mississippi River–that portion of the river south of the confluence of the Ohio and Mississippi Rivers–is the mostfuel efficient river on the Mississippi River system (Gervais and Baumel 1999). NTMG increase sharply as the number of tons increases in barge tows. Barge tows on the Lower Mississippi River can have 50 or more barges. That compares with a maximum of 15 barges on the Upper Mississippi River and as few as two on the upper Missouri River. Second, the river current on the Lower Mississippi River is swift because it is not impeded by dams. The swift current pushes

Figure 1: Blue Water Shipping Company Mississippi River Deep Water Corridor Map

the loaded barges downstream, further reducing fuel consumption. Third, since there are no locks on the Lower Mississippi River, barge tows move nonstop on this river segment. Barge tows on most other rivers must stop to transit the locks at each dam. This suggests that barge NTMG should be calculated for individual rivers to generate more accurate NTMG estimates.

Similar issues exist for railroads. The large tonnages and direct shipments of unit-trains make them more fuel efficient than trains consisting of a mix of different commodities. Trains that cross mountains consume more fuel than trains that essentially follow, but don't meander, along the Mississippi River (Gervais and Baumel 1999). Finally, new technology locomotives are highly fuel efficient (ICF International 2009). This suggests that NTMG should be estimated for different types of rail service.

Burton (1990), using the TVA's Barge Costing Model, estimated that barges operating on the Lower Mississippi River obtained 917 NTMG. Yet, TVA estimates, based on 1995-1997 fuel taxes collected from barge companies, ranged from 604 to 646 NTMG (Gervais and Baumel 1999). If the TVA's Barge Costing Model estimates are correct, barge companies paid taxes on fuel that they did not consume. This is highly unlikely. Fuel meters and physical measurements may be more accurate than some computer models not designed specifically to estimate NTMG. However, if fuel meters or physical measurements are used for barges, the fuel consumed by switch boats in switching barges into and out of tows must be added to the total fuel consumption. Moreover, fuel used to generate electricity on towboats must also be added to total fuel consumption. Only fuel used for propulsion is counted in waterway fuel tax receipts (IRS 2009).

Finally, backhaul estimates are needed to improve the accuracy of fuel consumption estimates. The backhaul rate for most unit-trains is typically zero. However, barge tows and ocean vessels typically have some level of backhaul, which increases the NTMG. Trucks also have backhauls but typically at a lower rate than barges and ocean vessels.

How to Measure NTMG

The most common, easiest, and least costly method to estimate NTMG is to divide aggregate data on ton miles of product hauled by a mode of transport, by the total gallons of fuel consumed to move those ton miles. It is also probably the least accurate method of estimation because it averages NTMG over thousands of products and movements and over many different types of equipment. Previous studies indicate that NTMG estimates vary substantially among products hauled (ICF International 2009), type of equipment used (Gervais and Baumel 1999), terrain and river segment (Baumel et al 1985), speed (ICF International 2009), and distance hauled.

A second method to measure fuel consumption is to install fuel meters on trucks, rail locomotives and barge tow boats. Fuel meters work well on trucks and railroad locomotives but not on barge tow boats. An alternative to fuel meters on tow boats is to use Internal Revenue Service excise fuel tax collections on barge fuel consumption to calculate barge fuel consumption (IRS 2009). The excise tax is collected on each gallon of fuel used to propel inland waterway and intra coastal waterway commercial vessels for the transport of commercial property. Therefore, fuel used to generate electricity and heat must be added to the estimated fuel used to propel the vessel. These excise tax collection data are available by river segment.

A third method is to develop computer simulation models that incorporate all of the major characteristics of the movement being simulated. On railroads, these characteristics include type and size of train, number and type of locomotive, product mix, distance, grade severity, curvatures, and speed. Truck characteristics include type and size of truck, road grades, road congestion, tire types, and speed. Barge characteristics include number and type of barges, size and type of towboat, river segments, locks traversed by size and congestion, and water levels. Properly constructed simulation models appear to have the potential to estimate total fuel consumption for a larger number of movements and types of equipment more accurately and cheaper than other methods that have been used in past studies.

CONCLUSIONS

1. NTMG, when used alone, is frequently an incomplete and misleading measure for modal fuel efficiency comparisons. It is an accurate measure of comparative fuel efficiency only if the comparative mode shipments are from the same origin to the same destination, the same distance from the origin to the destination, and there are no intermodal movements in each shipment.
2. A more accurate measure of comparative modal fuel efficiency is the total fuel consumed by each mode over the entire movement in the transfer of the product from the origin to the final destination. This measure can be calculated by dividing the total miles traveled by each mode by the appropriate NTMG for each mode. Fuel consumption by each mode in the transfer should be added to obtain the total fuel consumption for the entire multimodal shipment.
3. Appropriate NTMG should be estimated for different products, different rivers, and for different sizes and types of trains traveling over different terrains and with different types of locomotives.
4. There is no one “greenest” mode of freight transport. The greenest mode or group of modes depends on several variables. These include the origin, final destination, product, type of shipment, level of backhaul, accuracy of the NTMG, and the miles traveled by all modes involved in the transfer.

5. The comparisons should be made over actual shipment routes rather than over routes that may possibly be used sometime in the future.
6. Government officials should carefully examine proposals for public infrastructure investments that use NTMG alone to justify the proposal's fuel efficiency. These proposals may have the unintended consequence of increasing total fuel consumption. Accurate proposals should provide estimates of total fuel consumption from the beginning origin to the final destination. Total fuel consumption should be based on appropriate NTMG measures, routes and total miles traveled by each mode involved in the transfer. These estimates should be compared with the next best alternative movement. Table 1 is an example of that type of comparison.
7. The large differences in methodologies and results of previous fuel efficiency studies provide opportunities for university researchers, in cooperation with transportation organizations and agencies, to develop simulation models and data to generate unbiased and reliable fuel efficiency estimates for alternative modes, products, routes, and distances. These models would be very useful to public and private decision makers in allocating investment funds among transportation investment alternatives.

References

Abacus Technology Corporation. *Rail vs Truck Fuel Efficiency: The Relative Fuel Efficiency of Truck Competition Rail Freight and Truck Operations Compared in a Range of Corridors*. DOT/FRA-92/2, Federal Railroad Administration, U.S. Department of Transportation, Washington D.C., 1991.

Association of American Railroads. Personal Communication. Washington D.C. July, 2010.

Baumel, C. Phillip. "Is the Era of Cheap Barge Rates Over?" *Feedstuffs* 81 (40), September 28, 2009.

Baumel, C. Phillip, Charles R. Hurburgh, and Tenpao Lee. "Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain-Importing Countries by Alternative Modes and Routes." Special Report 90, Agriculture and Home Economics Experiment Station, Iowa State University, Ames, Iowa, August 1985.

Baumel, C. Phillip, Robert J. Hauser and Jeffrey Beaulieu. "Impact of Inland Waterway User Charges on Corn, Wheat and Soybean Flows: Study of Inland Waterway User Taxes and Charges." National Technical Information Service, U.S. Department of Commerce, PB82-196023, Springfield, Virginia, March, 1982.

Bernert Barge Lines, Inc. "Save Our Dams." www.gorge.net/digitaldesigner/bbl/dams.htm. Accessed July 27, 2010.

Blue Water Shipping Company. "Blue Water Mississippi River Deep Water Corridor Map." Metairie, Louisiana.

Burton, Mark L. "Missouri River Navigation Benefits: Incorporating the Effects of Air Quality Improvements." Prepared for the U.S. Army Corps of Engineers, Missouri Division, Attachment to Affidavit of Mark L Burton, Exhibit 28, MO-ARK Association, Motion to Alter Judgment, Case No. 96 4086-CV-C-66BA, Knox County, State of Tennessee, September 5, 1997.

Cambridge Systematics, Inc. "National Rail Freight Infrastructure Capacity and Investment Study." Cambridge, Massachusetts, September, 2007.

Eastman, S. E. "Fuel Efficiency in Freight Transportation." American Waterway Operators, Inc., Arlington, Virginia, 1980.

Gervais, Jean-Philippe and C. Phillip Baumel. "Fuel Consumption for Shipping Grain Varies by Origin and Destination." *Feedstuffs* 71 (36), August 30, 1999.

ICF International. *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors*. Federal Railroad Administration, U.S. Department of Transportation, Washington D.C., November, 2009.

Iowa Department of Transportation. *River Barge Terminal Directory, Revised 2005.* www.iowadot.gov.

IRS. *Excise Taxes*, Publication 510 (04/2009). www.irs.gov/publications/p510.html.

MapQuest Driving Directions North America, www.mapquest.com/directions.

National Waterways Foundation. "New National Study Compares Freight Transportation by Barge, Truck and Train." News Release, Arlington, Virginia, July 8, 2008.

Quigley, Leo. "Grain Transportation's Green Alternative." *World Grain*, October, 2009.

Texas Transportation Institute. "A Modal Comparison of Freight Transportation Effects on the General Public." Center for Ports and Waterways, Texas A&M University, Houston, Texas, December, 2007, Amended July, 2009.

The Journal of Commerce and Commercial. "Ship Fixture Breakdown." 110 Wall Street, New York, N.Y. 10005 (February 1-July 31 1983 and January 1-July 31, 1998).

U.S. Department of Transportation. *The Replacement of Alton Locks and Dam 26: An Advisory Report of the U.S. Department of Transportation to the Senate Commerce Committee*. Washington, D.C. September, 1975.

U.S. Department of Transportation. *Environmental Advantages of Inland Barge Transportation*. Maritime Administration, Washington D.C., August, 1994.

Van Der Kamp, Jerry. Personal Communication. President, AGRI Industries, Ankeny, Iowa, December, 2010.

Waterways Council, Inc. "Keep America Moving." Video presentation, Arlington, Virginia, February 25, 2010.

***C. Phillip Baumel** is a Charles F. Curtiss Distinguished Professor Emeritus of Economics at Iowa State University. He received the Transportation Research Forum's Distinguished Transportation Researcher Award in 1993, the Transportation Research Forum's Outstanding Research Paper Awards in 1982, 1989, and 1999, and the Transportation Research Forum's Best Agricultural and Rural Transportation Paper Awards in 1989, 1991, and 1995. He is a Fellow in the American Agricultural Economics Association. Baumel pioneered the use of economic network models for analyzing issues of agricultural product transportation by rail, truck, and barge. He retired in 2003 and currently lives in Iowa (summer) and Arizona (winter).*