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ENERGY USE AND POLLUTANT EMISSIONS IMPACTS  
OF SHORTLINE RAILROAD ABANDONMENT

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## Abstract

For a wide variety of reasons U.S. railroad mileage has declined by a significant amount. Railroad abandonment has potential negative effects, especially in rural areas that rely on railroads for outbound shipments of goods and inbound shipments of raw materials and other inputs. The objectives of the study are (1) to illustrate a model that can measure wheat transport modal ton-mile shifts resulting from hypothetical shortline railroad abandonment, (2) to measure modal energy use changes resulting from hypothetical shortline abandonment, and (3) to measure the modal emissions changes resulting from shortline railroad abandonment.

Ton-mile changes resulting from abandonment of Kansas shortlines were computed using a network model that computed the minimum transportation and handling costs for moving Kansas wheat from farms, through grain elevators, and then through unit train loading locations to the export terminals at Houston, Texas. This analysis is performed with and without shortline railroads in the wheat logistics system. Energy use by mode was computed by multiplying ton-miles by energy use coefficients. Energy use by mode is converted into emissions by mode through use of truck and locomotive emission factors.

Total ton-miles are about the same in the simulated shortline abandonment and no shortline abandonment cases, with the abandonment scenario generating 2% fewer ton-miles. Total energy consumption is nearly identical in the two scenarios; 0.2% higher in the shortline abandonment case. Grand total emissions are 2.87% lower in the scenario that doesn't include shortlines in the logistics system. All these results are attributable to the dominance of Class I railroads in the wheat logistics system. Class I railroad ton-miles, energy use, and emissions are not affected by shortline railroad abandonment.

## INTRODUCTION

According to Wilson (2002), in 2001 railroads accounted for nearly 42% of total U.S. ton-miles of freight and nearly 26% of total U.S. tons originated.<sup>1</sup> In 2003, railroads moved 7.4 million container and 2.6 million trailers.<sup>2</sup>

Despite the important role of railroads in the U.S. transportation system, railroad mileage has been declining. Table 1 displays the mileage of the top 10 states in railroad mileage in 1975 and their mileage in 2003. As a group, railroad mileage plunged 31.5% in these states. The largest decline occurred in Iowa (47.5%) and the smallest in California (21.4%). Table 2 contains miles of track owned by Class I railroads during the 1980-2003 period. The data indicate that miles owned fell 23% in the 1980s, followed by an additional decline of 15.5% in the 1990s, before stabilizing at about 169 thousand miles in 2000. The total decrease for the 1980-2003 period was 37.5%. Not all of this decrease in Class I mileage was due to abandonment since many miles of branchline were sold to Class II and Class III railroads during this period. However, the data in Tables 1 and 2 clearly indicate that the rail system has declined as a result of abandonment.

Railroad abandonments have occurred for a wide variety of reasons. The Staggers Rail Act of 1980 made railroad mergers and abandonments easier to accomplish by establishing strict time limits for making regulatory decisions. Significant government investment in the interstate highway system and the adoption of JIT (just-in-time) inventory practices have increased the demand for motor carrier service and had a negative impact on railroad demand.

Railroad abandonment has potential negative effects, especially in rural areas that rely on railroads for outbound shipments of goods and inbound shipments of raw materials and other inputs. Among the potential negative impacts on rural areas are the following:

Table 1  
Top 10 States in Railroad Mileage  
1975 and 2003

State	1975 Mileage	2003 Mileage	Percent Change 1975-2003
Texas	13,255	10,354	-21.9%
Illinois	10,555	7,292	-30.9
Pennsylvania	7,837	5,085	-35.1
Iowa	7,547	3,963	-47.5
Kansas	7,514	4,979	-33.7
Ohio	7,506	5,230	-30.3
Minnesota	7,294	4,631	-36.5
California	7,291	5,733	-21.4
Indiana	6,357	4,237	-33.3
Missouri	6,010	4,089	-32.0
Total	81,166	55,593	-31.5

Source: (1975) Association of American Railroads, *Yearbook of Railroad Facts*, 1978 edition, p. 47. (2003) Association of American Railroads, *Railroad Facts*, 2004 edition, p. 46.

Table 2  
Miles of Track Owned by Class I Railroads  
1980-2003

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<u>Year</u>	<u>1980s</u>	<u>Miles of Track Owned</u>
1980		270,623
1981		267,589
1982		263,330
1983		258,703
1984		252,748
1985		242,320
1986		233,205
1987		220,518
1988		213,669
1989		208,322
Percent Change		-23.0%
<u>Year</u>	<u>1990s</u>	<u>Miles of Track Owned</u>
1990		200,074
1991		196,081
1992		190,591
1993		186,288
1994		183,685
1995		180,419
1996		176,978
1997		172,564
1998		171,098
1999		168,979
Percent Change		-15.5%
<u>Year</u>	<u>2000s</u>	<u>Miles of Track Owned</u>
2000		168,535
2001		167,275
2002		170,048
2003		169,069
Percent Change		0.3%
Grand Total Percent Change		-37.5%

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Source: (1990-2003) Association of American Railroads, *Railroad Facts*, 2004 Edition, p. 45.  
(1980-1989) Association of American Railroads, *Railroad Facts*, 1992 Edition, p. 44.

- Higher transport costs for railroad shippers
- Reduction of market options for shippers
- Lost economic development opportunities
- Loss of local tax base to fund basic government services
- Increased road damage costs

Changes have occurred in the Great Plains region of the U.S. that have contributed to increased trucking of grain. Class I railroads have encouraged the construction of unit train (100 or more railcars) loading facilities (shuttle train locations) on their mainlines. Due to the scale economies of unit trains, Class I railroads offer lower rates to shuttle train shippers. This enables shuttle train shippers to pay a relatively high price for wheat. Thus wheat producers will truck their grain a much greater distance to obtain a higher wheat price at the shuttle train location. Farmers will bypass the local grain elevator and the shortline railroad serving it, and truck their wheat to the shuttle train facility.

Agriculture has consolidated into fewer, larger farms. With the increased scale of operations, farmer ownership of semitractor trailer trucks has increased.<sup>3</sup> With these trucks, farmers can bypass the local grain elevator and the shortline railroad serving it, and deliver grain directly to more distant markets.

Grain is the principal commodity market of most shortlines serving rural regions. Prater and Babcock (1998) found that the most important determinant of shortline railroad profitability is carloads per mile of track. Thus increased trucking of grain at the expense of shortline railroads threatens the economic viability of these railroads, possibility resulting in their abandonment.

The objective of this paper is to develop a methodology to measure the impact on energy

use and emissions resulting from potential abandonment of shortline railroads. Although Kansas wheat transport is used to empirically implement the methodology, the models can be used by other researchers to measure similar impacts for any modal substitution situation. The specific objectives of the paper are:

1. Illustrate a model that can measure wheat transport modal ton-mile shifts resulting from hypothetical shortline railroad abandonment.
2. Measure modal energy use changes resulting from hypothetical shortline abandonment using energy use coefficients for railroads and motor carriers.
3. Measure the modal emissions changes resulting from potential shortline abandonment using mobile source emissions factors.

To achieve the second and third objectives it is necessary to measure the wheat market ton-mile changes resulting from abandonment of Kansas shortlines. This is achieved by computing the minimum transportation and handling costs for moving Kansas wheat from farms, through grain elevators, and then through unit train loading locations to the export terminals at Houston, Texas. Using Arc View Geographic Information software and a truck routing algorithm from Babcock and Bunch (2002), wheat is routed through the logistics system to achieve minimum total transportation and handling costs. This analysis is performed with and without study area shortlines in the wheat logistics system. Thus rail and truck ton-miles before and after shortline abandonment are one of the outputs of the model. Energy use by mode is computed by multiplying ton-miles by energy use coefficients (Btu's per ton-mile). Energy use by mode is converted into emissions by mode through use of truck and locomotive emission factors (pounds of pollutants per 1,000 gallons of diesel fuel). The approach is similar to that found in Lee and Casavant (2002) and Ball and Casavant (2003).



## LITERATURE REVIEW

There have been many studies of the impacts of railroad abandonment. Early studies on the county level economic impacts of abandonment focused on income and employment effects. Public Interest Economics Center (1974) employed a general equilibrium model to estimate the income and employment effects of the reorganization of several bankrupt eastern U.S. railroads that became CONRAIL. Eusebio et al. (1992) used the Public Interest Economic Center's model for a Kansas study.

A number of recent studies have examined the road damage costs resulting from abandonment-related incremental truck traffic. Casavant and Lenzi (1990) outlined a methodology for determining the pavement costs of potential abandonments and applied the approach to potential abandonments in the state of Washington. Tolliver (1989) applied the HPMS system to calculate pavement damage costs avoided by railroads serving the state of North Dakota. Following Casavant and Lenzi (1990) and Tolliver (1989), Eusebio and Rindom (1991) developed a procedure for estimating road damage impacts related to potential abandonments, and applied the procedure to a group of counties in south central Kansas. Tolliver (1994) used an analysis similar to Eusebio and Rindom (1991) to simulate the loss of all rail service in the state of Washington and measure the resulting road damage costs. Babcock et al. (2003a) found that shortline railroads serving the western two-thirds of Kansas prevent nearly \$58 million in pavement damage costs annually. Other studies that have measured the road damage costs resulting from actual or potential abandonment include Babcock and Bunch (2002), Bitzan and Tolliver (2001), Tolliver and HDR Engineering (2000), Eriksen and Casavant (1998), Rindom et al. (1997), Lenzi et al. (1996), and Russell et al. (1995).

A few studies have investigated other potential impacts of railroad abandonment. For

example, Tolliver (1994) measured the impacts of loss of rail service in the state of Washington on the costs of highway congestion. Tolliver and HDR Engineering (2000) investigated the impact of potential abandonment on highway safety. Forkenbrock (1999) estimated the external costs of intercity truck transportation. These included uncompensated damage from accidents, costs of emissions and noise, and the unrecovered costs related to the maintenance of roads. Witt (2004) estimated incremental highway accident costs and benefits associated with shortline abandonment in Kansas. Babcock et al. (2003b) measured changes in transportation and handling costs resulting from simulated abandonment of four Kansas shortline railroads.

## THE STUDY AREA

The study area corresponds to the western two-thirds of Kansas encompassing the three central and three western Kansas crop reporting districts (Figure 1). During the 2000-2003 period the study area accounted for 88.7% of total Kansas wheat production, 79.9% of the state's sorghum production, 78% of Kansas corn production, and 39.8% of the soybean output. The study area produced 79.8% of Kansas production of the four crops combined.

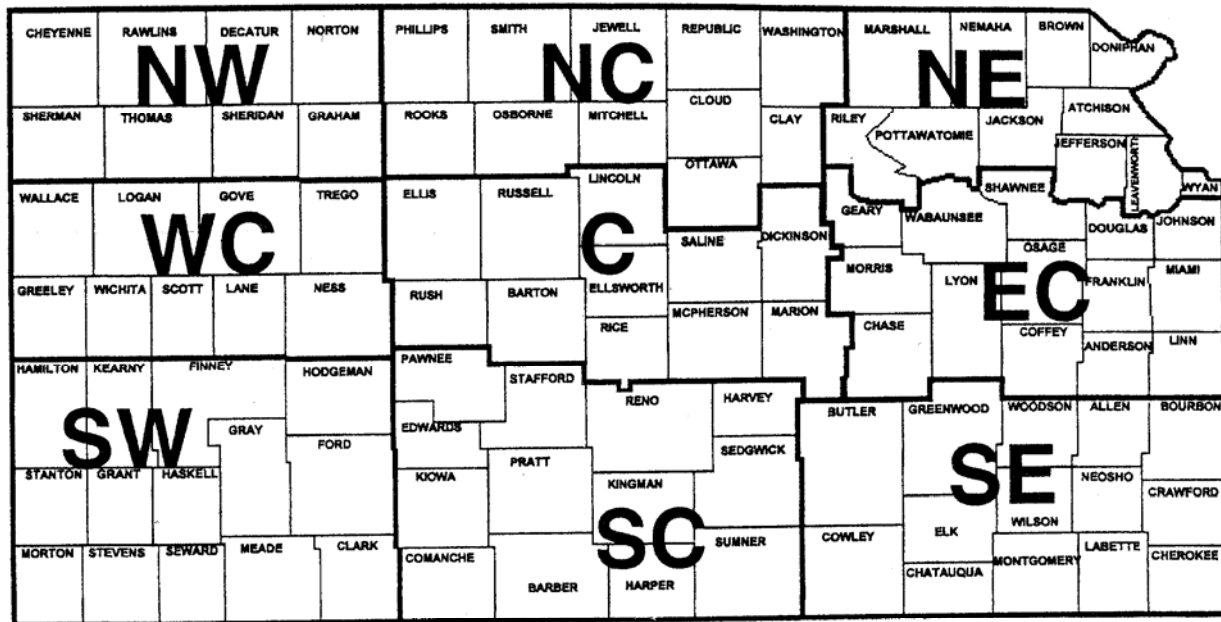
Four shortline railroads serve the study area—Kansas and Oklahoma Railroad, Kyle Railroad, Cimarron Valley Railroad, and Nebraska, Kansas, and Colorado Railnet. The Kansas and Oklahoma began operations in 2001 and serves the central part of the study area from Wichita, Kansas and west to the Colorado border. It also serves south central Kansas and has a line in north central Kansas as well. The Kansas and Oklahoma Railroad has 971 route miles in Kansas and 82 employees.

The Kyle Railroad serves the northern part of the study area with a 479-mile system. The Kyle began operations in 1982 and has 77 full-time employees. The Cimarron Valley Railroad (CV) has 254 route miles with 182 miles in southwest Kansas. The CV was purchased from the

Figure 1

## Kansas Crop Reporting Districts

## AGRICULTURAL STATISTICS DISTRICTS



Kansas is divided into nine Agricultural Statistics districts for convenience in compiling and presenting statistical information on crops and livestock. These nine districts are outlined on the above map. The districts are designated as follows: northwest (NW) (10), west central (WC) (20), southwest (SW) (30), north central (NC) (40), central (C) (50), south central (SC) (60), northeast (NE) (70), east central (EC) (80), and southeast (SE) (90). In tables showing statistical information by counties in this bulletin, counties within each district are grouped together in alphabetical order. Totals and averages are shown for each district.

Santa Fe Railroad and began operations in 1996. The CV has 15 full-time employees in Kansas. The Nebraska, Kansas and Colorado Railnet (NKC) serves five Kansas counties in the northwest part of the study area. The railroad has 122 miles in Kansas and 17 miles of trackage rights on the Kyle Railroad. The NKC began operations in 1996 and has 30 full-time employees.

The study area is also served by two Class I railroads, the Burlington Northern Santa Fe (BNSF) and the Union Pacific System (UP). The BNSF has 1,072 miles of mainline track in Kansas and 188 branchline miles. The UP has 1,378 mainline miles and 127 branchline miles.

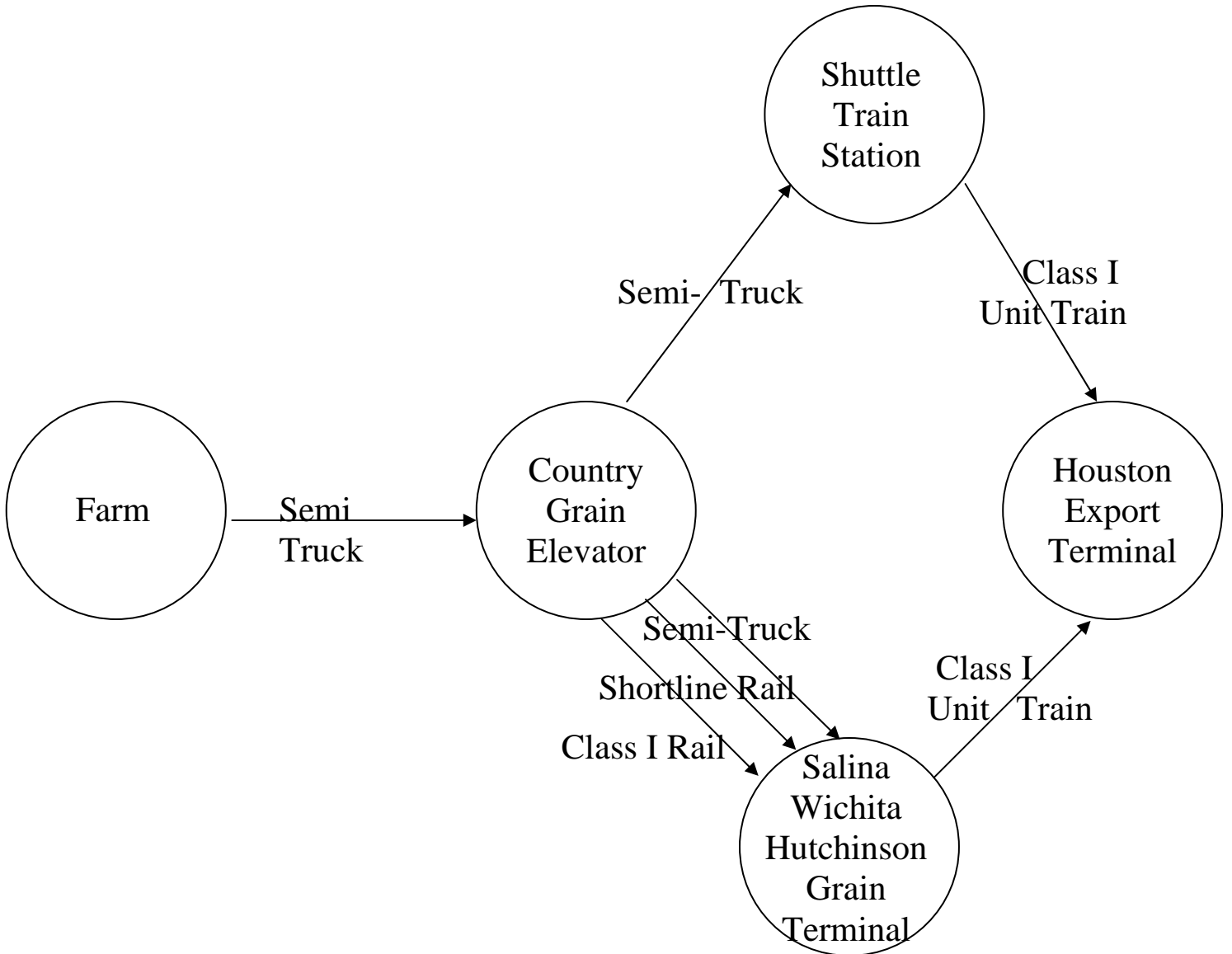
#### DESCRIPTION OF THE KANSAS WHEAT LOGISTICS SYSTEM

Figure 2 portrays a simplified version of the Kansas wheat logistics system. Wheat is shipped from farms in five axle, 80,000 pound semitractor trailer trucks (hereafter referred to as semi-truck) to country grain elevators, which are usually no more than 10 to 15 miles from the farm origin. Wheat is shipped from country elevators to either shuttle train stations (100-railcar shipping facilities at former country elevator locations) or the terminal elevators at Salina, Wichita and Hutchinson, Kansas. Wheat moves exclusively by semi-truck to shuttle train stations, but movements to Salina, Wichita and Hutchinson can be semi-truck, shortline railroad and Class I railroad. Wheat is then shipped by Class I unit train from the shuttle train facilities and the grain terminal elevators in Salina, Wichita and Hutchinson to Houston, Texas for export.

As noted above, this is a simplified version of the wheat logistics system. In some cases, farmers deliver wheat by semi-truck directly to shuttle train stations or Salina, Wichita and Hutchinson grain terminals. This occurs if the farm origins are relatively close to one of these facilities. Also Kansas wheat is shipped to many domestic flour milling locations as well as the Texas Gulf region for export.

Figure 2

## Wheat Logistics System



## THE WHEAT LOGISTICS SYSTEM MODEL

The movement of Kansas wheat is modeled as a transshipment network model with individual farms serving as supply nodes, grain elevators and unit train loading facilities serving as transshipment nodes, and the final demand node being the export terminals at Houston, Texas. The county and state road networks, shortline railroads, and Class I railroads constitute the arcs which connect these nodes.

Given the magnitude and complexity of the wheat logistics system, the movement of Kansas wheat through the various possible network paths is most clearly analyzed in four distinct steps. Step I involves the collection of wheat from production origins, or farms, into an intermediate storage facility (grain elevator) which can ship wheat to the terminal node represented by Houston in the wheat logistics system model. Since it is not economically feasible for firms to ship wheat by truck from Kansas to Houston, Step I consists of moving wheat from the farm to an elevator that has rail access capable of reaching Houston. Step II involves the handling of wheat at intermediate storage facilities. Step III analyzes the shipment of wheat from Kansas unit train shipping facilities to the network model final demand node represented by the Port of Houston. Step IV includes Steps I to III except shortline railroads are assumed to be abandoned and are deleted from the transportation network.

Although profit maximization is assumed to be the main goal of all agents (farmers, elevators, transport firms) in the wheat logistics system, costs serve as the most consistent influence on agents' behavior. Profits ultimately decide individual behavior; however, cost minimization is the consistent strategy for maximizing profits, regardless of the type of market involved. Thus, it is assumed that all agents in the system seek to minimize the costs involved in shipping wheat to market. Farmers seek to minimize both the financial and time costs of getting

wheat from the field to the grain elevator or unit train facility; grain elevators and unit train shipping facilities operate so as to minimize the cost of handling wheat and shipping it to various market destinations. Thus, the goal of the model is to determine the least cost transport route for Kansas wheat from production origin to final destination utilizing the available transportation network. Kansas wheat is shipped to both domestic and international export markets. The Port of Houston is assumed to approximate the cost of shipping Kansas wheat to the many destinations to which it is normally shipped in a given year. Thus, it is assumed that all agents minimize the costs involved in shipping wheat to market. This relationship is summarized in mathematical form by the following objective function:

$$(1) \text{ Minimize TSC} = \sum_i (H_i + T_i + R_i) X_i$$

Subject to the following constraints:

$$H_i, T_i, R_i \geq 0$$

$$\text{Total Wheat Demanded} = \text{Total Wheat Supplied}$$

$$\text{Actual Wheat Stored at Elevator } i \leq \text{Maximum Storage Capacity of Elevator } i$$

$$\text{Actual Transport by Truck } i \leq \text{Maximum Transport Capacity of Truck } i$$

$$\text{Actual Transport by Railcar } i \leq \text{Maximum Transport Capacity of Railcar } i$$

$$\text{Flow of Wheat into Elevator } i = \text{Flow of Wheat out of Elevator } i$$

Where:

TSC is the total wheat logistics system transportation and handling costs

$H_i$  is the sum of all handling costs of unit of wheat  $i$

$T_i$  is the sum of all trucking costs of unit of wheat  $i$

$R_i$  is the sum of all rail costs of unit of wheat  $i$

$X_i$  is the total amount of wheat shipped from Kansas farms to the Port of Houston

## Assumptions of the Network Model

Several assumptions were necessary in order to implement the network model. With respect to Step I, although other methods are available, the optimal methodology for determining wheat movements is individual routing choice analysis. By this method, the initial movement of wheat is determined independently by each farmer. A farmer may choose to truck wheat to a country grain elevator, a shuttle train station, or a terminal grain elevator. This choice is based on the wheat price offered by each available destination market and the costs of transporting wheat to that destination. Based on the spatial distribution of farms and potential destinations, the principal determinant in this choice of destination is usually the transportation cost. That is, the difference in wheat prices between destinations tends to be negligible due to low cost information and high levels of competition, while each farm is usually much closer to one destination than any other potential destination. Thus, producers are assumed to always choose the least-distant, least transport cost destination.

Three key assumptions were made governing system behavior for the Step II handling aspect of wheat transport. First, vehicle and storage capacities are available in equilibrium quantities such that a capacity constraint never influences wheat movements. The second key assumption for Step II is that a country grain elevator does not ship wheat to another country grain elevator. Instead, country grain elevators ship to unit train facilities because of the large volumes of wheat that must be handled, stored, and shipped to Houston. And finally, input costs and technologies across the study area are assumed to be uniform, thereby making it possible to characterize economic entities by type. Thus, all country elevators have the same characteristics, as do all grain trucks, Class I railroads, and shortline railroads.

Two additional assumptions were made for Steps III and IV of Kansas wheat movement.



A key assumption is that Kansas wheat must use rail transport to reach Houston. The high motor carrier variable (with distance) costs of shipping wheat makes trucking wheat to Houston economically infeasible. The large economies of scale associated with unit train transport makes rail the least cost mode of transport for every wheat long distance movement. Thus, if rail service is available from a grain elevator, it will be utilized, and wheat shipments will never change modes of transport once loaded on a rail car.

### Structural Elements of the Model

Before analyzing the movement of wheat, some structural elements had to be quantified and geo-spatially referenced. First, the farms where wheat is produced were determined. Second, the transshipment nodes (i.e. country grain elevators, shuttle train facilities, and Salina, Wichita, and Hutchinson, Kansas grain terminals) and the terminal node (Houston) were defined. Next, the road and rail systems available for transporting the wheat had to be specified. And finally, system behaviors as defined by the cost functions of activities were approximated using the four-step approach.

In traditional agricultural network models an area of the magnitude used in this study would probably be divided into 10 mile x 10 mile squares, with each square representing a "simulated farm" origin. While the simulated farm assumption was the best available approximation in the past, tremendous advances in computer technology have enabled a much more detailed approximation of reality. Using GIS software and satellite imagery data on land usage in each country, a specific land use map was generated for the entire study area. Distinct parcels of urban area, woodland, water, and cropland were defined for the entire study area, and all cropland was identified for its possible contribution to wheat production. The entire study area was subdivided into 640 acre plots which contained various parcels of cropland and other

land uses that were further analyzed to estimate simulated wheat farms in the model.

After the actual amount of cropland in a section (640 acres) was identified, the amount of wheat that it would be estimated to produce for the simulation had to be determined. The wheat production of origin points for study area wheat is determined by dividing the average wheat produced in a particular county by the total cropland in that county and multiplying this result by the exact amount of cropland in each section in that county. That is:

$$(2) \quad \text{SectionWheat}_i = \text{SectionCropLand}_{i,t} \cdot [\text{Wheat}_{j,\text{avg}} \div \text{CountyCropLand}_{j,t}]$$

Where:

$\text{SectionWheat}_i$  is the amount of wheat originating in section  $i$

$\text{SectionCropLand}_{i,t}$  is the land used to produce crops in section  $i$  in year  $t$

$\text{Wheat}_{j,\text{avg}}$  is the average wheat produced in county  $j$  over a four year period

$\text{CountyCropLand}_{j,t}$  is the total land in county  $j$  used to produce crops in year  $t$

By applying the resulting estimated wheat production for a particular section to the centroid, or center point of the simulated farm, the result was a geo-referenced set of origin points which served to spatially distribute the average county wheat production according to the actual distribution of study area cropland. This approach, therefore, allowed the model to account for geographical variances in both land usage patterns and historic wheat yields, thereby offering a vastly more accurate estimate of origin point locations and wheat production than postulating homogenous 10 mile by 10 mile simulated farms.

Having established the origin nodes for the model, transshipment and terminal nodes were identified. The numbers of country grain elevators, shuttle train stations, Salina, Wichita, and Hutchinson, Kansas grain terminals, and terminal nodes (Houston) were small enough that actual data concerning these entities could be used. Street addresses for facilities licensed to

handle and store grain in the state of Kansas were used to identify and geo-reference the transshipment nodes in the model. The Salina, Wichita, and Hutchinson grain terminals and shuttle train facilities were those identified in Babcock et al. (2003). The geographic center of the Port of Houston served as the terminal node for the model.

Having defined all of the nodes in the system, the next step in formulating a model of the wheat logistics system was to define the arcs that serve to connect the different origin, transshipment, and terminal nodes of the network. The actual Kansas road system maintained by state and county governments was utilized to define road network arcs. Likewise, systems of railroads operating in Kansas were used to specify railroad network arcs.

#### Data for the Network Model

The model in this study requires much more data than traditional agricultural network models. Identifying wheat origin points requires two sets of data. Data describing the *location* and *amount* of all cropland in the study area is required. This data is available through the State of Kansas Data Access and Support Center (DASC), an initiative of the state's GIS policy board. The data of interest to this study is collected by DASC for each county, so the data for the 66 counties in the study area were obtained from DASC and used to form a single land use map of the entire study area, providing the spatial location of all origin points. The amount of wheat produced at each origin point is the subject of the second set of data. The amount of wheat produced per Kansas county in 2000, 2001, 2002, and 2003 is found in *Kansas Farm Facts*, published by the Kansas Agricultural Statistics Service, Kansas Department of Agriculture, 2002 and 2004 issues. The wheat production for each county was averaged over this four-year period and the county average production is distributed across all wheat origins in the county.

The system of county and state roads in the study area was provided in digitized form by

the Kansas Department of Transportation (KDOT). The locations and storage capacities of country grain elevators and terminal grain elevators were obtained from the *2003 Kansas Official Directory*, published by the Kansas Grain and Feed Association. Shuttle train facility locations were from Babcock et al. (2003). Rail systems for Class I (UP and BNSF) and shortline railroads were obtained through Kansas rail maps provided by KDOT and the Kansas Corporation Commission.

The key data for generating wheat movements are the various transport costs involved in the wheat logistics system. Truck costs incurred by farmers when transporting wheat from origin points to the nearest destination (Step I) are from the Kansas Department of Agriculture's annual survey of custom cutters published in *2000 Kansas Custom Rates*. In the study area the costs vary from a low of .89 cents to a high of 1.17 cents. Thus, truck movements from origin points are assumed to cost 1.0 cent per bushel per mile.

Truck shipments of wheat by grain elevators typically involve for-hire trucking companies. To estimate the for-hire truck costs (per hundred pounds) for various distances, the study by Mark Berwick (2002) was used. For-hire truck costs for wheat are based on the assumptions of a 100 mile trip by a five axle semi-tractor trailer operating at a gross vehicle weight (GVW) of 80,000 pounds and hauling 943 bushels of wheat (no backhaul miles).

Elevator charges for loading and unloading wheat by truck and rail are required under Kansas statute to be publicly posted. Based on the reported averages of 345 country grain elevators, truck unload and loadout costs were found to average nine cents per bushel. The rail loadout cost at country elevators, based on 238 reports, was also found to average nine cents per bushel. Rail and truck unloading and loadout costs at 16 shuttle train facilities and Salina, Wichita and Hutchinson terminal elevators were all found to average seven cents per bushel.

The rail costs of shipping wheat per hundred pounds was obtained through the Uniform Rail Costing System (URCS) Phase III Movement Costing Program which is maintained by the Surface Transportation Board. These costs range from a low of \$656 to \$990 per car, depending on the distance of the wheat shipment.

See the Appendix for a detailed mathematical presentation of the wheat logistics model.

## TRANSPORTATION ENERGY CONSUMPTION

Energy intensity for freight transportation is measured in British Thermal Units (Btu) per ton-mile, the number of Btu's required to move one ton-mile. A single Btu is the amount of energy required to raise the temperature of one pound of water by one degree Fahrenheit at or near 39.2 degrees Fahrenheit.

Class I railroad energy intensity coefficients (Btu per ton-mile) for 2001 and 2002 were obtained from Davis and Diegel (2004, p. 2-18). Data to calculate the coefficient for 2003 was obtained from Association of American Railroads (2004, p. 27 and p. 61).<sup>6</sup>

According to Babcock and Bunch (2002, pp. 16-17), farmers and commercial grain trucking companies use large trucks (semi-tractor trailer) to deliver grain to elevators. Thus, energy intensity coefficients were calculated for combination trucks, defined by Davis and Diegel (2004) as a power unit (truck tractor) and one or more trailing units (a semi-trailer).

Energy intensity coefficients for 2001-2003 were calculated for combination trucks as follows:

$$(3) \text{ Btu's per Vehicle Mile} = \left( \frac{\text{Combination Truck Fuel Consumed}}{\text{Combination Truck Vehicle Miles}} \right) \bullet 138,700 \text{ where } 138,700 \text{ is}$$

the heat content used to convert diesel fuel to Btu's.

$$(4) \text{ Btu's per Ton-Mile} = \frac{\text{Btu's per Vehicle Mile}}{\text{Tons per Vehicle}}$$

Assuming the typical combination truck is a five axle semi, the total tons per vehicle is

40 (80,000 pounds).

The data to calculate equation (3) for 2001 and 2002 was obtained from Davis and Diegel (2004, p. 5-3) while the data for 2003 was from U.S. Department of Transportation (2005, Table 4-14).

The calculated energy intensities for Class I railroads and combination trucks for the 2001-2003 period are as follows:

Year	Class I Railroads	Combination Trucks
2001	346	648
2002	345	662
2003	344	674
Average 2001-2003	345	661

The energy emission intensities in this analysis are the average intensities over the 2001-2003 period, or 345 and 661 Btu's per ton-mile for Class I railroads and combination trucks, respectively. Thus the energy intensity of combination trucks is nearly 92% higher than Class I railroads. There is no published data source for energy intensity of shortline railroads, so shortlines are assumed to have the same energy intensity as Class I railroads. This is a strong assumption since shortlines operate older, less energy efficient locomotives. However, since there is no information there is no realistic alternative to making this assumption.

The energy intensities are used in conjunction with truck and rail ton-miles derived from the wheat logistics system model to determine energy consumption with and without shortlines in the Kansas grain logistics system.

## EMISSION FACTORS

### Mobile Source Emissions

Mobile sources such as trucks and locomotives emit a number of air toxics associated

with adverse effects on human health including heart problems, asthma, eye and lung irritation, and cancer. The principal air pollutants are the following:

Hydrocarbons (HC) – these are chemical compounds that contain hydrogen and carbon which are in diesel fuel. Hydrocarbon pollution results when partially burned fuel is emitted from the engine as exhaust, and also when fuel evaporates directly into the atmosphere.

Carbon Monoxide (CO) – is a colorless, odorless, poisonous gas that forms when carbon in diesel fuel is not burned completely.

Nitrogen Oxide (NO<sub>x</sub>) – is formed when the oxygen and nitrogen in the air react with each other during fuel combustion. Nitrogen oxides can travel long distances, causing a variety of environmental problems including smog and ozone.

Particulate Matter – comes from diesel exhaust and refers to tiny particles or liquid droplets suspended in the air that can contain a variety of chemical compounds. Larger particles (PM-10) are visible as smoke or dust and settle out relatively rapidly. The smallest particles (PM-2.5) aren't visible to the naked eye but are major contributors to haze. Virtually all particulate matter from mobile sources is PM-2.5.

Sulfur Dioxide – is found in diesel exhaust and contributes to the formation of particulate matter and other air toxics.

#### Rail And Truck Emission Factors

Emission factors (pounds per 1000 gallons of diesel fuel) for Class I railroads, shortline railroads, and Class 8 trucks are displayed in Table 3.<sup>7</sup> The emission factors for Class I railroads and Class 8 trucks are national averages for the 2001-2003 period. The emission factors for Kansas shortline railroads were based on a survey of these railroads conducted in July 2005 and USEPA publications.





The emission factors for line-haul Class I railroads were calculated using the following procedure.

- (1) Convert tons of each pollutant to thousands of pounds per year.
- (2) Divide (1) by annual fuel use (thousands of gallons) of Class I railroads
- (3) Multiply (2) by 1000 to obtain annual pounds of pollutant per 1000 gallons of diesel fuel.

Annual tons of each pollutant was obtained from USEPA (2005), and Class I railroad annual fuel use was from Association of American Railroads (2004, p. 61).

The emission factors for Class 8 trucks were calculated using a similar procedure.

- (1) Convert tons of each pollutant to millions of pounds per year.
- (2) Divide (1) by millions of Class 8 truck vehicle miles and multiply the result by 5.25.<sup>8</sup>
- (3) Multiply (2) by 1000 to obtain annual pounds of pollutant per 1000 gallons of diesel fuel.

Annual tons of each pollutant and vehicle miles of Class 8 trucks was obtained from USEPA (2005). Average miles per gallon was from USDOT (2005, Table 4-14).

Emission factors for Kansas shortline railroads were estimated by combining a survey of Kansas freight-carrying shortlines with data in USEPA (1992). Four of the five carriers surveyed provided information on a combined total of 73 line-haul locomotives used to haul grain. The shortlines provided five pieces of information for each locomotive including:

- Locomotive manufacturer
- Year of manufacture
- Locomotive model
- Locomotive engine type
- Locomotive horsepower

USEPA (1992, Appendix 6-6) has HC, CO, NO<sub>x</sub>, and PM emission factors (pounds per

gallon) for all the engine types of locomotives used by the Kansas shortlines. USEPA (1992, Appendix 6-7) outlines a five step procedure for calculating average emission factors for the sample of 73 line-haul locomotives. Locomotives built after 1972 were required to meet lower emission rate standards. About one-third of the shortlines' locomotives were built or rebuilt after 1972. USEPA (1997, p. 3) provides estimated emission factors for HC, CO, NO<sub>x</sub>, and PM for locomotives manufactured between 1973 and 2001. These emission factors were used to calculate weighted average emission factors for Kansas shortline locomotives. The USEPA publications provided no SO<sub>2</sub> emission factors for shortlines so the Class I railroad estimate was used.

The data in Table 3 indicate that, with the exception of carbon monoxide, the emission factors for Class 8 trucks are less than that of Class I railroads and substantially lower than shortline railroads.

Energy use by mode is converted into emissions by mode through the use of truck and locomotive emission factors. Emissions by mode are calculated with and without shortline railroads in the Kansas wheat logistics system to measure the pollution impact of shortline abandonment.

## EMPIRICAL RESULTS

### Energy Use

Table 4 contains the ton-miles by mode for the Kansas export wheat logistics system with and without shortline railroads in the system. The ton-mile values were obtained by solving the network model discussed above, assuming the two scenarios of no shortline abandonment and complete abandonment. Truck ton-miles increase from 216.8 million in the logistics system that includes shortline railroads to 445.4 million without them, a 105.4% increase. Shortline railroad



ton-miles are 414.8 million in the wheat logistics system that includes them, and zero in the simulated shortline abandonment scenario. Class I railroad ton-miles are unaffected by shortline abandonment and are 8,693.4 million in both scenarios. Since Class I railroads are the dominant mode in the export wheat logistics system, and Class I ton-miles are unaffected by simulated shortline abandonment, total ton-miles are about the same in the simulated abandonment and no abandonment cases, with the abandonment scenario generating 2% fewer ton-miles.

Table 5 displays energy consumption by mode for the Kansas export wheat logistics system for the shortline abandonment and no abandonment cases. The values in Table 5 were computed by multiplying modal energy intensities (Btu's per ton-mile), which were 345 for railroads and 661 for trucks, by the corresponding modal ton-miles in Table 4. Since energy consumption is directly proportional to ton-miles, the modal percentage changes for energy consumption are identical to the percentage changes in ton-miles, i.e., 105.4% for trucks, -100% for shortline railroads, and no change for Class I railroads. The combined truck and shortline railroad Btu's increase from 286,411 million in the no abandonment case to 294,409 million in the shortline abandonment scenario, a 2.8% increase. However, due to the dominance of Class I railroads in the export wheat logistics system, combined with the same Class I energy consumption in both scenarios, total energy consumption in the two cases is nearly identical, 0.2% higher in the abandonment case.

#### Pollutant Emissions

Pounds of emissions by type of pollutant and mode were calculated using the following procedure.

1. Since the heat content of a gallon of diesel fuel is 138,700, divide Btu's from Table 5 by 138,700. For example, Class 8 truck emissions for the with shortline scenario is

$143,305/138,700 = 1.0332$  gallons of energy use.

2. Multiply (1) by 1000 to obtain thousands of gallons of energy usage or  $1.0332 (1000) = 1033.2$ .

3. Multiply (2) by the appropriate emission factor. Thus pounds of Class 8 truck emissions for hydrocarbons is  $1033.2 (12.06) = 12,460$  pounds.

Table 6 contains total emissions by type of emission for the Kansas wheat logistics system with and without shortline railroads. Since system ton-miles and energy consumption are dominated by Class I railroads, the total emissions data in Table 6 also reflect this fact. Although the percentage changes in Class 8 truck and shortline ton-miles and energy consumption are large (Tables 4 and 5), between the no abandonment and abandonment scenarios, Class I railroads account for the great majority of ton-miles and energy consumption, and neither variable is affected by shortline abandonment. Thus the percentage changes in total emissions are relatively small for all emission types. Total emissions of carbon monoxide increase 0.49% as a result of shortline abandonment, while emissions of all other types decrease by 2.33% to 3.45% in the without shortlines case. This is expected since the estimated emission factors were relatively lower for Class 8 trucks with the exception of carbon monoxide. Grand total emissions are 2.87% lower in the scenario that doesn't include shortlines in the export wheat logistics system.

Table 7 displays emissions data by emission type and mode for the with and without shortlines scenarios. As indicated in Table 3, Class 8 trucks have substantially lower emission factors than Kansas shortline railroad locomotives, except for carbon monoxide. Class 8 truck emissions increase from 320,953 pounds in the with shortline case to 659,374 pounds in the without shortline scenario, an increase of 105.4%. Likewise shortline railroad emissions fall



from 614,675 pounds to zero. Grand total emissions decrease because combined truck and shortline railroad emissions decline from 935,529 (320,953 + 614,675) in the with shortlines case to 659,374 pounds in the without shortlines scenario, a decrease of 29.5%. However, as noted above, this relatively large percentage change is offset by the dominance of Class I railroads whose total emissions are 8,695,152 pounds in both scenarios.

## CONCLUSION

This paper developed a methodology to measure the impact on energy use and emissions from potential abandonment of shortline railroads. Although the Kansas wheat transport market was used to empirically implement the methodology, the models can be used to measure similar impacts for any modal substitution situation. For example, Class I railroad versus TL motor carrier, Class I railroad versus truck-barge, and oil pipeline versus water carrier.

To the authors, some of the results of the study were expected while others were surprising. The conventional wisdom is that railroads are more energy efficient than motor carriers. This expectation was confirmed by the result that during the 2001-2003 period Class 8 combination trucks consumed nearly twice as much energy (Btu's) per ton-mile as Class I railroads. However, the conventional wisdom of railroads producing fewer emissions than trucks was not confirmed by the study. Emission factors (pounds per 1000 gallons of diesel fuel), with the exception of carbon monoxide, were lower for Class 8 combination trucks than either Class I or shortline railroads.

The results seem to indicate that the ton-mile, energy use, and emission impacts of modal substitutions depend on the geographical context of the transport market and the unique mix and characteristics of modes operating in that market. For example in this study, the shortline abandonment scenario generated 2% fewer ton-miles. However, this effect was partially offset

by the greater energy efficiency of railroads with the result being virtually no change in the energy consumption of the abandonment and no abandonment scenarios. Also, while combination trucks have substantially lower emission factors (with the exception of carbon monoxide) than shortlines, grand total emissions were only 2.87% lower in the shortline abandonment scenario. This result was attributable to the dominance of Class I railroads in the wheat logistics system whose emissions are not affected by shortline abandonment.

#### Endnotes

1. Wilson (2002), pp. 42 and 44.
2. Association of American Railroads (2004), p. 26.
3. Babcock and Bunch (2002b) pp. 34-35.
4. Kansas Agricultural Statistics Service, *Kansas Farm Facts*, 2002 and 2004.
5. Texas Gulf ports, of which Houston is the largest, is the most important single destination of Kansas wheat, accounting for about 50% of the shipments [*Kansas Agricultural Statistics* (2001, pp. 13 and 15), and *Kansas Agricultural Statistics* (2002, pp. 13 and 15)].
6. Class I railroad fuel use in 2003 was 3,849.229 and revenue ton-miles were 1,551,438 where both variables are measured in millions. Btu's per gallon of diesel fuel are 138,700. Thus Class I railroad Btu's per ton-mile in 2003 are calculated as follows:  $\left( \frac{3,849.229}{1,551,438} \right) \cdot 138,700 = 344$ .
7. Class 8 trucks are the largest diesel semi-tractor trailer trucks with gross vehicle weight of 33,001 pounds or more.
8. Combination truck average miles per gallon in the 2000-2003 period was 5.25.



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Table 3  
Emission Factors for Railroads and Class 8 Trucks<sup>1</sup>  
2001-2003 National Averages

Emission Type	Class I Railroads	Shortline Railroads	Class 8 Trucks <sup>2</sup>
Hydrocarbons (HC)	13.41	20.02	12.06
Carbon Monoxide (CO)	35.80	66.45	67.02
Nitrogen Oxide (NO <sub>x</sub> )	321.62	474.75	219.88
Particulate Matter (PM-10)	8.95	12.20	6.71
Particulate Matter (PM-2.5)	8.68	11.83 <sup>3</sup>	5.84
Sulfur Dioxide (SO <sub>2</sub> )	22.33	22.33 <sup>4</sup>	4.97

<sup>1</sup> Pounds per 1000 gallons of diesel fuel

<sup>2</sup> Class 8 trucks are the largest diesel semi-tractor trailer trucks and have gross vehicle weight of 33,001 pounds or more

<sup>3</sup> Estimated based on Class I rail data

<sup>4</sup> Assumed to be the same as Class I railroads since the data to calculate the emission factor was unavailable

Sources: (Class I railroads) U.S. Environmental Protection Agency, Office of Transportation and Air Quality, ASD at <http://www.epa/otaq/m6.htm>. Association of American Railroads, *Railroad Facts 2004*, Washington D.C., 2004. (Shortline railroads) survey of Kansas shortline railroads. (Class 8 trucks) U.S. Environmental Protection Agency, Office of Transportation and Air Quality, ASD at <http://www.epa/otaq/m6.htm>. U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 2005* (Table 4-14) at <http://www.transtats.bts.gov/>.

Table 4

## Ton-Miles by Mode

(Millions of Ton-Miles)

Mode	With Shortlines	Without Shortlines	Percent Change
Truck	216.8	445.4	105.4%
Shortline Railroad	414.8	0	-100
Class I Railroad	8,693.4	8,693.4	0
Total	9,325.0	9,138.8	-2.0%

Table 5

## Btu per Ton-Mile and Btu's Consumed by Mode

(Millions of Btu's)

Mode	Btu per Ton-Mile	Btu's Consumed With Shortlines	Btu's Consumed Without Shortlines	Percent Change
Truck	661	143,305	294,409	105.4%
Shortline Railroad	345	143,106	0	-100
Class I Railroad	345	2,999,223	2,999,223	0
Total Btu's Consumed		3,285,634	3,293,632	0.2

Table 6

Total Emissions of Truck and Railroad Transportation of Wheat,  
With and Without Shortline Railroads

(Pounds)

(1) Emission Type	(2) With Shortlines	(3) Without Shortlines	(4) [(3)/(2)-1] · 100
HC	323,091	315,574	-2.33%
CO	911,939	916,392	0.49
NO <sub>x</sub>	7,671,662	7,421,375	-3.26
PM-10	213,054	207,776	-2.48
PM-2.5	205,935	200,091	-2.84
SO <sub>2</sub>	511,034	493,409	-3.45
Total*	9,630,780	9,354,526	-2.87

\* Total doesn't include PM-2.5 since it is included in PM-10.

Table 7

Emissions by Emission Type and Mode,  
With and Without Shortline Railroads

(Pounds)

Emission Type	<u>Class 8 Truck</u>		<u>Shortline Railroad</u>		<u>Class I Railroad</u>	
	With Shortlines	Without Shortlines	With Shortlines	Without Shortlines	With Shortlines	Without Shortlines
HC	12,460	25,599	20,656	0	289,975	289,975
CO	69,245	142,259	68,561	0	774,133	774,133
NO <sub>x</sub>	227,180	466,724	489,831	0	6,954,651	6,954,651
PM-10	6,933	14,243	12,588	0	193,533	193,533
PM-2.5	6,034	12,396	12,206	0	187,695	187,695
SO <sub>2</sub>	5,135	10,549	23,039	0	482,860	482,860
Total*	320,953	659,374	614,675	0	8,695,152	8,695,152

\* Total doesn't include PM-2.5 since it is included in PM-10.

Energy Intensities for Combination Trucks<sup>1</sup>  
1970, 1975, and 1980-2003

Year	Vehicle Miles Traveled (Millions of Miles)	Fuel Use (Millions of Gallons)	Btu's per Vehicle Mile <sup>2</sup>	Btu's per Ton-Mile <sup>3</sup>
1970	35,134	7,348	29,008	725.2
1975	46,724	9,177	27,241.9	681.0
1980	68,678	13,037	26,329.1	658.2
1981	69,134	13,509	27,102.4	677.6
1982	70,765	13,583	26,622.8	665.6
1983	73,586	13,796	26,003.7	650.1
1984	77,377	14,188	25,432.3	635.8
1985	78,063	14,005	24,883.7	622.1
1986	81,038	14,475	24,774.6	619.4
1987	85,495	14,990	24,318.5	608.0
1988	88,551	15,224	23,845.8	596.1
1989	91,879	15,733	23,750.4	593.8
1990	94,341	16,133	23,718.7	593.0
1991	96,645	16,809	24,123.4	603.1
1992	99,510	17,216	23,996.2	599.9
1993	103,116	17,748	23,872.6	596.8
1994	108,932	18,653	23,750.3	593.8
1995	115,451	19,777	23,759.6	594.0
1996	118,899	20,192	23,554.7	588.9
1997	124,584	20,302	22,602.3	565.1
1998	128,159	21,100	22,835.5	570.9
1999	132,384	24,537	25,707.7	642.7
2000	135,020	25,666	26,365.5	659.1
2001	136,584	25,512	25,907.2	647.7
2002	138,737	26,480	26,472.9	661.8
2003	138,322	26,895	26,968.5	674.2

Sources: Vehicle Miles and Fuel Use obtained from Bureau of Transportation Statistics.  
*National Transportation Statistics 2004*. Tables 1-32 and 4-14.

<sup>1</sup> Combination trucks are semi-tractor trailer trucks.

<sup>2</sup> Btu's per vehicle mile was obtained by multiplying fuel use by 138,700 (Btu's per gallon of diesel fuel) and dividing the result by vehicle miles.

<sup>3</sup> Btu's per ton-mile was obtained by dividing Btu's per vehicle mile by 40 (weight in tons of a five axle semi-tractor trailer truck).