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Feasibility of an Intermodal Terminal in Rural Texas to Enhance Marketing and Transportation Efficiency

by Stephen Fuller, John Robinson, Francisco Fraire, and Sharada Vadali

This study examines the economic feasibility of investment in an intermodal terminal in west Texas and its implications for reducing roadway maintenance costs and CO_2 emissions. The study focuses on cotton, a leading agricultural commodity in Texas, which is highly dependent on the international market and truck transport from west Texas to the Dallas-Fort Worth complex for purposes of accessing containerized railroad transportation to West Coast ports. Analyses were accomplished with a spatial model of the U.S. cotton industry that features details regarding cotton handling, storage, and transportation activities. The analyses indicate an intermodal terminal in west Texas' intensive cotton-production region to be economically viable, attracting nearly 30% of Texas' average cotton production. Implementation of an intermodal terminal in west Texas would annually reduce truck travel on state roadways and lower pavement maintenance expenditure by approximately $1 million and reduce CO_2 emissions by 42% to 47%.

INTRODUCTION

This study examines the feasibility of investment in an intermodal terminal in west Texas and its implications for reducing roadway maintenance costs and CO_2 emissions. The study focuses on cotton, a leading agricultural commodity in Texas, which is highly dependent on the international market and on truck transport from west Texas to the Dallas-Fort Worth complex to access containerized railroad transportation to West Coast ports. Conceptually, an intermodal terminal in west Texas would allow cotton to access the intermodal system near its production location, removing the need for truck transport into the Dallas-Fort Worth metropolitan area. The assembly of cotton into the Dallas-Fort Worth railroad hub is at distances of up to 335 miles. Therefore, truck miles, roadway maintenance, and CO_2 emissions may be significantly decreased by the introduction of an intermodal terminal in west Texas, the locus for Texas' cotton production.

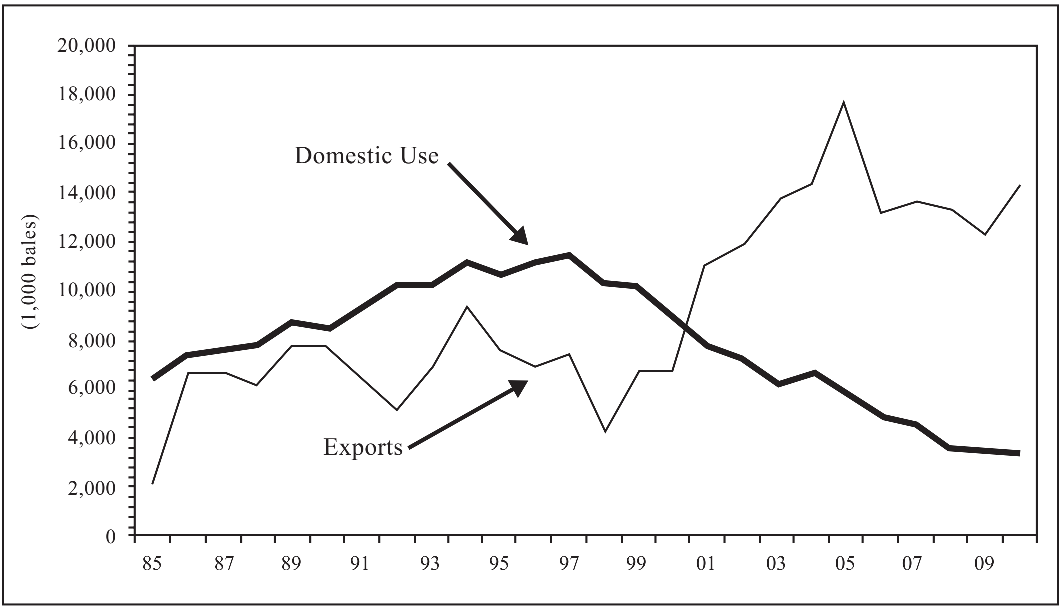
The objectives of this study are to (1) determine the economic feasibility of an intermodal terminal in the intensive cotton-production region of west Texas and evaluate the sensitivity of the intermodal terminal's feasibility to selected exogenous forces, (2) estimate reduced roadway maintenance expenditure resulting from investment in the terminal, and (3) estimate reduction in CO_2 emissions associated with the intermodal terminal and the value of the reduced emissions.

Many of the analyses were accomplished with a spatial model of the U.S. cotton industry that features cotton handling, storage, and transport activities that link cotton gins to warehouses and ultimately to intermodal terminals, domestic textile mills, U.S. port areas, and border-crossing locations.

BACKGROUND

The transport and logistics system serving the U.S. cotton industry has undergone important changes as a result of the demise of the domestic textile industry and the corresponding growth in cotton exports. Currently, exports comprise nearly 80% of annual cotton disappearance (Figure 1).

Figure 1: Domestic U.S. Cotton Use and U.S. Exports 1985/86–2010/11



Source: U.S. Department of Agriculture (2010)

Cotton that had historically been transported by truck and railcar to southeast U.S. textile mills is now largely routed to export via the U.S. West Coast, Gulf of Mexico, southeast ports, and the Mexican border. Fuller, Park and Robinson (2007) show Texas, the leading cotton-producing state, ships the majority of its export-destined cotton to West Coast ports (Long Beach/Los Angeles). Nationally, about 48% of U.S. cotton is exported via West Coast ports, with the Gulf of Mexico and East Coast ports handling about 17% and 16%, respectively, and border-crossing locations accommodating about 19% of exports (WISERtrade 2009). All cotton exported from U.S. ports is in marine containers, and because of unequal trade flows between Asia and the United States, considerable U.S. cotton is backhauled in containers to Asian textile mills. Unfortunately, the intense cotton-producing regions in Texas are geographically remote and cannot efficiently access the westward flow of empty containers to West Coast ports.

REVIEW OF LITERATURE

A review of literature indicated few efforts to construct spatial models of the U.S. cotton industry. However, spatial equilibrium models of the international grain economy have been successively employed by Fellin, Fuller, Kruse, Meyers, and Womack (2008), and Wilson, Dahl, Taylor, and Woo (2007) to analyze grain transportation issues. These models will serve as a prototype for the spatial cotton model constructed for this study.

The economic feasibility of an intermodal terminal was previously examined by the Upper Great Plains Transportation Institute (2007), which investigated a terminal featuring container/trailer intermodal services in rural Minnesota and North Dakota. Vachal and Berwick (2008) examined the feasibility of using a container-on-barge facility to export Illinois grain to Asia, and the Minnesota Department of Agriculture and Wilbur Smith Associates (2008) examined the feasibility of investments in intermodal terminals on short-line and regional railroads in the Midwest.

The west Texas intermodal terminal investigated in this study is expected to reduce roadway maintenance cost since cotton will enter the intermodal stream near its production area rather than routed to distant intermodal facilities in Dallas-Ft. Worth. Therefore, there is interest in examining previous studies that measure road maintenance costs. The Washington State Department of Transportation (2003) estimated increased road maintenance costs resulting from abandonment of a railroad in eastern Washington, and related studies by Babcock, Bunch, Sanderson, and Witt (2003a, 2003b) estimated road damage costs resulting from the proposed abandonment of short-line railroads serving Kansas using a pavement-damage model by Tolliver and HDR Engineering, Inc. (2000). Warner and Terra (2006) estimated the reduction in pavement damage to Texas roadways that result from the operation of the state's short-line railroads using a method outlined by Bitzan and Tolliver (2001). They estimated pavement damage to rural interstate highways was 12.7 cents per truck-mile, while the pavement damage to rural major collectors was estimated at 30.5 cents per truck-mile. After considering federal and state fuel taxes paid by trucks, the uncompensated road damage was estimated at 5.03 cents per truck-mile for rural interstate highways and 22.83 cents per truck-mile on rural major collectors.

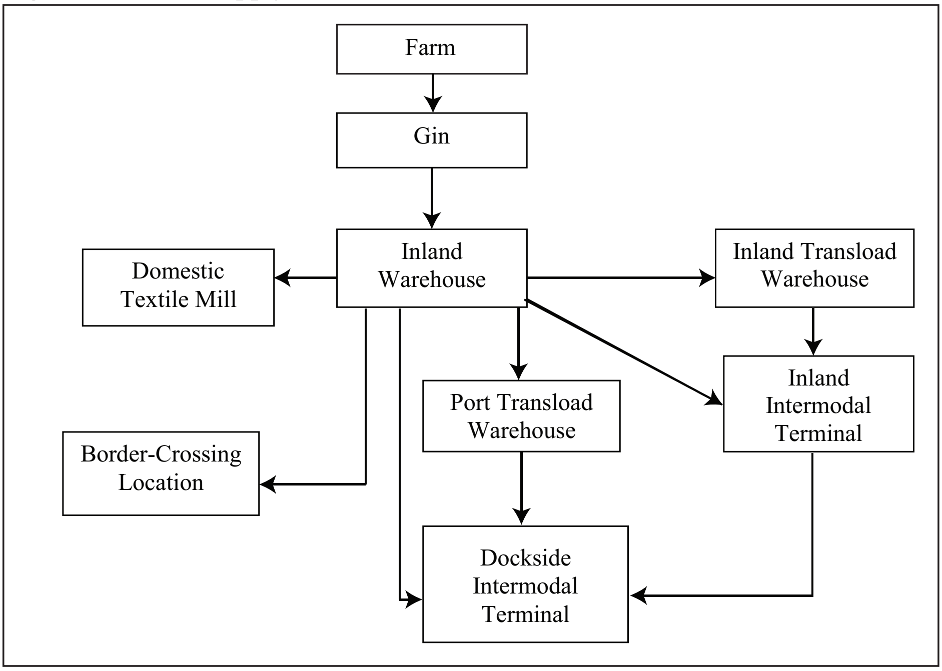
Andrieu and Weiss (2008) review methods and tools available for the measurement of CO_2 for major transport modes under alternative operating conditions and, following the approach by McKinnon (2007), show how the calculated emission parameters may be adjusted to reflect the truck's capacity utilization (backhaul frequency). The EPA's Office of Transportation and Air Quality (EPA 2010) recently developed a modeling system titled the *Motor Vehicle Emissions Simulator* (MOVES), which estimates emissions from cars, trucks, and motorcycles. It shows the average atmospheric emission rates for Class 8 trucks (heavy-duty trucks) is about 2,000 grams of CO_2 per mile at average speeds of 50 to 60 miles per hour. In addition, analysis shows that emissions are affected by truck capacity utilization (backhaul frequency) through its impact on fuel use. Franzese, Knee, and Slezak (2009) estimate the effect of load size (frequency of empty haul) on fuel efficiency of Class 8 trucks, and the analyses suggest the reasonableness of the rule of thumb "each additional 10,000 pounds of payload decreases fuel economy about 5%." The Federal Railroad Administration (USDOT 2009) provides a comparative evaluation of rail and truck fuel efficiency for 23 competing moves. Eleven of the moves compared fuel efficiency of trucks with double-stack container cars for moves ranging from 294 to 2,232 miles, with results indicating rail transport was 2.2 to 5.5 times more fuel efficient than trucks.

MODEL

The cotton spatial model developed for this study is a cost-minimizing, transshipment model that links gins, warehouses, domestic textile mill regions, inland intermodal terminals, and U.S. ports and border-crossing locations (Figure 2). Although farms are included in Figure 2, the cotton supply chain represented in the developed model originates at gins since farm-level supplies have no direct bearing on study objectives. New-crop cotton supply in the spatial model is generated in the first quarter of the crop year at gins while the carry-in stocks from the previous year are largely held at inland warehouses. Cotton gins ship new crop production by truck (flatbed/van) to nearby inland warehouses.

Inland warehouses ship to domestic mills, border-crossing export locations (Canada, Mexico), inland transload warehouses, inland intermodal terminals, port transload warehouses, and dockside intermodal terminals (Figure 2). Transload warehouses (inland, port) typically receive cotton by truck (flatbed/vans) and then place it into containers, which are drayed to nearby intermodal terminals (inland, dockside). If the inland warehouse has loaded a container, chassis, and truck combination, it may be directly transported to an inland intermodal terminal where it is loaded to a double-stack car for transport to a dockside intermodal terminal, or the container of cotton may be transported directly to a dockside intermodal terminal for loading to a container ship (Figure 2). Truck transportation dominates except for links between inland intermodal terminals, and dockside intermodal terminals which involve the containerized rail movements, and on selected routes between inland warehouses and ports and border-crossing locations where rail transport (boxcar)

Figure 2: Cotton Supply Chain



has a limited role. Trucking and rail linkages in the developed model are without constraints since cotton haulage was small as compared with all transport activity.

In the developed model, domestic cotton demands are fixed in U.S. demand regions (domestic textile mill), and foreign demands are fixed at U.S. ports and border-crossing locations (Figure 2). Cotton handling and storage costs in the model are incurred at inland and transload warehouses, while handling costs are incurred at all intermodal facilities, ports, and border-crossing locations. Plant capacity constraints are included for each gin and inland and transload warehouse; however, intermodal terminals (inland, dockside) and border crossings have no capacity constraints since cotton is a small portion of total volume at these sites (Figure 2).

Table 1 includes the definition of subscripts, parameters, and variables in the following mathematical description of the cost-minimizing, transshipment model:

(1) Objective function:

$$\begin{aligned} Min \textstyle\sum_i \sum_w \sum_t c_{iw} X_{iwt} + \sum_w \sum_n \sum_s \sum_t c_{wnst} X_{wnst} + \sum_w \sum_l \sum_t c_{wlt} X_{wlt} + \\ \textstyle\sum_w \sum_k \sum_s \sum_t c_{wkst} X_{wkst} + \sum_j \sum_m \sum_s \sum_t c_{jmst} X_{jmst} + \sum_k \sum_n \sum_t c_{kn} X_{knt} + \\ \textstyle\sum_w \sum_t cs_w H_{wt} \end{aligned}$$

(2) Quarterly demand constraints:

2a. $\sum_w \sum_s X_{wnst} + \sum_k X_{knt} \geq D_{nt}$, $for\ all\ n, t$.

2b. $\sum_w \sum_{wlt} \geq D_{lt}, for\ all\ l, t$.

2c. $[(\sum_{it} S_{it} + \sum_w H_{w0}) - (\sum_n \sum_t D_{nt} + \sum_l \sum_t D_{lt})] \cdot \gamma_u \leq \sum v \in \sum_j \delta_v H_{j4},\ for\ all\ u.$

(3) Quarterly supply constraints:

$\sum_w X_{iwt} \leq S_{it}, for\ all\ i, t.$

(4) Warehouse shipment balance constraint:

$$\sum_n \sum_s X_{jnst} + \sum_l X_{jlt} + \sum_k \sum_s X_{jkst} + \sum_m \sum_s X_{jmst} + H_{jt} - H_{j,t-1} \leq \sum_i X_{ijt}, \; for\ all\ t\ and\ j \subset w.$$

(5) Transloading warehouse balance constraint:

$$\sum_n \sum_s X_{mnst} + \sum_l X_{mlt} + \sum_k \sum_s X_{mkst} + H_{mt} - H_{m,t-1} - \sum_j \sum_s X_{jmst} \leq \sum_i X_{imt}, \; for\ all\ t\ and\ m \subset w.$$

(6) Quarterly intermodal terminal shipment balance constraints:

$$\sum_n X_{knt} \leq \sum_w \sum_s X_{wkst}, \; for\ all\ k,\ t.$$

(7) Quarterly warehouse storage capacity constraints:

$$H_{wt} \leq Capacity_{wt}, \; for\ all\ w,\ t.$$

(8) Non-negativity constraint:

$$X_{iwt}, X_{wnst}, X_{wlt}, X_{wkst}, X_{jmst}, X_{knt}, H_{w,t} \geq 0, \quad for\ all\ i, j, k, l, m, n, s, t.$$

Table 1: Subscripts, Parameters and Variables in Formulated Model

Subscripts:	
t	Quarter (Q1, Q2, Q3, Q4)
i	U.S. excess supply location (i = 1, 2, 3, ..., 811)
l	U.S. excess demand locations (l = 1, 2, 3, ..., 11)
w, j, m	Originating warehouses (w = 1, 2, 3, ..., 415) *j* are originating warehouses that may not transload *m* are transloading facilities
k	Inland intermodal terminals (k=1, 2, 3, 4)
n	U.S. ports and border crossings (n = 1, 2, 3, ..., 17)
s	Inland modes of transportation (s = 1, 2, ..., 5)
u	U.S. regions (u = 1, 2, 3, 4)
v	U.S. states (v = 1, 2, 3 ..., 17)
Parameters:	
C	Transportation and handling cost per metric ton for truck, railroad, and ship modes as appropriate
CS	Storage cost per metric ton
$Capacity_{wt}$	Maximum storage capacity at warehouse *w* in quarter *t*
δ_v	Indicator variable for state *v* ($\delta = \{0,1\}$)
γ_u	Final quarter storage for region *u*
Variables:	
S_{it}	U.S. excess supply in quarter *t* at location *i*
D_n	Excess demand at U.S. port *n* (foreign excess demand)
D_l	Excess demand at U.S. mill *l*
H_{wt}	Storage in quarter *t* at warehouse *w*
X	Cotton flow in metric tons between nodes

Equation 1 minimizes the costs (C) associated with handling, storage (*H*), and transportation (*X*) of baled cotton that originates at U.S. gins over the four quarters of a crop year that extends from August 1 through July 31. The letter *t* identifies the quarter, where *t* = Q1 corresponds to the initial quarter of the crop year when harvest commences.

The model allows cotton to be routed from gins (*i*=811) to inland warehouses (*w*=415) and then, for export-destined cotton, to transloading warehouses (*m*=37) and inland intermodal terminals (*k*=4), before arriving at ports and border crossings (*n*=17).

Further, the model allows for direct shipment from inland warehouses to domestic mill demand regions (*l*=11), and to ports and border crossings (*n*=17). Cotton can be transported via five transportation alternatives (*s*=5). Railroad boxcar and intermodal (containers) shipments are included on selected corridors, while three truck assembly alternatives are included. The trucking possibilities include (1) truck, chassis, container combination (source-loaded) (2) flatbed/van shipments and (3) flatbed/van shipments with backhauls on selected routes. All transportation arcs are without constraints. Lastly, storage in inland warehouses and transloading warehouses is allowed in all four quarters.

Equation 2a is a demand constraint requiring the shipment of predetermined quantities per quarter to ports and border crossings (*n*), while Equation 2b is a constraint requiring predetermined quantities per quarter to domestic mill demand regions (*l*=11). The third demand equation (Equation 2c) specifies the ending stocks ($H_{j,4}$) in four regions (*u*). These regions are the mid-south, southeast, southwest, and west. Each region contains several states *(v)*. Therefore, given that $d_v = 1$ when state *s* belongs to region *u,* and zero otherwise, the equation distributes the excess supply into the model according to the proportions specified by g_u, while allowing each warehouse's storage of cotton to be determined endogenously.

Equation 3 describes a gin plant's maximum output of baled cotton.

The inland warehouse and the transload warehouse represent two types of warehouses (*w = j + m*), whose distinction is their ability to receive (*m*) or not receive (*j*) baled cotton shipments from other warehouses. Inland warehouses are located in proximity to cotton production and receive cotton from area gins. Transloading warehouses receive from inland warehouses and gins. Transloading warehouses in proximity of inland intermodal terminals are inland transload warehouses (Figure 2), while those near a port are identifed as port transloading warehouses. Equation 4 constrains the sum of quarterly shipments from inland warehouses to intermodal terminals (*k*), transloading terminals (*m*), ports (*n*), and mills (*l*), and constrains storage for the next period (H_t) to be no more than the incoming new-crop quarterly supplies (X_{ijt}) plus carry-in storage stock (H_{t-1}), where $H_{j,0}$ refers to the stocks carried in from the previous year.

Equations 5 and 6 are similarly interpreted for the transloading warehouses and intermodal terminals, respectively. The transloading warehouses are a subset of the regular warehouses. Thus, Equation 5 applies only to the transloading warehouses and is in place of Equation 4. Equation 7 constrains the quarterly storage in warehouses to not exceed their capacity, and equation 8 is the standard non-negativity constraint in linear programming.

The specified model includes 811 gins and 415 originating warehouses located in 17 states (Alabama, Arizona, Arkansas, California, Florida, Georgia, Kansas, Louisiana, Mississippi, Missouri, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia). Four major intermodal terminals serve the cotton industry, and these include Memphis, Dallas, Houston, and Lubbock. The Lubbock operation is currently privately operated, comparatively small, and available to few cotton shippers. The analysis focuses on construction of an intermodal terminal in Lubbock that is capable of accommodating all area shippers seeking its service. Trade sources indicate the current Lubbock operation would close if a modern facility were available.

Thirty-seven transloading warehouses operate in the inland intermodal terminal centers and receive truck-delivered cotton (flatbed/van) from originating warehouses and gins. In addition, inland intermodal terminals operate in conjunction with selected port areas that receive containers of rail-transported cotton from these terminals. The dockside intermodal terminals that receive rail-transported cotton are at the following locations: California (Los Angeles/Long Beach and San Francisco), Georgia (Savannah), Louisiana (New Orleans), South Carolina (Charleston), Texas (Galveston/Houston), Washington (Seattle), and Virginia (Norfolk). Additional ports are located in Alabama (Mobile), Florida (Everglades/Jacksonville), Mississippi (Gulfport), and Texas (Freeport).

All ports in the model feature a transload warehouse that receives truck-transported (flatbed/van) cotton, which is placed in containers and drayed to dockside. In addition, all dockside intermodal terminals may receive source-loaded cotton (containers) that is truck transported from inland warehouses. Border-crossing locations are in Michigan (Detroit), New York (Buffalo), and Texas (Laredo/Harlingen). Eleven domestic mill demand regions are included in the following states: Alabama (two), Georgia (two), North Carolina (two), South Carolina (two), Tennessee (one), Texas (one), and Virginia (one).

Because truck transport is central to the marketing of U.S. cotton, several truck assembly systems are featured in the model. Trucks (flatbeds/vans) assemble baled cotton from gins to inland and transloading warehouses and are central to the shipment of cotton from inland warehouses. Trucks (flatbeds/vans) ship from inland warehouses to domestic mill demand locations, border-crossing sites, and transloading warehouses at inland and dockside intermodal terminal locations. The transloading warehouses receive truckloads of cotton, which are placed into containers and drayed to intermodal terminals (inland and dockside). The containerized cotton received at inland intermodal terminals is subsequently rail transported (double-stack cars) to dockside, and similarly containerized cotton exiting a port transload warehouse is drayed to dockside for export.

An additional truck assembly system involves a truck, chassis, and container combination (source-loaded), which travels to an inland cotton warehouse where the container is loaded and then transported to an inland intermodal terminal for loading aboard a container car for shipment to a port area. Similarly, truck, chassis, and container (source-loaded) may transport cotton from inland cotton warehouses to dockside. The assembly system involving truck, chassis, and container (source-loaded) removes the need to transship cotton through transloading warehouses, which reduces handling and associated drayage charges.

The model also features a truck assembly system (flatbed/van) that includes truck-backhaul opportunities for cotton moving from inland warehouses in west Texas and Oklahoma to transloading warehouses in the Dallas-Fort Worth intermodal terminal market areas and the Houston and Galveston port areas.

Intermodal transport is central to the movement of cotton to West Coast ports and, to a lesser extent, to East Coast ports. Railroad boxcars are used to transport small quantities from selected inland warehouses to ports and border crossings.

DATA

The following discussion regarding cotton supply and warehousing and the transportation and logistics network relates to data incorporated into the spatial model, while discussion pertaining to intermodal terminal investments and costs, roadway pavement costs, and CO_2 emissions offers insight on data used in combination with the spatial model to accomplish study objectives.

Cotton Supply and Warehousing

The annual production of baled cotton was generated at the spatial model's gin plant sites based on plant capacity and cotton production in the crop reporting district where the gin plant was located. Carry-in cotton stocks were created at each warehouse based on regional carry-in stock data and warehouse storage capacity. In particular, a gin plant's annual output was determined by allocating a crop reporting district's production to area gin plants based on plant capacity. Temporal output of baled cotton at cotton-gin plants was based on data from the regional cotton classing offices. A state's carry-in cotton stocks were distributed among state warehouses based on each warehouse's storage capacity and Intercontinental Exchange (ICE) (2009) data on stored cotton at cotton-futures delivery points.

The gin plant population came from the Cotton Board (2009), and proprietary information on historical gin plant capacity and output was obtained from a national cotton industry organization. The temporal ginning pattern in each production region was approximated with the USDA's (2009c) Agricultural Marketing Service cotton classing office data. Cotton production data by crop reporting district were from the USDA's (2009d) National Agricultural Statistical Service, while the USDA's (2009b) Farm Service Agency was the source of information on the cotton warehouse population and associated warehouse capacity. Data on carry-in cotton stocks were available from the U.S. Census Bureau (2009b), the USDA's (2009a) Economic Research Service *Cotton and Wool Yearbook 2009*, and the Intercontinental Exchange's (2009) *Cotton Certified Stock Report*. The Census Bureau's cotton carry-in stocks data by state were adjusted to reflect the USDA's national carry-in estimate. In addition, the Intercontinental Exchange's data on cotton storage stocks in each of the five cotton-futures delivery markets (Galveston and Houston, Texas; Greenville, South Carolina; Memphis, Tennessee; and New Orleans, Louisiana) were used to allocate carry-in stocks among delivery-point warehouses based on the storage capacity in each delivery market. A state's remaining cotton carry-in stocks were allocated among warehouses outside of the futures-market delivery locations based on storage capacity. Individual cotton warehouse handling and storage charges were obtained from a survey of Texas warehouses, Fuller et al. (2007), the Texas Cotton Association (2009), warehouse websites, and a proprietary list constructed by a national cotton industry organization.

Estimates of domestic cotton-mill demand by state were obtained from the U.S. Census Bureau's (2009a) *Current Industrial Reports* on cotton consumption. Employment at broad-woven fabric mills and yarn-spinning mills was used to estimate cotton use for the 11 sub-state domestic demand regions. Employment at U.S. broad-woven fabric and yarn-spinning mills were taken from Manta (2009a, 2009b). Cotton exports via individual ports and border-crossing locations were from WISERtrade (2009).

Transportation and Logistics Network

Truck brokers, freight forwarders, and selected cotton merchants provided information on truck rates connecting warehouses to ports, domestic mills, transload facilities, and intermodal terminals. Information on cotton trucking rates that link gin plants to warehouses was obtained by a telephone survey of 263 Texas, Oklahoma, New Mexico, and Kansas cotton gin plant operators in 2008 and 2009. These data were used to estimate truck rate equations explained by distance of haul where distance was determined by the route that minimized the trucker's drive time, binary variables that accounted for geographic region and distance zones. Further, with scalars provided by industry personnel, the base truck rates—obtained from the estimated rate equations and the drayage charges—were adjusted to reflect fuel surcharges that were based on the U.S. Department of Energy's (USDOE) (2009) *Monthly Retail On-Highway Diesel Prices* for nine U.S. regions. The regional diesel price information yielded truck rates and drayage charges that differed by U.S. region. See Fuller, Robinson, Fraire, and Vadali (2011) for estimated truck rate equations.

Railroad rate and routing data were obtained from the Surface Transportation Board's (STB) (2009) *Public Use Waybill*, selected cotton merchants, freight forwarders, and railroad company personnel. Waybill data on cotton shipments were sparse and generally inadequate to estimate rate equations, however, it provided insight on ranges of rates by shipping location, and with counsel from cotton merchants and railroad industry personnel, representative values were obtained. Some warehouses in the mid-south and Texas plains shipped small quantities of cotton by boxcar to Gulf ports and U.S.-Mexico border-crossing locations. In contrast, large quantities of containerized cotton were shipped from selected inland intermodal terminals (e.g., Memphis, Dallas-Ft. Worth) to West Coast ports. Typically, intermodal (containerized) shipments were shipped via multicar arrangements and unit trains while boxcar shipments included two cars or less.

Intermodal Terminal Investment and Costs

Based on a survey of Texas cotton warehouses (Fuller et al. 2007) regarding shipments to various destinations and on regional cotton-production trends, investment levels and costs were estimated for intermodal terminals that shipped 12,000, 14,000, 16,000, or 18,000 containers of cotton per year. Each 40-foot marine container (FEU) holds 88 cotton bales. Information on terminal investment levels and costs were used to estimate a cost-volume model for each terminal size.

Estimated terminal dimensions, terminal investment requirements, and costs were largely based on previous studies. Stewart, Ogard, and Harder (2004) examined intermodal terminal requirements in small and medium-size communities and offered parameters useful in prescribing terminal yard dimensions and associated railroad track. A study by the Michigan Department of Transportation and U.S. Department of Transportation (2008) provided insight on type and number of rail turnouts and costs, as well as information on container parking. Loading space requirements came from the Victoria Transport Policy Institute (2008). Personnel from Wilbur Smith Associates offered information on requirements regarding terminal lighting, lifters, tractors, chassis, and employees based on previous study efforts. Estimated land costs for an intermodal terminal came from the website of the Lubbock Economic Development Alliance (2008), while a study by the Minnesota Department of Agriculture and Wilbur Smith Associates (2008) provided information on investment in truck scales, utilities, lifters, tractors, and chassis. Estimated investment in the 12,000-, 14,000-, 16,000-, and 18,000-container-per-year terminals were \$7.92, \$8.82, \$9.79, and \$10.69 million, respectively (Fuller et al. 2011).

The estimation of depreciation expense, insurance expense, maintenance and repair costs, energy costs, and taxes was partially based on a study by Berwick (2007) of the Upper Great Plains Transportation Institute, who researched intermodal terminals in rural areas and offered insight on computation methods to estimate these costs. Based on the Berwick (2007) study and with selected computational adjustments for location and time period, the annual costs were estimated for the four intermodal terminal sizes. Annual fixed costs for the 12,000-, 14,000-, 16,000-, and 18,000-container-per-year terminals were estimated to be \$2.11, \$2.35, \$2.61, and \$2.85 million, respectively. When the terminals were operating at capacity, the estimated operating costs were \$0.86, \$0.91, \$1.02, and \$1.07 million, respectively. Total cost per handled container ranged from \$248 or \$2.81 per bale for the 12,000-container terminal to \$218 per container or \$2.48 per bale for the 18,000-container terminal (Fuller et al. 2011).

Roadway Pavement Cost

To estimate the effect on total pavement costs of introducing an intermodal terminal into the west Texas cotton marketing system, the loaded truck-miles *ex ante* and *ex post* the new terminal were calculated with the spatial model. Then these data in combination with marginal pavement cost parameters per loaded truck-mile were converted into total pavement cost estimates.

Pavement cost estimation required use of the Federal Highway Administration’s (FHWA) functional roadway classification guidelines (USDOT 2000a) to approximate miles traveled over each functional system and updated marginal pavement cost parameters for each functional roadway classification. Marginal pavement cost for the rural interstate highway (12.7 cents for an 80,000-pound, five-axle truck) was taken from FHWA’s *Federal Highway Cost Allocation Study* (USDOT 1997). Dr. Denver Tolliver of the Upper Great Plains Transportation Institute provided previous estimates of pavement costs for principal and minor arterials and collectors. The collected pavement costs were subsequently updated with FHWA's *Construction Cost Trends for Highways, Table PT-1* (USDOT 2010) and FHWA's *Price Trends for Federal-Aid Highway Construction* (USDOT 2006*)*. After consideration of federal and state fuel taxes (44.4 cents per gallon) and an estimated 5.5-miles-per-gallon fuel efficiency, the uncompensated marginal costs per loaded truck-mile were estimated for an 80,000-pound, five-axle truck operating on interstate ($0.059), principal arterial ($0.259), minor arterial ($0.359), and collector ($0.876) roadways.

CO_2 Emissions

The anticipated reduction in CO_2 emissions that result from introducing a new intermodal terminal in west Texas was estimated by contrasting truck mileages obtained from spatial model solutions *ex ante* and *ex post* the new facility in combination with CO_2 emission per truck-mile. In particular, truck mileages from these solutions in combination with CO_2 emissions per loaded and empty truck-mile were used to estimate total emissions *ex ante* and *ex post* the new terminal.

The Center for Air Quality Studies at the Texas Transportation Institute provided a per-mile CO_2 emission rate for loaded Class 8 trucks operating at average speeds: the emission rate was estimated with MOVES 2010 (EPA 2010). At an assumed average speed of 55 miles per hour, the Class 8 truck has a CO_2 emission rate of 2,003.7 grams per loaded mile. For empty truck mileage, the emission rate was adjusted downward in proportion to reduced fuel consumption. Franzese et al. (2009) analyses indicate the reasonableness of the rule of thumb "that each additional 10,000 pounds of payload decreases fuel economy about 5%." Further, the Federal Railroad Administration's *Comparative Evaluation of Rail and Truck Fuel Efficiency in Competitive Corridors* (USDOT 2009) indicate the reasonableness of this rule of thumb. Based on these data, the CO_2 emission rate per loaded truck-mile was estimated to be 2,003.7 grams, and the rate per empty truck-mile was 1,615.8 grams.

Important quantities of cotton that involve a truck, chassis, and container (source-loaded) are transported from west Texas to Dallas-Fort Worth terminals. Typically, the container is empty when departing the intermodal terminal; therefore, for all CO_2 computations, it was assumed that one-half of the round-trip mileage associated with source-loaded cotton involves empty truck-miles. Further, based on information from a truck broker, it was assumed that all truck-transported cotton moving via van/flatbed into Dallas-Fort Worth involved a backhaul percentage of 50%.

Introduction of an intermodal terminal in west Texas will require the railroad to reposition empty containers from the Dallas-Fort Worth complex to the west Texas terminal. The net effect of this activity is assumed to be neutral regarding railroad's CO_2 emissions. *Ex ante* the west Texas terminal, truck-transported west Texas cotton would be routed to Dallas-Fort Worth and placed in containers for shipment to West Coast ports. This containerized cotton will pass through west Texas on its route to West Coast ports. *Ex post* the west Texas facility, empty containers will be routed by railroad to west Texas and then loaded for shipment to West Coast ports. Thus, the affected mileage that the rail-transported container travels is little altered by introduction of an intermodal terminal. Therefore, it was assumed that railroad CO_2 emissions would not be significantly affected by the introduction of an intermodal terminal in west Texas.

RESULTS

Feasibility of Intermodal Terminal

Initial analyses with the spatial model focused on determining total revenues and associated volumes resulting from alternative per-bale charges by the new or hypothetical intermodal terminal in Lubbock. This process was designed to determine feasibility of various per bale charges that might be levied by the hypothetical terminal and its associated total revenues. After determination of an attractive per-bale charge, a linear total revenue equation was generated for the hypothetical terminal. The total revenue equation in combination with the linear total cost equation (fixed and variable costs) for each of the four intermodal terminal sizes was used to determine the break-even output and profitability for each terminal size. No constraints relating to terminal size were placed into the spatial model when identifying attractive per-bale charges that might be levied by the new facility. Further, there was no need to segregate the effect of the current intermodal operator since trade sources indicated the current facility would close with the opening of the hypothetical facility.

The least-cost spatial model projected that 3.57 million bales would be assembled to the hypothetical intermodal terminal if $1 per bale were charged above all costs and when the charge was increased to $2, $3, $4, and $5 per bale the associated terminal volume declined to 3.08, 2.58, 2.02, and 0.538 million bales, respectively. These analyses show a $4 per-bale charge ($352 per container) would generate the greatest intermodal terminal revenue ($4 per bale × 2.02 million bales = $8.08 million).

The developed linear cost-volume model for the 12,000-, 14,000-, 16,000-, and 18,000-container terminals in combination with the $4 per-bale revenue was used to identify terminal profitability and break-even volumes. The estimated break-even volume for the 12,000-, 14,000-, 16,000-, and 18,000-container terminals was 7,539, 8,211, 9,061, and 9,758 containers per year, respectively (Table 2). All containers are assumed to be 40-foot marine containers (FEU), which hold 88 bales. When the terminal operates at capacity, the expected annual returns above specified costs for the four analyzed terminals (12,000-, 14,000-, 16,000-, and 18,000-container terminals) are an estimated $1.25, $1.66, $2.00, and $2.41 million, respectively, and the estimated rates of return on investment were 15.8%, 18.8%, 20.4%, and 22.5% (Table 2). Rates of return were estimated by dividing returns above specified costs (Table 2) for each size of container terminal by its associated investment and multiplying the resulting value by 100. Rate of return calculations were as follows for each respective intermodal terminal ($ values in millions): $1.25/$7.92 = 15.8%; $1.66/$8.82 = 18.8%; $2.00/$9.79 = 20.4%; $2.41/$10.70 = 22.5%.

Table 2: Estimated Annual Revenues and Costs for 12,000-, 14,000-, 16,000-, and 18,000-Containers-per-Year Intermodal Terminal Operating in Lubbock, Texas

	Containers per Year (FEU) 12,000	Container per Year (FEU) 14,000	Container per Year (FEU) 16,000	Containers per Year (FEU) 18,000
Fixed Cost ($)	2,113,466	2,354,044	2,613,110	2,853,593
Management, Employee, and Other Expenses ($)	860,080	914,001	1,017,978	1,072,030
Total Cost ($)	2,973,546	3,268,045	3,631,088	3,925,623
Total Revenue ($)	4,224,000	4,928,000	5,632,000	6,336,000
Break-Even Volume (Containers)	7,539	8,211	9,061	9,758
Returns above Specified Costs ($)	1,250,454	1,659,955	2,000,912	2,410,377
Rates of Return on Investment (%)	15.8	18.8	20.4	22.5

Sensitivity of Intermodal Terminal's Feasibility to Selected Exogenous Forces

Low and high regional cotton-production levels were included in the spatial model to evaluate the effect on the feasibility of the hypothetical intermodal terminal. The analysis shows that at the high production levels of 2005 and 2007 (7.0 million bales), the Lubbock terminal would attract 2.66 million bales, whereas at the low production level of 2.54 million bales (2000 production), approximately 1.7 million bales would transit the Lubbock terminal. These analyses indicate the largest of the examined intermodal terminals (18,000 containers per year or 1.58 million bales) would have ample cotton supplies to operate at full capacity in all years during 2000–2009.

Additional analysis was carried out to determine if operation of an existing intermodal terminal in Amarillo, Texas, as a cotton shipping center would unfavorably affect the economic feasibility of the hypothetical Lubbock terminal. Amarillo is approximately 120 miles north of Lubbock and is at an extended distance from the intensive cotton-production area surrounding Lubbock. Further, in contrast to Lubbock, Amarillo has modest cotton warehouse capacity and associated cotton marketing infrastructure. Regardless, USDA's Farm Service Agency showed one large cotton warehouse to operate in Amarillo (USDA 2009b). Further, Amarillo is located on the Burlington Northern (BNSF) railroad line that connects the Chicago area to southern California, a route that transports empty containers from the Midwest to California; therefore, a possible opportunity to efficiently route empty containers into the Amarillo terminal.

The spatial model featuring the hypothetical intermodal terminal in Lubbock was modified to allow assembly of cotton to Amarillo from area gins and warehouses and its shipment to West Coast ports. The modified model reflected flatbed/van costs of trucking into an Amarillo transloading warehouse and associated drayage charges to the Amarillo intermodal terminal as well as a source-loaded assembly system involving truck, container, and chassis. Further, the modified model included a charge by the Amarillo terminal for container handling and lifts, and an estimated railroad rate to West Coast ports.

Analysis showed operation of the Amarillo intermodal facility as a cotton shipping site has negative implications for investment in the hypothetical Lubbock terminal. If the source-loaded assembly system (truck, container, and chassis) operating around Lubbock and Amarillo was limited to a distance of 50 miles and the flatbed/van system was without distance restrictions, the Lubbock intermodal terminal volume would decline modestly to 1.9 million bales from 2.02 million bales ($4 per-bale charge), with an estimated quantity through Amarillo of 0.147 million bales. However, if Amarillo and Lubbock had a source-loaded assembly system operating at a distance of 100 miles, Lubbock's hypothetical intermodal terminal would experience a precipitous loss in volume, handling an estimated 0.76 million bales, while the Amarillo terminal would increase to 1.69 million bales. Therefore, the investment required to construct and operate the hypothetical facility in Lubbock places it at a competitive disadvantage to the existing intermodal terminal in Amarillo.

Many agricultural crop producers, including cotton producers, participate in federal commodity programs. Removal of these commodity programs could influence west Texas cotton production and the feasibility of the hypothetical intermodal terminal in Lubbock. An investigation of this concern showed that flexibility provisions of recent farm legislation and high cotton prices since 2008 have reduced the influence of selected federal subsidies. However, federally subsidized crop insurance has in recent years been a major determinant of cotton plantings in the study area. If this program were curtailed, riskier dry land cotton production may exit the production region and unfavorably affect the feasibility of the intermodal terminal.

Effect of Intermodal Terminal on Annual Roadway Pavement Costs

By contrasting spatial model solutions representing the current cotton marketing system and a marketing system featuring the hypothetical terminal, it was possible to estimate how truck routes and loaded truck-miles would be affected by the new facility. Unfortunately, measurement of truck routes and loaded truck-miles associated with the current cotton transportation system was complicated by the small intermodal operator in Lubbock who ships an unknown number of bales per year to the West Coast. Trade sources indicate the private intermodal operation annually ships from 500,000 to 750,000 cotton bales from Lubbock to West Coast ports. Therefore, the current cotton marketing system was represented by two spatial model solutions where one solution featured a Lubbock volume constraint of 500,000 bales and the other a 750,000 bale constraint. This approach yields a range of truck-miles associated with the current marketing system and, therefore, a range of saving associated with the hypothetical terminal.

The two spatial model solutions representing the current cotton marketing system were perused to obtain all origin-destination combinations for truck haulage between involved cotton warehouses and terminals. Next, a routing code was used to record the routes between these facilities from which mileages traveled via interstate, principal arterial, minor arterial, and collector roadways were measured. Although the portion of miles traveled via each functional roadway classification varied, principal arterials and interstates were the primary roadway carriers (85%) while minor arterials (12%) and collectors (3%) had a lesser role. Finally, the total recorded mileages via each functional roadway classification was multiplied by estimated uncompensated marginal costs per loaded truck-mile for interstate ($0.059), principal arterial ($0.259), minor arterial ($0.359), and collector ($0.876) roadways to arrive at a range of total annual pavement cost estimates. Similarly, the spatial model solution featuring introduction of the hypothetical intermodal terminal in Lubbock was analyzed and estimated parameters representing various functional roadway classifications used to estimate an annual pavement cost.

When the current private operator in Lubbock is assumed to handle 500,000 bales, the analysis shows 9.80 million loaded truck-miles would be expended in assembling west Texas cotton to the existing cotton marketing facilities in Lubbock and Dallas-Fort Worth, and when the existing Lubbock operation handles 750,000 bales, total loaded truck-miles decline to 9.02 million. As expected, total loaded truck-miles decline when the current Lubbock operator handles greater volumes since less west Texas cotton is routed to the distant Dallas-Ft. Worth intermodal terminals. The corresponding uncompensated annual pavement cost associated with shipment of 500,000 bales via Lubbock is an estimated $2.26 million, and with 750,000 bales, an estimated $2.08 million.

The cotton marketing system featuring the hypothetical intermodal terminal in Lubbock and existing intermodal terminals in Dallas-Fort Worth is estimated to annually expend 5.27 million loaded truck-miles and incur annual uncompensated pavement costs of $1.11 million. Based on these values, introduction of the hypothetical intermodal terminal in Lubbock is estimated to reduce uncompensated pavement cost between $0.97 million ($2.08 − $1.11 = $0.97) and $1.15 million per year ($2.26 − $1.11 = $1.15).

Effect of Intermodal Terminal on CO_2 Emissions

To calculate the anticipated reduction in CO_2 emissions associated with introduction of the hypothetical intermodal terminal in Lubbock, an approach similar to that used in estimation of roadway pavement costs was followed. The CO_2 emissions associated with the current private intermodal terminal operation in Lubbock when handling 500,000 bales and then 750,000 bales were estimated with the spatial model. Then, the resulting range of CO_2 emission values were contrasted with the CO_2 emission estimate associated with introduction of the hypothetical intermodal terminal in Lubbock.

The developed spatial model records the selected truck assembly system for each origin-destination combination and *ex post* the spatial model solution aggregates the mileage for each assembly system on selected corridors. The resulting mileage values for each truck assembly system in combination with estimates regarding backhaul and empty-mile ratios on evaluated corridors were used in combination with estimates of CO_2 emissions per loaded (2,003.7 grams) and empty mile (1615.8 grams) to convert mileages into CO_2 emissions.

Total annual CO_2 emissions attributable to truck assembly were estimated to be 38,667 short tons when marketing west Texas cotton if the private terminal operator in Lubbock handles 500,000 bales and truck-assembled cotton to Dallas-Fort Worth terminals is included in the CO_2 computation. Total annual CO_2 emissions attributable to truck assembly are estimated to be 35,566 short tons when the current Lubbock operator expands volume to 750,000 bales. As expected, estimated CO_2 emissions decline when the current Lubbock operator handles greater volumes since less west Texas cotton is required to travel extended distances into Dallas-Ft. Worth intermodal terminals.

If the intermodal terminal in Lubbock were implemented (two million bales), total CO_2 emissions would decline to 20,588 short tons; this yields reductions in CO_2 emissions that range from 14,978 (35,566 − 20,588 = 14,978 short tons) to 18,079 (38,667 − 20,588 = 18,079 short tons) short tons per year. Based on the Tol (2005) estimate regarding the marginal cost of CO_2 ($39 per short ton), the estimated annual value of reduced CO_2 emissions range between $0.584 million (14,978 short tons x $39= $584,142) and $0.705 million (18,079 short tons x $39 = $705,081) per year.

CONCLUSIONS

This study examines the economic feasibility of investment in an intermodal terminal in west Texas to accommodate cotton exports and explores its implications for reducing roadway maintenance costs and CO_2 emissions. Cotton is a leading agricultural commodity in Texas, which is highly dependent on the international market and truck transport from west Texas to the Dallas-Fort Worth metroplex for purposes of accessing containerized railroad transportation to West Coast ports. Much of the analysis was accomplished with a spatial model representing the U.S. cotton industry. The least-cost model features cotton handling, storage, and five transportation systems that link cotton gins to warehouses and ultimately to intermodal terminals, domestic textile mills, U.S. port areas, and border-crossing sites.

The analyses show an intermodal terminal in west Texas' intensive cotton-production region (Lubbock) to be economically viable. It is estimated that the facility could attract about two million bales, or nearly 30% of Texas' average cotton production. The largest intermodal terminal examined in this study (18,000 container shipments per year or 1.58 million bales) would require an investment of $10.69 million and would be expected to earn a rate of return on investment exceeding 20%. Additional analyses show the 18,000 container-per-year terminal would attract profitable volumes during the region's lowest cotton-production years, but would be vulnerable if an existing intermodal terminal at a nearby location (Amarillo) were to commence cotton shipments to West Coast ports.

Implementation of an intermodal terminal in west Texas that handles approximately two million cotton bales is estimated to reduce truck (80,000-pound, five-axle) travel on state roadways by an estimated 3.75 to 4.53 million loaded truck-miles and to lower annual pavement expenditures by approximately $1 million. The reduced truck-miles expended to assemble Texas cotton to intermodal facilities are estimated to reduce CO_2 emissions by 42% (14,978 short tons) to 47% (18,079 tons) relative to the current marketing system. The estimated value of the reduced CO_2 emissions range between $0.584 and $0.705 million per year.

In summary, the analysis indicates investment in intermodal terminals in rural areas may offer opportunities to improve commodity marketing efficiency, and reduce roadway maintenance costs and vehicle emissions.

References

Andrieu, N. and L. Weiss. *Transport Mode and Network Architecture: Carbon Footprint as a New Decision Metric.* Master's thesis. Massachusetts Institute of Technology, 2008. Accessed September 12, 2010. http://dspace.mit.edu/handle/1721.1/45250.

Babcock, M. W., J. L. Bunch, J. Sanderson, and J. Witt. *Economic Impacts of Railroad Abandonment on Rural Kansas Communities.* Kansas Department of Transportation, Report No. KS-03-4, 2003a, Topeka, Kansas.

Babcock, M.W., J. L. Bunch, J. Sanderson, and J. Witt. "Impact of Short Line Railroad Abandonment on Highway Damage Costs: A Kansas Case Study." *Journal of the Transportation Research Forum* 57 (4),(2003b): 105–121.

Berwick, M. *Feasibility of a Logistics Center Including Container/Trailer Intermodal Transportation in Fargo/Moorhead.* Report DP193, Upper Great Plains Transportation Institute, North Dakota State University, Fargo, North Dakota, September 2007. Accessed June 18, 2010. http://www.ugpti.org/pubs/pdf/DP193.pdf.

Bitzan, J. and D. Tolliver. *North Dakota Strategic Freight Analysis. Item IV. Heavier Loading Rail Cars.* MPC Report 01-127.4, Mountain-Plains Consortium: A program of Upper Great Plains Transportation Institute, North Dakota State University, Fargo, North Dakota, 2001.

Cotton Board. *Gin Code List*, 2009. Accessed May 18, 2010. http://www.cottonboard.org/CB_Home.aspx?SectionID=4&ContentURL=CBBuyer1\gincodelist.htm&TabID=2&ContentType=2&ContentURLID=29.

Environmental Protection Agency (EPA). *MOVES Motor Vehicle Emissions Simulator*. Office of Transportation and Air Quality, 2010. Accessed August 12, 2010. http://www.epa.gov/otaq/models/moves/index.htm.

Fellin, L., S. Fuller, J. Kruse, S. Meyers, and A. Womack. "The Upper Mississippi and Illinois Rivers as Grain Transport Arteries: A Spatial Equilibrium Analysis." *Journal of the Transportation Research Forum* 47 (2), (2008):73–88.

Franzese, O., H. E. Knee, and L. Slezak. *Effect of Tires on Class-8 Heavy Truck Fuel Efficiency,* 2009. Accessed March 23, 2010. http://info.ornl.gov/sites/publications/files/ Pub20686.pdf.

Fuller, S., J. Robinson, F. Fraire, and S. Vadali. *Improving Intermodal Connectivity in Rural Areas to Enhance Transportation Efficiency: A Case Study.* University Transportation Center for Mobility, Texas Transportation Institute, The Texas A&M University System, May 2011. Accessed June 3, 2011. http://utcm.tamu.edu/publications /final_reports/Fuller_07-07.pdf

Fuller, S., J. Park, and J.R.C. Robinson. "Cotton Transportation and Logistics: A Dynamic System." Transportation Research Forum, *48th Proceedings of the Transportation Research Forum*, Boston, Massachusetts, March 2007. Accessed March 20, 2008. http://www.trforum.org/forum/viewabstract.php?id=233

Intercontinental Exchange (ICE). *Cotton Certified Stock Report,* 2009. Accessed May 8, 2010. https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=4 &productId=588&hubId=732.

Lubbock Economic Development Alliance. *Property Values,* 2008. Accessed March 15, 2010. http://www.lubbockeda.org/.

Manta. *Broadwoven Fabric Mills, Companies in the U.S.,* 2009a. Accessed May 16, 2010. http://www.manta.com/mb_34_E90D3_000/broadwoven_fabric_mills_cotton.

Manta. *Cotton Spinning Mills in the U.S.*, 2009b. Accessed May 16, 2010. http://www.manta.com/mb_34_E9119_000/yarn_spinning_mills.

McKinnon, A. *CO_2 Emissions from Freight Transport in the UK*. Report prepared for the Climate Change Working Group of the Commission for Integrated Transport, Logistics Research Center, Heriot-Watt University, Edinburgh, Scotland, 2007. Accessed July 21, 2010. http://resilientcities.gaiaspace.org/mushin/files/-1/7/2007climatechange-freight.pdf.

Michigan Department of Transportation and the U.S. Department of Transportation. *Detroit Intermodal Freight Terminal: Wayne and Oakland Counties, Cost Estimates*, August 2008.

Minnesota Department of Agriculture and Wilbur Smith Associates. *Assessing Feasibility of Intermodal Transport of Agricultural and Related Products on Short Line and Regional Railroads.* Minnesota Department of Agriculture, 2008. Accessed June 8, 2010. http://www.mda.state.mn.us/news/publications/food/business&marketing/ intermodaltrans.pdf.

Stewart, R., L. Ogard, and F. Harder. "Intermodal Terminal Requirements for Small to Medium Size Communities: A Case Study." Transportation Research Board, 83rd Annual Meeting, Washington, D.C., January 2004.

Surface Transportation Board (STB). *Public Use Waybill*, 2009. Accessed May 24, 2010. http://www.stb.dot.gov/stb/industry/econ_waybill.html.

Texas Cotton Association. *Texas Warehouse Tariffs,* 2009.Accessed April 22, 2010. http://www.storesonline.com/site/417921/page/428041.

Tol, R.S. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of Uncertainties." *Energy Policy* 33 (16), (2005): 2064–2074.

Tolliver, D. and HDR Engineering, Inc. *Benefits of Rail Freight Transportation in Washington: A Multimodal Analysis*. Appendix D. Washington State Department of Transportation, Olympia, Washington, 2000.

U.S. Census Bureau. *Current Industrial Reports. M313P-Consumption on Cotton System and Stocks, Table 2. Consumption and Stocks, End of Period, Held by Consuming Establishments of Cotton, Manmade Fiber Staple, and Linters,* 2009a. Accessed May 14, 2010. http://www.census.gov/manufacturing/cir/historical_data/m313p/index.html.

U.S. Census Bureau. *Current Industrial Reports. M313P-Consumption on Cotton System and Stocks, Table 2A. Stocks, End of Period, of Cotton Held in Public Storage and at Compresses,* 2009b. Accessed May 14, 2010. http://www.census.gov/manufacturing/ cir/historical_data/m313p/index.html.

U.S. Department of Agriculture (USDA). *Cotton and Wool Yearbook 2009*. Economic Research Service, 2009a. Accessed May 10, 2010. http://usda.mannlib.cornell.edu/ MannUsda/viewStaticPage.do?url=http://usda.mannlib.cornell.edu/usda/ers/89004/./2009/index.html

U.S. Department of Agriculture (USDA). *Cotton On-line Processing System*. Farm Service Agency, 2009b. Accessed June 12, 2010. https://dlnt01.fsa.usda.gov/logon.jsp.

U.S. Department of Agriculture (USDA). *Cotton Estimates*. Office of the Chief Economist, World Agricultural Demand and Supply Estimates, 2010. Accessed February 12, 2011. http://usda.gov/oce/commodity/wasde

U.S. Department of Agriculture (USDA). *USDA-AMS Cotton Program, National Database*. Agricultural Marketing Service, 2009c. Accessed May 22, 2010. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELDEV3018864.

U.S. Department of Agriculture (USDA). *Quick Stats 1.0*. National Agricultural Statistical Service, 2009d. Accessed May 23, 2010. http://www.nass.usda.gov/.

U.S. Department of Energy (USDOE). *Monthly On-Highway Retail Diesel Prices.* U.S. Energy Information Administration, 2009. Accessed May 18, 2010. http://tonto.eia.doe.gov/oog/info/wohdp/diesel.asp.

U.S. Department of Transportation (USDOT). *Federal Highway Cost Allocation Study: Summary Report.* Federal Highway Administration, 1997. Accessed May 22, 2010. http://www.fhwa.dot.gov/policy/hcas/summary/index.htm.

U.S. Department of Transportation (USDOT). *FHWA Functional Classification Guidelines.* Federal Highway Administration, 2000a. Accessed August 10, 2010. http://www.fhwa.dot.gov/planning/fctoc.htm.

U.S. Department of Transportation (USDOT). *Price Trends for Federal-Aid Highway Construction.* Federal Highway Administration, 2006. Accessed February 23, 2011. http://www.fhwa.dot.gov/programadmin/pt2006q1.cfm.

U.S. Department of Transportation (USDOT). Federal Highway Administration, *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors***,** 2009. Accessed February 3, 2011. http://www.fra.dot.gov/Downloads /Comparative_ Evaluation_Rail_Truck_Fuel_Efficiency.pdf.

U.S. Department of Transportation (USDOT). Federal Highway Administration, *Construction Cost Trends for Highways, Table PT-1,* 2010. Accessed August 10, 2010. http://www.fhwa.dot.gov/ohim/nhcci/pt1.cfm.

Upper Great Plains Transportation Institute. *Feasibility of a Logistics Center Including Container/Trailer Intermodal Transportation in the Fargo/Moorhead Area.* North Dakota State University, September 2007.

Vachal, K. and M. Berwick. *Exporting Local Grains via Container from an Illinois River Agricultural Hub,* 2008. Accessed June 14, 2010. http://www.ilsoy.org/_data/media Center/files/608.pdf.

Victoria Transport Policy Institute. *Parking and Loading Space Minimum Requirements, Table 5.1-6(f*), 2008. Accessed April 13, 2010. http://www.cityofvernon.org/assets/docs /ParkRegs.pdf.

Warner, J. and M. S. Terra. "Assessment of Texas Short Line Railroads." Transportation Research Board, 85th Annual Meeting, Washington, D.C., 2006. Accessed March 12, 2010. http://ctr.ra.utk.edu/LRRFT/cmte_activities/papers/ TRBAM%2006-Warner Terra.pdf.

Washington State Department of Transportation. *East Washington Grain-Hauling Short-Line Rails.* Study performed by HDR Engineering, Inc., and Denver Tolliver, February 2003. Accessed March 24, 2009. http://www.palouse.org/rtpo/PRTPappendix Cgrainhaultin_rpt.pdf.

Wilson, W., B. L. Dahl, R. Taylor, and W. Koo. *Grain Shipments on the Mississippi River System: A Long-Term Projection*. Center for Agricultural Policy and Trade Studies, Department of Agricultural Economics, North Dakota State University, July 2007. Accessed May 22, 2009. http://ageconsearch.umn.edu/bitstream/9080/1/aer605.pdf.

WISERtrade. *Foreign Trade Data*, 2009. Accessed March 18, 2010. http://www.wisertrade.org/home/index.jsp.

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