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Improving Intermodal Connectivity in Rural Areas to Enhance Transportation Efficiency: A Case Study

Final Report

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16. Abstract

Congested roadways in Texas' metropolitan centers are important arteries for transporting agricultural commodities into domestic and international markets. Truck transportation of these commodities contributes to the observed congestion and delay in these urban centers. As an example, cotton, which is a major field crop in Texas, is transported via Dallas-Ft. Worth and Houston roadways to access container transport to the international market, the principal outlet for this commodity. This study examines the feasibility of investment in intermodal terminals in rural Texas with the implications for reducing roadway maintenance costs, greenhouse gases and truck transportation in Texas' metropolitan areas. The analyses show an intermodal terminal in west Texas' intensive cotton production region (Lubbock, Texas) would be economically viable, reducing loaded truck-miles on state roadways, $C0_2$ emissions, and truck-travel in the Dallas-Ft. Worth metropolitan center.

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IMPROVING INTERMODAL CONNECTIVITY IN RURAL AREAS TO ENHANCE TRANSPORTATION EFFICIENCY: A CASE STUDY

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DISCLAIMER

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EXECUTIVE SUMMARY

Texas, a state whose economy is closely tied to the agricultural, manufacturing, and mining (petroleum) sectors, experiences high levels of congestion in several of its leading economic centers. Dallas-Fort Worth and Houston-Baytown rank as the fifth and sixth most congested areas in the United States, respectively, with roadway travel times increasing 13 percent during peak congestion periods. Unfortunately, the congested roadways in Dallas-Fort Worth and Houston are important arteries for transporting agricultural products and commodities into domestic and international markets. For example, cotton, which is a major field crop in Texas, is transported over the roadways of these urban centers for purposes of accessing container transport to the international market, the principal outlet for this commodity.

This study examines the economic feasibility of investment in an intermodal terminal in west Texas and its implications for reducing roadway maintenance costs, CO_2 emissions, and truck transport in Texas' metropolitan areas. The study focuses on cotton, a leading agricultural commodity in Texas, which is highly dependent on the international market and truck transport into the Dallas-Fort Worth complex for purposes of accessing containerized railroad transportation to West Coast ports. 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. Because the transportation of cotton into the Dallas-Fort Worth railroad hubs is at distances of up to 335 miles, truck-miles, roadway maintenance, and CO_2 emissions may be significantly decreased with the introduction of a rural intermodal terminal.

Many of the analyses were accomplished with a spatial model of the U.S. cotton industry. The developed model features details regarding cotton handling, storage, and transportation activities. The cost-minimizing, transshipment model includes gins, warehouses, domestic textile mill regions, inland intermodal terminals, and U.S. ports and border-crossing locations. The transshipment model features 811 gins, 415 warehouses, 13 port areas, four border-crossing locations, four inland intermodal terminals that are central to the cotton trade, 37 transloading warehouses at inland intermodal terminal locations, and 11 domestic textile mill demand regions; the model represents a cotton crop year (four quarters). Domestic demands are based on historical mill consumption in southeast U.S. regions, and foreign demands are fixed at historical cotton export levels at U.S. ports and border-crossing locations.

The cotton transportation and logistics network featured in the national spatial model links the cotton-gin plants to cotton warehouses, and links warehouses to domestic mill demand regions, inland intermodal terminals, ports, border-crossing locations, and other warehouses (transloading warehouses) by quarterly transport rates. Further, the inland intermodal terminals are connected to selected ports in the national model. Truck transportation is central to movement of U.S. baled cotton. Cotton-gin plants ship entirely by truck to warehouses, and warehouses ship large quantities by truck to domestic mill demand regions, ports, transloading warehouses, border-crossing locations, and inland intermodal terminals. Railroads transport large quantities of cotton in containers from selected inland intermodal terminal locations to port areas, and selected warehouses ship via boxcars to ports, domestic mill sites, and border-crossing locations.

The analyses show an intermodal terminal in west Texas' intensive cotton-production region (Lubbock, Texas) to be economically viable. The facility could attract up to 2 million bales or nearly 30 percent of Texas' average cotton production. For example, an intermodal terminal capable of handling 18,000 containers per year (1.58 million bales) would require an investment of $10.69 million and could be expected to earn a rate of return on investment exceeding 20 percent. 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, Texas) were to commence cotton shipments to West Coast ports.

Implementation of an intermodal terminal in west Texas that handles approximately 2 million cotton bales is estimated to annually reduce truck (80,000-pound, five-axle) travel on state roadways by 3.75 to 4.53 million loaded truck-miles and lower pavement maintenance expenditure by approximately $1 million. This positive externality suggests an opportunity for public- and private-sector cooperation. Further, the reduced truck-miles expended to assemble Texas cotton to intermodal facilities are estimated to reduce CO_2 emissions by 42 to 47 percent (14,978 to 18,079 tons) relative to the current transportation system. The estimated value of reduced CO_2 emissions ranges up to $0.705 million per year. Finally, estimated traffic into the Dallas-Fort Worth metroplex would be reduced by 13,800 to 16,700 trucks per year with introduction of the west Texas intermodal terminal.

In summary, the analyses suggest that investments in intermodal terminals in rural areas may offer opportunities to improve marketing system efficiency, and reduce roadway maintenance costs and vehicle emissions.

PROBLEM

Agriculture, manufacturing, mining, and related sectors in the United States are highly dependent on an efficient freight transport system, connecting businesses to domestic and world markets. Globalization mandates the availability of reliable and efficient freight transportation to enhance international competitiveness and economic growth in the domestic economy. As the economy has grown and freight volume increased, the capacity of existing infrastructure has become strained, which has diminished the reliability and efficiency of U.S. freight transportation.

Texas experiences high levels of congestion in several of its leading economic centers. INRIX (2009) reports Dallas-Fort Worth and Houston-Baytown rank as the fifth and sixth most congested areas in the United States, respectively, with roadway travel times increasing 13 percent during peak congestion periods. Similarly, the Texas Department of Transportation (2008) reports that eight of the state's 10 most congested roadway segments are in these economic centers, with the annual cost of delay per roadway segment ranging from $50 million to $88 million. Unfortunately, the congested roadways in Dallas-Fort Worth and Houston are important arteries for transporting agricultural products and commodities into domestic and international markets. For example, cotton, which is a major field crop in Texas and whose principal outlet is the international market, is transported over the roadways of these urban centers for purposes of accessing container transportation.

The Transportation Research Board (TRB) (2007), in its recent publication titled *Rail Freight Solutions to Roadway Congestion—Final Report and Guidebook,* notes the potential to reduce congestion on roadways by transferring traffic to railroads, and importantly notes the associated decrease in deterioration of existing roadways, decrease in pollution that results from this transfer of traffic, and improvement in roadway safety. In addition, the TRB report notes the potential for private-public cooperation, which could include cost sharing of construction and the operation of future intermodal terminals.

This study examines the feasibility of investment in an intermodal terminal in west Texas and its implications for reducing roadway maintenance costs, CO_2 emissions, and truck traffic in Texas' metropolitan areas. The study focuses on cotton, a leading agricultural commodity in Texas, which is highly dependent on the international market and on truck transport into 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. Because the assembly of cotton into the Dallas-Fort Worth railroad hubs is at distances of up to 335 miles, truck-miles, roadway maintenance, and CO_2 emissions may be significantly decreased by the introduction of a rural intermodal terminal.

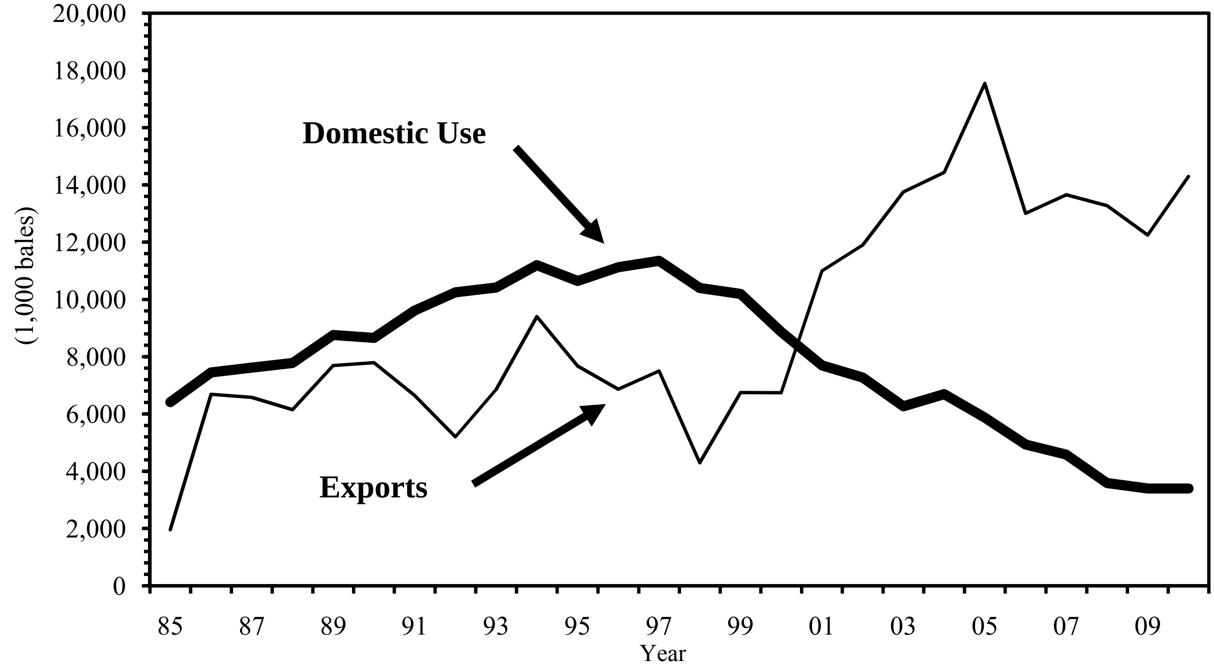
The objectives of this study are to (1) determine the economic feasibility of an intermodal terminal in the intensive cotton-production region of west Texas and evaluate the sensitivity of the intermodal terminal's feasibility to selected exogenous forces, (2) estimate truck traffic diversion from the Dallas-Fort Worth metropolitan area and the reduced roadway maintenance expenditure resulting from this terminal, (3) estimate reduction in CO_2 emissions associated with the intermodal terminal and the value of the reduced emissions, and (4) evaluate the opportunity for private-public cooperation regarding intermodal terminals in rural Texas.

This study measures several of many effects that would likely result from the development of an intermodal terminal in west Texas, attempting to measure reduced pavement costs resulting from diversion of traffic from the comparatively lengthy trips connecting west Texas cotton warehouses to Dallas-Fort Worth intermodal terminals and the associated reduction in CO_2 emissions. The study does not measure any possible benefits from the west Texas terminal that relate to reduced traffic congestion, crashes, and noise or possible gains to other businesses that are using these roadways. It is assumed that the diversion of cotton truck traffic, while substantial regarding cotton transportation and logistics, is not large as compared to total traffic on the highway network linking west Texas into the Dallas-Fort Worth metropolitan area.

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, and U.S. port areas. The developed spatial model features considerable detail regarding cotton transportation and logistics. Domestic cotton demand is represented in regions that feature textile mills, and foreign demand is represented at U.S. cotton ports.

APPROACH AND METHODOLOGY

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 percent of annual cotton disappearance (Figure 1). 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, and southeast ports, and the Mexican border. Survey data 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 percent of U.S. cotton is exported via West Coast ports, with Gulf of Mexico and East Coast ports handling about 17 and 16 percent, respectively, and border-crossing locations accommodating about 19 percent of exports (WISERtrade 2009). All cotton exported from U.S. ports moves 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, many of the intense cotton-producing regions in Texas and the United States are geographically remote and cannot efficiently access the westward flow of empty containers to West Coast ports.



Source: USDA, Office of the Chief Economist, 2010

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

Review of Literature

A review of literature indicated modest effort to construct spatial models of the U.S. cotton industry that incorporated transportation and logistics details; however, some research has focused on the spatial dimension of the cotton-ginning industry giving consideration to optimal number, size, and location of these facilities (Fuller et al. 1976). Although the spatial dimension has not been the focus of cotton marketing research, similar agricultural commodities have been successfully modeled in a spatial equilibrium framework. For example, spatial equilibrium models (quadratic programming) of the international grain economy have recently been employed by Fellin et al. (2008) to evaluate a catastrophic event on the U.S. inland waterways, and Wilson et al. (2005) have developed for the U.S. Army Corps of Engineers a cost-minimizing spatial model of the world grain economy for purposes of estimating long-run grain movements on the Mississippi River.

The Upper Great Plains Transportation Institute (2007) examined the feasibility of a logistics center featuring container/trailer intermodal transportation in rural Minnesota and North Dakota. The study surveyed shippers/receivers in the area to gain information on potential users of the facility, carried out an economic-engineering study to gain insight on fixed and variable costs per lift under varying volume levels, and examined potential funding sources for investment in the intermodal facility. In addition, Vachal and Berwick (2008) examined the feasibility of using a container-on-barge facility to export Illinois grain to Asia and bypass congested roadways in the Chicago area. The low-cost option involved shipping containers of grain to Gulf ports via the Mississippi River. More recently, 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 analyses show containerized grain movement by short-line railroads to be economically feasible under limited conditions.

The Washington State Department of Transportation (2003) in a study titled *East Washington Grain-Hauling Short-Line Rail* examined the implications for pavement deterioration and road maintenance costs resulting from abandonment of the Palouse River and Coulee City Railroad in eastern Washington State. It was estimated that 645 miles of roadway would be affected by the rail abandonment. The additional expenditure on road maintenance resulting from abandonment was estimated to be near $39 million. Related studies by Babcock et al. (2003a, 2003b) estimated road damage costs resulting from the proposed abandonment of short-line railroads serving Kansas. As part of the research effort, a four-step pavement-damage model by Tolliver and HDR Engineering, Inc., (2000) was employed to calculate additional damage costs for county and state roadways, and a time-decay model with an equivalent single-axle model was employed to evaluate the pavement service life. The study found short-line railroads in the Kansas study region annually saved $57.8 million in roadway damage costs.

Warner and Terra (2006) estimated the reduction in pavement damage to Texas roadways that results from the operation of the state's short-line railroads. To accomplish study objectives, it was necessary to estimate additional pavement damage associated with increased truck traffic resulting from short-line abandonment. The estimated pavement damage was calculated 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.

Because of the diversity of opinion among states, carriers, shippers, and interest groups regarding appropriate truck size and weight regulations, the U.S. Department of Transportation (USDOT) carried out a study to address a variety of related issues; the resulting document was titled *The Comprehensive Truck Size and Weight Study* (USDOT 2000b). The study estimates expected vehicle-miles traveled under alternative truck size and weight regulations and estimates the effect on a variety of costs including pavement, bridge, congestion, energy, and shipper costs. Chapter 6 of the *The Comprehensive Truck Size and Weight Study* (USDOT 2000c) report offers details on the effect of truck weight, axle configuration, tire characteristics, and related factors on pavement cost.

Andrieu and Weiss (2008) examined the tradeoff between carbon footprint, transport costs, time, and risk in alternate supply chains. The study reviews methods and tools available for the measurement of CO_2 for major transport modes under alternative operating conditions. They note the difference in CO_2 emission estimates per tonne-kilometer proposed by often-used methods, giving particular attention to *The Greenhouse Gas Protocol Initiative* (World Resource Institute [WRI] and World Business Council for Sustainable Development [WBCSD] 2003) and the Environmental Protection Agency (EPA) SmartWay Transport tools (2006). In addition, Andrieu and Weiss (2008), following the approach by McKinnon (2007), adjusts the calculated emission parameters to reflect the truck's capacity utilization (backhaul frequency). EPA's Office of Transportation and Air Quality (EPA 2010) recently developed a modeling system to estimate emissions for mobile sources that covers a broad range of pollutants. The developed model, the Motor Vehicle Emissions Simulator (MOVES), estimates emissions from cars, trucks, and motorcycles. It shows that the average atmospheric emission rates for Class 8 trucks (heavy-duty trucks) averages about 2,000 grams of CO_2 per mile at average speeds of 50 to 60 miles per hour. The analysis also shows that emissions are affected by truck capacity utilization (backhaul frequency) through its impact on fuel use.

Franzese et al. (2009) estimate the effect of load size (frequency of empty haul) and truck-tire configuration on fuel efficiency of Class 8 trucks. Their analyses suggest the reasonableness of the rule of thumb "each additional 10,000 pounds of payload decreases fuel economy about 5 percent." The Federal Railroad Administration (USDOT 2009) provides a comparative evaluation of rail and truck fuel efficiency on corridors where both compete. The study compares fuel efficiency for 23 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. Additional insight on truck fuel efficiency was offered by TRB's recent publication (TRB 2010), *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.*

The Transportation Research Board (2009) report titled *Public and Private Sector Interdependence in Freight Transportation Markets* examines the relationship between public- and private-sector stakeholders in the freight transportation industry and sheds light on the perspective of each with the intent to improve communications and freight policy planning. The report notes that the criteria to evaluate investment decisions by the private and public sector are often different, and these differences are often unrecognized by the other sector. Examples where the public and private sectors have successfully cooperated are offered, such as the Alameda Corridor project, the Northeast Ohio Intermodal Terminal initiative, and others.

Spatial Cotton Model

The spatial model developed for this study features details regarding cotton handling, storage, and transportation activities. The cost-minimizing, transshipment model includes gins, warehouses, domestic textile mill regions, inland intermodal terminals, and U.S. ports and border-crossing locations. The transshipment model features 811 gins, 415 warehouses, 13 port areas, four border-crossing locations, four inland intermodal terminals that are central to the cotton trade, 37 transloading warehouses at inland intermodal terminal locations, and 11 domestic textile mill demand regions; the developed model represents a cotton crop year (four quarters) that extends from August 1 through July 31. Domestic demands are based on historical mill consumption in southeast U.S. regions, and foreign demands are fixed at historical cotton export levels at U.S. ports and border-crossing locations (Figure 2).

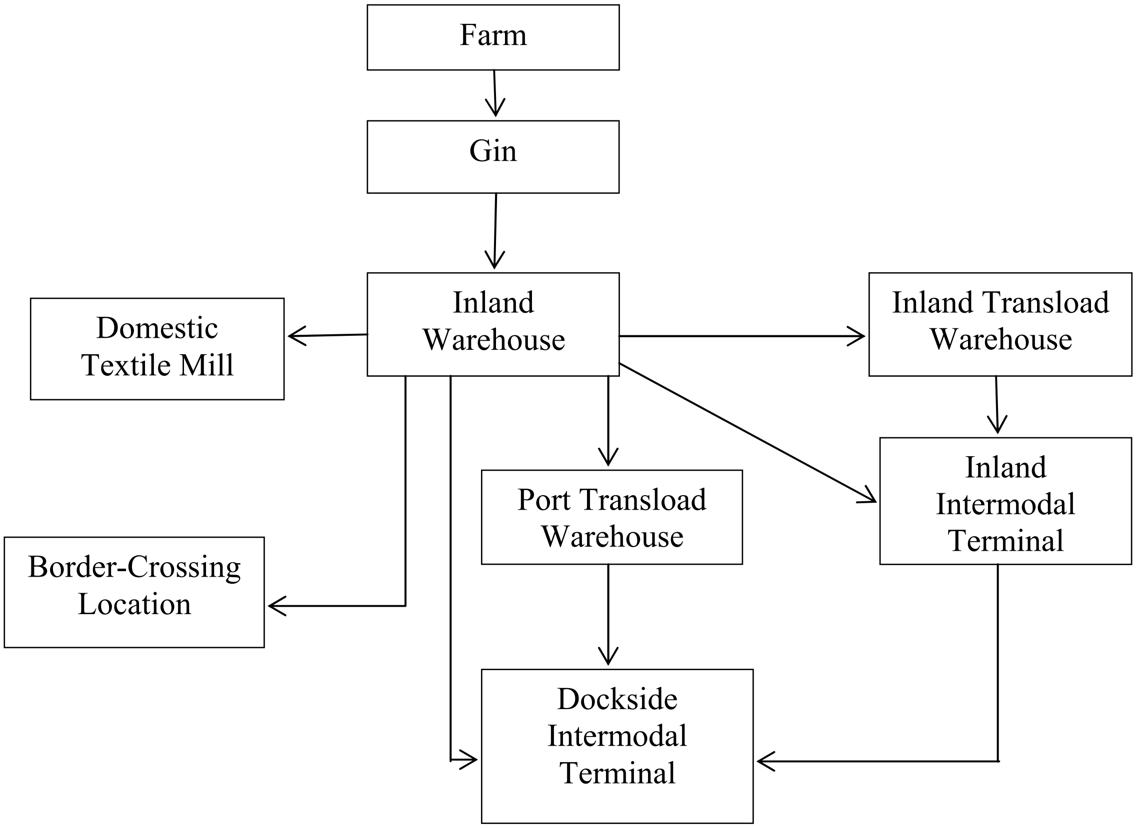


Figure 2: Cotton Supply Chain Represented in Spatial Model

Cotton supply is generated in the first quarter of the crop year and carried forward into subsequent quarters. Cotton supply includes carry-in stocks plus cotton production. Cotton handling and storage costs are incurred at warehouses, intermodal facilities, ports, and border-crossing locations. Truck transportation typically dominates except for those transportation links between intermodal facilities and ports that involve containerized rail movements, and on selected routes between warehouses and ports/border-crossing locations where rail transport (boxcar) has some role.

A cost-minimizing, transshipment model was developed to represent the national cotton marketing system with its associated handling, storage, and transportation network. A description of the mathematical model follows:

(1) Objective function:

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

(2) Quarterly demand constraints:

2a.

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

2b.

$$\sum_w X_{wlt} \geq D_{lt}, \ for\ all\ l, t.$$

2c.

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

(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:

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

(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:

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

Equation 1 minimizes the costs associated (*C*) 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 extend 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 warehouses (w=415) and then, for export-destined cotton, to transloading facilities (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 warehouses to domestic mill demand regions (l=11), and to ports and border crossings (n=17). The cotton can be transported via five transportation systems (s=5). Lastly, quarterly storage in originating 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 $\delta_v = 1$ 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 γ_u, while allowing each warehouse's storage of cotton to be determined endogenously.

Equation 3 describes the gin plants' maximum output of baled cotton.

There are 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. Originating warehouses are generally located in proximity to cotton production and receive cotton from area gins. Transloading warehouses receive from other warehouses and gins and are typically in proximity to inland intermodal terminals or port areas. Equation 4 constrains the sum of quarterly shipments from originating 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 ($m \subset w$). 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. 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 are featured at inland locations, which include Memphis, Dallas, Houston, and Lubbock. The Lubbock operation is currently privately operated, comparatively small, and available to few cotton shippers. The feasibility analysis focuses on the development of an intermodal terminal in Lubbock that is capable of accommodating all area shippers seeking its service. Thirty-seven transloading warehouses operate in these inland intermodal terminal centers and receive truck-delivered cotton from originating warehouses and gins. In addition, intermodal terminals operate in conjunction with selected port areas and receive containers of rail-transported cotton from inland intermodal terminals. In the model, the port 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 included in the model are located in Alabama (Mobile); Florida (Everglades/Jacksonville); Mississippi (Gulfport); and Texas (Freeport). All ports in the model feature a transloading warehouse that receives truck-transported (flatbed/van) cotton, which is placed in containers and drayed to dockside for export. In addition, all ports may receive source-loaded cotton (containers) that is truck-transported from originating 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. In the model, trucks (flatbeds/vans) assemble baled cotton from gins to originating or transloading warehouses. Trucks are also central to the shipment of cotton from originating warehouses. Trucks (flatbeds/vans) may ship from originating warehouses to domestic mill demand locations, border-crossing sites, and transloading warehouses at inland intermodal terminal locations and port areas. The transloading warehouses receive truckloads of cotton, which are placed into containers and drayed to inland intermodal terminals or dockside depending on the location of the intermodal terminal. The containerized cotton received at inland intermodal terminals is loaded onto double-stack cars, which are subsequently rail-transported to a port area for export. Containerized cotton exiting a transloading warehouse in a port area is drayed to dockside where it will be loaded onto a container ship for export.

One of the modeled truck assembly systems involves a truck, chassis, and container (source loaded), which travels to an originating cotton warehouse where the container is loaded and then transported to an inland intermodal terminal for loading aboard a double-stack container car for shipment to a port area. Similarly, truck, chassis, and container (source loaded) may transport cotton from originating cotton warehouses to ship 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 features an additional truck assembly system that includes truck-backhaul opportunities for cotton moving from originating 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.

Important quantities of cotton move into the cotton export channel via railroad’s inland intermodal terminals. This system is central to the movement of cotton to West Coast ports and, to a lesser extent, to East Coast ports. Comparatively small quantities of cotton are transported by railroad boxcars from selected originating warehouses to ports and border-crossing locations. Both rail transportation systems are featured in the developed spatial model of the U.S. cotton economy.

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 was obtained 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 the various cotton-production regions was approximated with the USDA's (2009c) Agricultural Marketing Service cotton classing office data. Cotton-production data by crop reporting district was 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 of warehouses in each delivery market. The remaining cotton carry-in stocks in each state were allocated among those warehouses outside of the futures-market delivery locations based on warehouse storage capacity.

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 consumption for the 11 sub-state domestic demand regions included in the national model. Data on 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), whose data are obtained from the U.S. Census Bureau's Foreign Trade Division.

Individual cotton warehouse handling and storage charges were obtained from a survey of Texas warehouses, the Texas Cotton Association (2009), warehouse websites, and a proprietary list constructed by a national cotton industry organization. Warehouse charges were for receiving, storing, and loading of baled cotton. The receiving charge at cotton warehouses averaged about \$3.50 per bale, as did the per-bale load-out charge, while quarterly storage charges averaged about \$5.50 per bale.

Transportation and Logistics Network

The cotton transportation and logistics network featured in the national spatial model links the cotton-gin plants to cotton warehouses, and then links warehouses to domestic mill demand regions, inland intermodal terminals, ports, border-crossing locations, and other warehouses (transloading warehouses) by quarterly transport rates. Further, the inland intermodal terminals are connected to selected ports in the national model. Truck transportation is central to movement of U.S. baled cotton. Cotton-gin plants ship entirely by truck to warehouses. Warehouses ship large quantities by truck to domestic mill demand regions, ports, transloading warehouses, border-crossing locations, and inland intermodal terminals. Railroads transport large quantities of cotton in containers from selected inland intermodal terminal locations to port areas, while selected warehouses ship via boxcars to ports, domestic mill sites, and border-crossing locations.

Information on cotton trucking rates that link gin plants to warehouses was obtained by telephone survey of 263 Texas, Oklahoma, New Mexico, and Kansas cotton-gin plant operators in 2008 and 2009. These data were used to estimate a rate-dependent equation, where rate was determined by distance of haul and binary variables that accounted for geographic regions and a distance zone. This equation was used to estimate all gin-to-warehouse routes in the national cotton model (Appendix A).

Texas and mid-south truck brokers, freight forwarders, and selected cotton merchants provided information on truck rates connecting warehouses to ports, domestic mills, transload facilities, and intermodal terminals. These data were used to estimate truck rate equations that were explained by distance of haul where distance was determined by the route that minimized the trucker's drive time. In addition, drayage charges between transloading facilities and inland intermodal terminals and dockside locations were provided by cotton industry personnel (Appendix A). The truck rate data used to estimate the rate equations and drayage charges were base rates or rates that did not reflect fuel surcharges. However, 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 allowed for estimation of truck rates and drayage charges that differed by U.S. region.

Railroad rate and routing information was obtained from the Surface Transportation Board's (STB) (2009) *Public Use Waybill*, selected cotton merchants, freight forwarders, and railroad company personnel. 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 to West Coast ports.

Intermodal Terminal Investment and Costs

To estimate the feasibility of intermodal freight terminals in rural areas, it was necessary to estimate the size of intermodal terminals that might be required to accommodate regional cotton export shipments to West Coast ports and then obtain information on the terminal's investment requirements and operation costs. Based on a survey of Texas cotton warehouses 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 container holds 88 cotton bales.

Estimated terminal dimensions, terminal investment requirements, and costs were largely based on previous studies. Stewart et al. (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 parking. Loading space requirements came from the Victoria Transport Policy Institute (2008). Personnel from Wilbur Smith Associates offered perspective on requirements regarding terminal lighting, lifters, tractors, chassis, and employees based on their previous study efforts. Estimated costs of land for an intermodal terminal came from the website of the Lubbock Economic Development Alliance, 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. Appendix B contains the estimated terminal dimensions and specifications (Table B1), and information on investment levels and personnel requirements and expenses (Tables B2 and B3). 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.

The estimated investment in the 12,000-, 14,000-, 16,000-, and 18,000-container-per-year terminals was amortized at 7 percent over a 10-year period. Information on 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 examined the feasibility of 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. In contrast to the Berwick study that depreciated equipment and infrastructure for a 15- to 20-year period, the annual depreciation expense associated with infrastructure and equipment in this study was calculated using a straight-line method over a 10-year time frame with an assumed salvage value of zero. 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 (Appendix Table B4). However, if the focus were on annual cash outlay without consideration of depreciation expense, terminal costs range from \$182 per container or \$2.07 per bale for the 12,000-container terminal to \$159 per container or \$1.81 per bale for the 18,000-container terminal.

Roadway Pavement Cost

The introduction of an intermodal terminal in the intense cotton-production region of west Texas is expected to reduce the quantity of cotton transported by truck from this region to existing intermodal facilities in Dallas-Fort Worth but increase truck transport into that potential intermodal site. To determine the effect of introducing an intermodal terminal in west Texas on total loaded truck-miles and pavement costs, it was necessary to estimate the change in loaded truck-miles that would result with introduction of the intermodal terminal and the marginal cost associated with pavement use. The change in total loaded truck-miles was approximated by contrasting spatial model solutions *ex ante* and *ex post* operation of the intermodal terminal in west Texas.

The change in total pavement cost that results with introduction of the intermodal terminal was estimated by using the Federal Highway Administration's (FHWA) functional classification guidelines (USDOT 2000a) to approximate miles traveled over each functional system and by updating related marginal pavement cost parameters. 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 cost 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*)*. Interestingly, the Construction Cost Index increased nearly 40 percent from 2000 to 2006, but by 2009 the index had declined so it was about 10 percent larger than the 2000 index. 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 on interstate (\$0.059), principal arterial (\$0.259), minor arterial (\$0.359), and collector (\$0.876) roadways.

CO_2 Emissions

Introduction of an intermodal terminal in the intense cotton-production region of west Texas is expected to reduce CO_2 emissions because of the reduced need to truck-transport cotton to distant intermodal terminals in Dallas-Fort Worth. To approximate the likely reduction in CO_2 emissions that may result with an intermodal terminal in west Texas, it was necessary to estimate emissions *ex ante* and *ex post* the studied intermodal terminal in west Texas. This was accomplished by contrasting cotton model outcomes regarding truck mileages, and using estimated parameters relating to CO_2 emissions and truck fuel use during loaded and empty hauls.

Dr. Josias Zietsman of 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 estimated emission rate was estimated with MOVES 2010, which is EPA's state-of-the-art tool (EPA 2010). At an assumed average speed of 55 miles per hour, the Class 8 truck has an estimated CO_2 emission rate of 2003.7 grams per loaded mile. For empty truck mileage, the emission rate was adjusted downward in proportion to reduced fuel consumption. Franzese et al.

(2009) estimate the effect of load size and truck-tire configuration on fuel efficiency of Class 8 trucks. Their analyses suggest the reasonableness of the rule of thumb "that each additional 10,000 pounds of payload decreases fuel economy about 5 percent." Further, the Federal Railroad Administration's *Comparative Evaluation of Rail and Truck Fuel Efficiency in Competitive Corridors* (USDOT 2009) indicates the reasonableness of this rule of thumb. Based on these data, the CO_2 emission rate per loaded truck-mile was estimated to be 2003.7 grams, and the rate per empty truck-mile was 1615.8 grams.

Introduction of an intermodal terminal in west Texas will require the railroad to relocate empty containers from the Dallas-Fort Worth complex to the west Texas terminal. It is assumed that the net effect of this rail activity is neutral regarding CO_2 emissions. *Ex ante* the west Texas terminal, truck-transported west Texas cotton would be routed to Dallas-Fort Worth to be 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 in west Texas. For this reason, it was assumed that railroad CO_2 emissions would not be significantly affected by the introduction of the intermodal terminal.

Truck brokers and cotton shippers indicate that important quantities of cotton that involve a truck, chassis, and container (source-loaded) move from west Texas to Dallas-Fort Worth intermodal terminals. Typically, the container is empty when departing the intermodal facility; 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 a van or flatbed into Dallas-Fort Worth involves a backhaul percentage of 50 percent.

COTTON MODEL VALIDATION AND METHOD OF ANALYSIS

Model Validation

To develop confidence in the spatial model of the cotton economy, the model solution output was contrasted with actual or real-world information. The national model of the U.S. cotton industry features detail on regional cotton production and domestic and international cotton demands for the 2008–2009 crop year (August 1–July 31). Further, the spatial model includes all U.S. cotton gins, cotton warehouses, transloading warehouses, relevant intermodal terminals, and ports with linking transport modes and associated handling, storage, and transportation charges and rates. The output from the spatial model identifies cotton flows through cotton warehouses, transloading warehouses, intermodal terminals, and port areas that minimize cotton handling, storage, and transportation charges subject to regional cotton supplies, regional domestic cotton mill demands, and international demands as represented at port areas and border-crossing sites. The solution to the developed spatial model with its associated cotton flows and costs was contrasted with secondary cotton flow data for 2008–2009 to develop confidence in the model and its ability to correctly project flows and costs. Initial model-generated solutions showed quarterly and annual carryover stocks to be misrepresented in various regions, but with counsel of industry experts and additional data, the model was successfully altered by constraining regional carryover. In the final analysis, the base model solution representing the 2008–2009 crop year revealed cotton flows that closely approximated reality. In particular, cotton flows via each port area were within 2 percent of actual flows, as were domestic demand flows; therefore, the model was judged capable of accomplishing study objectives.

Procedure to Determine Feasibility of Investment in Intermodal Terminals

The spatial model was central to determining the economic feasibility of an intermodal facility in the intensive cotton-production region of west Texas. First, the costs of assembling cotton from nearby gins and warehouses to the hypothetical intermodal terminal site in Lubbock, Texas, were introduced into the spatial model in conjunction with the estimated costs of shipping the rail-transported containers of cotton from the potential terminal to West Coast ports. After introduction of these costs and charges, the least-cost model was solved to determine the quantities of cotton that would be assembled to the potential terminal site under alternative intermodal terminal charges; this offered insight into the potential terminal's annual revenues. The information on quantities of cotton assembled to the intermodal site at alternative charges was subsequently examined in conjunction with the estimated costs associated with operating an inland intermodal facility that annually ships 12,000, 14,000, 16,000, or 18,000 containers per year to identify the profitability of the hypothetical terminal. This heuristic analysis permits an estimate of the break-even volume for each terminal and its expected revenues, costs, and profits.

Currently a small, private intermodal facility operates in Lubbock. Based on discussions with industry personnel and an area planner, researchers assumed that this facility would cease to operate if a new expanded terminal were constructed. Hence, the feasibility analysis assumes the existing intermodal facility is not in operation.

Because variability of cotton production in the west Texas plains was thought to affect the economic feasibility of the intermodal terminal, analyses were carried out to examine the sensitivity of the terminal's feasibility to variation in cotton production. Analyses showed cotton production in the Texas plains in the 2008–2009 crop year (the base year for the model) to be slightly below the average production over the past decade; therefore, cotton production in Texas crop reporting districts 11, 12, 21, 22, and 70 was adjusted upward in the base model to reflect the historic average over the past decade. To examine the effect of variability in cotton production on intermodal terminal feasibility, production levels in applicable crop reporting districts were scaled to reflect historic production, and the spatial model was subsequently solved to estimate the quantity of cotton attracted to the hypothetical Lubbock terminal under alternative charges or tariffs. This revenue information in combination with costs for the 12,000-, 14,000-, 16,000-, and 18,000-container terminals was used to evaluate the effect of variable cotton-production levels on the economic feasibility of the hypothetical terminal.

The effect of introducing containerized cotton shipments from a nearby intermodal terminal (Amarillo, Texas) was thought to unfavorably influence the feasibility of the hypothetical Lubbock terminal. Therefore, additional analysis was carried out. To evaluate competition from the existing intermodal terminal in Amarillo, Texas, the charges of assembling cotton from gins and warehouses to this competing site were included in the spatial model, as were the estimated costs of shipping containerized cotton from Amarillo to West Coast ports. After the introduction of these costs, the least-cost spatial model was solved to determine the quantities of cotton assembled to the hypothetical intermodal terminal (Lubbock, Texas) and the competing site (Amarillo, Texas) at alternative tariffs. This procedure offered insight into the sensitivity of the Lubbock facility to the nearby competition in Amarillo.

Procedure to Determine Effect of Intermodal Terminal on Roadway Pavement Costs

The introduction of an intermodal terminal in the intensive cotton-production region of west Texas was expected to reduce truck-transported cotton movement from west Texas to the Dallas-Fort Worth intermodal terminals but increase flow to the supposed terminal in Lubbock, Texas. The spatial model output and marginal pavement costs by functional highway classes were central to estimating the effect of an intermodal terminal in west Texas (Lubbock) on roadway pavement costs.

The spatial model output that denoted the origin and destination of all truck hauls, in combination with a roadway routing tool that identifies the associated highway names and mileages, was used to approximate distance by functional roadway classification. The *FHWA Functional Classification Guidelines* (USDOT 2000a) was followed to approximate mileages by principal arterials, minor arterials, and collectors, with the principal arterials subdivided into the interstate system and other principal arterials. This information, in combination with the associated uncompensated marginal pavement costs (loaded truck-mile costs), facilitated estimation of roadway pavement cost *ex ante* and *ex post* introduction of the intermodal terminal. By summing pavement costs for all involved roadways in the two solutions and contrasting the summed estimate of pavement costs, the potential effect of the hypothetical intermodal facility on roadway pavement cost was approximated. All analyses with the spatial model were carried out when regional cotton production (crop reporting districts 11, 12, 21, 22, and 70) reflected average production during the most recent decade (2000–2009).

The optimization method and associated procedure used to estimate truck mileages *ex ante* and *ex post* introduction of the intermodal terminal in west Texas implied that trucks will tend to follow the least-cost routing in the very short run. This procedure abstracted from a phased-in truck traffic pattern that may be more realistic; therefore, the measured reduction in pavement deterioration may be overstated in the short run.

Procedure to Determine Effect of an Intermodal Terminal on CO_2 Emissions

The effect of introducing an intermodal terminal in Lubbock, Texas, on CO_2 emissions by the truck mode was accomplished with the spatial model output that relates truck mileage *ex ante* and *ex post* introduction of the intermodal terminal in west Texas. In addition, truck CO_2 emission rates (when trucks were loaded and empty) and truck backhaul percentages were utilized in calculation of CO_2 emissions. Analyses focused on truck mileage associated with the assembly of cotton to applicable intermodal terminals (Lubbock and Dallas-Fort Worth). All analyses with the spatial model were carried out when regional cotton production (crop reporting districts 11, 12, 21, 22, and 70) reflected average production during the past decade (2000–2009).

Tol (2005) studied peer-reviewed articles that estimated the marginal damage cost of CO_2 emissions and concluded its mean value to be $43 per metric ton. This value was used to offer an approximation of the value of CO_2 removed through introduction of an intermodal terminal in west Texas.

The procedure to estimate the reduction in CO_2 emissions failed to consider a phased-in truck traffic pattern; therefore, measured reductions in CO_2 emissions and the associated value of the reduced emissions may be overstated in the short run.

FINDINGS

Feasibility of Intermodal Terminal

Initial analyses with the spatial model focused on estimating revenues of the hypothetical intermodal terminal in Lubbock, Texas. Total revenues were calculated for the terminal when it levied a charge of $1, $2, $3, $4, or $5 per bale by multiplying the charge and associated quantity of cotton assembled to the terminal as determined by the spatial model. The information on total revenue in combination with intermodal terminal costs was used to evaluate the economic viability of the hypothetical intermodal terminal. The per-bale charge introduced into the spatial model was in addition to the costs associated with assembling cotton from area gins and warehouses to the proposed intermodal terminal site in Lubbock (source-loaded and flatbed/van assembly systems) and the shipment of this cotton to West Coast ports on double-stack railroad cars.

Analysis with the spatial model projected that an estimated 3.57 million bales would be handled by the supposed intermodal terminal in Lubbock if $1 per bale were charged by the terminal. When the charge was adjusted to $2 per bale, the volume handled by the hypothetical terminal declined to 3.08 million bales, and when the charge was $3, $4, or $5 per bale, the associated quantities were 2.58, 2.02, or 0.538 million bales, respectively.

The 12,000-container intermodal terminal had a projected annual capacity of approximately 1.06 million cotton bales (88 bales per container), while the estimated 14,000-, 16,000-, and 18,000-container terminals had projected annual capacities of 1.23, 1.41, and 1.58 million bales, respectively. The above analyses showed that the projected quantities of baled cotton handled by the hypothetical Lubbock terminal at tariffs of $1 (3.57 million bales), $2 (3.08 million bales), $3 (2.58 million bales), or $4 per bale (2.02 million bales) exceeded the capacity of the four evaluated intermodal terminals. Further, the analyses indicated the $4-per-bale charge or $352 per container charge maximizes intermodal terminal revenues ($4 per bale × 2.02 million bales = $8.08 million).

The estimated total annual cost associated with investment and operation of the 12,000-, 14,000-, 16,000-, and 18,000-container terminals is shown in Appendix B (Table B4). When the evaluated intermodal terminal is assumed to levy a charge of $352 per container or $4 per bale, the estimated breakeven volumes for the 12,000-, 14,000-, 16,000-, and 18,000-container terminals are 7,539, 8,211, 9,061, and 9,758 containers per year, respectively (Table 1). All containers are assumed to be 40-foot marine containers (FEU). When the terminal operates at capacity, the expected 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. The estimated rate of return for each terminal size was estimated by dividing its estimated return by total terminal investment in Table B2. The estimated rates of return on investment were estimated to be 15.8 percent, 18.8 percent, 20.4 percent, and 22.5 percent for the 12,000-, 14,000-, 16,000-, and 18,000-containers-per-year terminals, respectively.

Table 1: 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	Containers per Year (FEU) 14,000	Containers per Year (FEU) 16,000	Containers per Year (FEU) 18,000
Fixed Cost[1] ($)	2,113,466	2,354,044	2,613,110	2,853,593
Management, Employee, and Other Expenses[1] ($)	860,080	914,001	1,017,978	1,072,030
Total Cost ($)	2,973,546	3,268,045	3,631,088	3,925,623
Total Revenue[2] ($)	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[3] ($)	1,250,454	1,659,955	2,000,912	2,410,377

[1] From Table B4 in Appendix B.

[2] Analyses with the spatial model show the operator of the terminal has the ability to charge up to $4 per bale and attract 22,728 containers (2 million bales) to the intermodal facility under average production levels in the region.

[3] Total cost does not reflect federal corporation taxes.

Sensitivity of Intermodal Terminal's Feasibility to Selected Exogenous Forces

After the alternative cotton-production levels were included in the spatial model, the model with inclusion of all handling and transportation costs associated with the hypothetical Lubbock terminal and the $4-per-bale tariff ($352 per container) was solved to determine the quantity of cotton attracted to the terminal site. The analysis showed that at the high production levels of 2005 and 2007 (7.0 million bales), the Lubbock terminal would attract about 2.66 million bales, whereas at the low production levels of about 2.54 million bales (2000 production), approximately 1.7 million bales would transit the Lubbock terminal. These analyses suggested 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.

Sensitivity of Intermodal Terminal's Feasibility to a Competing Intermodal Terminal

Additional analysis was carried out to determine if operation of an existing intermodal terminal in Amarillo, Texas, as a cotton shipping terminal would affect the economic feasibility of the studied Lubbock, Texas, terminal. Amarillo is approximately 120 miles north of Lubbock and is at an extended distance from the intensive cotton-production area surrounding Lubbock. USDA's Farm Service Agency showed that a large cotton warehouse operates in Amarillo (USDA 2009c). Further, Amarillo is located on the Burlington Northern (BNSF) railroad line that connects the Chicago, Illinois, 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, Texas, terminal exists.

To evaluate the potential effect of cotton shipments through the competing Amarillo intermodal terminal, the edition of the spatial model featuring an 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 existing terminal in Amarillo for container handling and lifts, and an estimated railroad rate to West Coast ports.

Analysis showed that 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 about 1.9 million bales from 2.02 million bales ($4-per-bale tariff), 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. And, as expected, if the Amarillo terminal included a charge, the region's cotton production would shift back to the Lubbock terminal. For example, if Amarillo introduced a charge of $1 per bale, the Amarillo volume would decline to 1.64 million bales; when a charge of $2, $3, or $4 per bale was levied, Amarillo terminal volume would decline to an estimated 1.42, 0.80, or 0.12 million bales, respectively. And, as the Amarillo's terminal volume declined at charges of $2, $3, or $4 per bale, the Lubbock terminal's volume would increase to 0.85, 1.29, or 1.93 million bales, respectively.

Analysis suggested investment in the Lubbock intermodal terminal could be vulnerable if the existing intermodal terminal in Amarillo were to become a competing cotton-handling site. The investment required to construct and operate the hypothetical facility in Lubbock placed it at a competitive disadvantage relative to the existing intermodal terminal in Amarillo.

Effect of Intermodal Terminal on Annual Roadway Pavement Costs

To estimate the approximate reduction in roadway pavement cost resulting from introduction of the hypothetical intermodal terminal in Lubbock, it was necessary to contrast loaded truck-miles expended with the current cotton transportation system and the loaded truck-miles expended with the cotton marketing system that features the hypothetical facility. Unfortunately, measurement of loaded truck-miles with the current cotton transportation system was not straightforward because of a private cotton terminal operator in Lubbock who shipped an unknown number of cotton-filled containers to West Coast ports. Trade sources estimated that the private intermodal operation annually ships from 500,000 to 750,000 cotton bales. Therefore, these values were assumed when calculating loaded truck-miles with the current cotton transportation system.

When the private operator in Lubbock handled 500,000 bales, it was estimated that 9.80 million loaded truck-miles would be expended in assembling cotton to the existing intermodal terminals in Lubbock and Dallas-Fort Worth, and when that existing Lubbock operation handled 750,000 bales, total loaded truck-miles declined to 9.02 million. The corresponding 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 estimated values, introduction of the hypothetical intermodal terminal in Lubbock would annually reduce uncompensated pavement cost from \$0.97 million (\$2.08 − \$1.11 = \$0.97) to \$1.15 million (\$2.26 − \$1.11 = \$1.15).

Effect of Intermodal Terminal on CO_2 Emissions

Analyses show introduction of an intermodal terminal in Lubbock that handled approximately 2 million bales of cotton would reduce CO_2 emissions associated with truck assembly of cotton to intermodal terminals in Lubbock and Dallas-Fort Worth by 42 to 47 percent relative to the current system. Total annual CO_2 emissions attributable to truck assembly are estimated to be 38,667 short tons when the private 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. If the intermodal terminal in Lubbock were implemented (2 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 (\$43 per metric ton), the estimated annual value of reduced CO_2 emissions ranges from \$0.584 to \$0.705 million per year.

CONCLUSIONS

This study examines the economic feasibility of investment in an intermodal terminal in west Texas and explores 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 metroplex for purposes of accessing 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. Because the assembly of cotton into the Dallas-Fort Worth railroad hubs is at distances of up to 335 miles, truck-miles and roadway maintenance may significantly decrease, as may CO_2 emissions, with the introduction of rural intermodal terminals.

Much of the analysis in this study was accomplished with a spatial model representing the U.S. cotton industry. The least-cost model features cotton handling, storage, and transport activities that link cotton gins to warehouses and ultimately to intermodal terminals, domestic textile mills, and U.S. port areas. Domestic cotton demand is represented in regions that feature textile mills, and foreign demand is represented at U.S. cotton ports. All U.S. cotton gins (811) and warehouses (452) in operation during the 2008–2009 crop year are featured in the model. The developed spatial model includes considerable detail regarding cotton transportation and logistics.

The analyses show an intermodal terminal in west Texas' intensive cotton-production region (Lubbock, Texas) to be economically viable. It is estimated that the facility could attract about 2 million bales or nearly 30 percent 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 percent. 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, Texas) were to commence cotton shipments to West Coast ports.

Implementation of an intermodal terminal in west Texas that handles approximately 2 million cotton bales is estimated to reduce truck (80,000-pound, five-axle) travel on state roadways an estimated 3.75 to 4.53 million loaded truck-miles and to lower annual pavement expenditures approximately $1 million. This positive externality suggests an opportunity for public- and private-sector cooperation. Further, the reduced truck-miles expended to assemble Texas cotton to intermodal facilities are estimated to reduce CO_2 emissions by 42 percent (14,978 short tons) to 47 percent (18,079 tons) relative to the current marketing system. The estimated value of reduced CO_2 emissions ranges from $0.580 million to $0.699 million per year. Finally, estimated traffic into the Dallas-Fort Worth metroplex would be reduced by 13,800 to 16,700 trucks per year with introduction of the west Texas intermodal terminal.

In summary, the analysis suggests that investments in intermodal terminals in rural areas may offer opportunities to improve marketing system efficiency and reduce roadway maintenance costs and vehicle emissions.

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APPENDIX A: TRUCKING COSTS

Appendix A offers information on trucking and drayage charges included in the developed spatial cotton model. Included are estimated truck rate equations linking (1) gins to warehouses and (2) warehouses to ports, mills, transloading facilities, border-crossing sites, and other locations. Included is information on charges associated with source-loaded cotton transported from warehouse to inland intermodal terminal and dockside terminal, and drayage of cotton from transloading warehouse to inland intermodal terminal and dockside terminal. In addition, discussion is offered regarding truck fuel surcharges.

Table A1 includes the definition of variables in the four estimated truck rate equations, and Table A2 includes the estimated equations. The gin-to-warehouse truck rate equation was estimated by ordinary least squares and included 221 observations; the associated adjusted R-square for this equation was 0.86, and all explanatory variables were highly significant except one. The truck rate equation representing shipments from warehouses to ports and inland transloading warehouses included 48 observations and an adjusted R-square of 0.89 with all explanatory variables significant at the 1 percent level. The equation used to estimate truck rates when cotton was the backhaul had an adjusted R-square of 0.72, and the explanatory variables were highly significant; the equation was based on 16 observations. The truck rate equation representing shipments from warehouses to mills, border-crossing locations, and other sites was based on 48 observations. The estimated equation had an adjusted R-square of 0.93, and all variables were statistically significantly at the 1 percent level.

Source-loaded cotton refers to the direct shipment of cotton in a marine container from an originating warehouse to an inland intermodal terminal or a dockside terminal. The empty container is transported on a chassis from a terminal (inland or port area intermodal terminal) to the cotton warehouse in the production region where the container is loaded and transported to either an inland intermodal terminal or a dockside terminal. These source-loaded rates include a per-mile charge times the round-trip distance plus a fuel surcharge. Based on conversations with brokers and freight forwarders, the rate was estimated to be $1.30 per mile for all source-loaded shipments, except for those to inland terminals in Dallas-Fort Worth and the west Texas area (Lubbock, Texas) where the rate was $1.10 per mile.

Truck fuel surcharges were not applicable for estimated gin-to-warehouse movements since fuel surcharges were included in the estimated rate. In addition, the rate equation representing cotton as a backhaul did not include fuel surcharges since these charges were not paid for this type of haul. The remaining truck rate equations were estimated from base rates or rates without fuel surcharges. The fuel surcharge was incorporated by an upward adjustment in the base rate. For example, if the current No. 2 diesel price was in a range of $2.20 to $2.30 per gallon, the surcharge was 12 percent, which would involve a 12 percent increase in the base rate.

Drayage service is required to move the cotton-filled containers to an inland intermodal terminal or a dockside terminal. Cotton that has been drayed to an inland intermodal terminal is typically placed on double-stack container cars for shipment to selected East Coast and West Coast ports, while cotton assembled to dockside will ultimately be loaded on a container ship for export. Source-loaded cotton is loaded into a container at an originating cotton warehouse in the cotton-production region and does not require drayage since the loaded container moves directly to the inland intermodal terminal or dockside terminal. The collected drayage fees ranged from $150 to $250 per container and typically included a fuel surcharge. Finally, the charge for intermodal terminal lifts is estimated to be $1.14 per bale or $100 per container.

Table A1.1: Variables in Gin to Warehouse Equation

Variables	Definition
Rate	Truck rate in $/bale/mile
Miles	One-way miles of haul
<200 miles	0,1 variable for hauls less than 200 miles
South Texas	0,1 variable for hauls that originate in south Texas
East central Texas	0,1 variable for hauls that originate in east central Texas
OKNM	0,1 variable for hauls that originate in Oklahoma and New Mexico

Table A1.2: Variables in Warehouse to Port and Transload Center Equation

Variables	Definition
Rate	Truck rate in $/bale/mile
Miles	One-way miles of haul

Table A1.3: Variables in Warehouse Shipment (Backhaul Rate) Equation

Variables	Definition
Rate	Truck rate in $/bale/mile
Miles	One-way miles of haul

Table A1.4: Variables in Warehouse Shipments to Border, Mill, and Other Sites Equation

Variables	Definition
Rate	Truck rate in $/bale/mile
Miles	One-way miles of haul
LKan	0,1 variable for hauls originating from a Liberal, Kansas, warehouse

Table A2.1: Gin to Warehouse Equation

Variable	Coefficient	T-statistics
Intercept	1.2522	14.05*
Miles	0.0248	27.21*
<200 miles	−0.7984	2.11**
South Texas	0.4267	2.45*
East central Texas	0.6894	2.97**
OKNM	0.3071	1.45

Table A2.2: Warehouse to Port and Transload Center Equation

Variable	Coefficient	T-statistics
Intercept	2.6611	10.22*
Miles	0.0101	19.46*

Table A2.3: Warehouse Shipment (Backhaul Rate) Equation

Variable	Coefficient	T-statistics
Intercept	3.5121	6.89*
Miles	0.0101	6.38*

Table A2.4: Warehouse Shipments to Border, Mill, and Other Sites Equation

Variable	Coefficient	T-statistics
Intercept	2.7767	12.56*
Miles	0.0096	20.25*
LKan	3.9634	9.27*

* significant at 1% level
** significant at 5% level

APPENDIX B: INTERMODAL TERMINAL METRICS AND COSTS

Table B1: Intermodal Terminal Metrics for Alternate Terminal Sizes (12,000, 14,000, 16,000, and 18,000 Containers per Year)

Metrics for Infrastructure and Equipment	Containers per Year (FEU) 12,000	Containers per Year (FEU) 14,000	Containers per Year (FEU) 16,000	Containers per Year (FEU) 18,000
Containers/week	231	270	308	346
Lifts/week	462	540	616	692
Acres in terminal yard				
Acres (2000 lifts/acre)[1]	12	14	16	18
Square feet/acre	43,560	43,560	43,560	43,560
Total square feet	522,720	609,840	696,960	784,080
Terminal yard parking space				
Parking spaces (100 lifts/parking space)[2]	240	280	320	360
Square feet/parking space	750	750	750	750
Total parking area (square feet)	180,000	210,000	240,000	270,000
Parking area (acres)	4.13	4.82	5.51	6.20
Track				
Rail loading track (feet)[1]	1,600	1,866	2,133	2,400
Rail car storage track (feet)	3,200	3,732	4,266	4,800
Total track (feet)	4,800	5,598	6,399	7,200
Rail #10 turnout (number)[3]	2	2	2	2
Rail #15 turnout (number)[3]	2	2	2	2
Fencing				
Fencing (linear feet)	2,892	3,124	3,339	3,542
Lights				
Lights (number)[4]	5	6	7	8
Lifters				
Primary lifter (number)	1	1	1	1
Backup lifter (number)	1	1	1	1
Tractors				
Hostler tractor[5]	2	2	3	3
Chassis				
Chassis[6]	4	4	6	6

[1] Stewart et al. (2004)

[2] Victoria Transport Policy Institute (2008)

[3] Michigan Department of Transportation and USDOT (2008)

[4] One light per 300 feet of loading space

[5] One tractor per 12,000 lifts

[6] Two chassis per tractor

Table B2: Intermodal Terminal Investment Costs for Alternate Terminal Sizes (12,000, 14,000, 16,000, and 18,000 Containers per Year)

Terminal Land, Yard, and Equipment Costs	Containers per Year (FEU) 12,000	Containers per Year (FEU) 14,000	Containers per Year (FEU) 16,000	Containers per Year (FEU) 18,000
Land in terminal yard				
Acres (number)	12	14	16	18
Land cost/acre ($)[1]	4,000	4,000	4,000	4,000
Total land cost ($)	48,000	56,000	64,000	72,000
Terminal yard				
Grading cost/cubic yard ($)[2]	10	10	10	10
Total grading cost ($)	580,800	677,600	774,400	871,200
Paving cost/square yard ($)[2]	40	40	40	40
Total paving cost ($)	2,323,200	2,710,400	3,097,600	3,484,800
Security fencing ($/foot)[2]	28	28	28	28
Silt fencing ($/foot)	2	2	2	2
Total fencing cost ($)	86,759	93,711	100,181	106,258
Lights required	5	6	7	8
Cost/light ($)[2]	35,000	35,000	35,000	35,000
Total light cost ($)	175,000	210,000	245,000	280,000
Total track (feet)	4,800	5,598	6,399	7,200
Cost/foot ($)[2]	200	200	200	200
Total track cost ($)	960,000	1,119,600	1,279,800	1,440,000
Total turnout cost ($)[2]	480,000	480,000	480,000	480,000
Roadway access/exit cost ($)	380,000	380,000	380,000	380,000
Building cost ($)[2]	215,000	215,000	215,000	215,000
Truck scale cost ($)[3]	65,000	65,000	65,000	65,000
Utilities investment costs ($)[3]	65,000	65,000	65,000	65,000
Total terminal yard costs ($)[1]	5,330,759	6,016,311	6,701,981	7,387,258
Total land and yard costs ($)[2]	5,378,759	6,072,311	6,765,981	7,459,258
Engineering/contingencies (30%)[4]	1,613,628	1,821,693	2,029,794	2,237,777
Total land, yard, and contingencies costs ($)	6,992,387	7,894,004	8,795,775	9,697,035
Terminal equipment costs				
Primary lifter cost ($)[3]	540,000	540,000	540,000	540,000
Backup lifter cost ($)[3]	250,000	250,000	250,000	250,000
Hostler tractor cost ($)[3]	115,214	115,214	172,821	172,821
Chassis cost($)[3]	23,040	23,040	34,560	34,560
Total equipment cost ($)	928,254	928,254	997,381	997,381
Total terminal investment costs ($)	7,920,641	8,822,258	9,793,156	10,697,416

[1] Lubbock Economic Development Alliance (2008)

[2] Michigan Department of Transportation and USDOT (2008)

[3] Minnesota Department of Agriculture and Wilbur Smith Associates (2008)

[4] 10% attributable to engineering, and remaining 20% are contingencies

Table B3: Intermodal Terminal Management/Employee Costs for Alternate Terminal Sizes (12,000, 14,000, 16,000, and 18,000 Containers per Year)

Management and Employee Requirements and Costs	Containers per Year (FEU) 12,000	Containers per Year (FEU) 14,000	Containers per Year (FEU) 16,000	Containers per Year (FEU) 18,000
Gate employees (number)[1]	4	4	4	4
Yard employees (number)[2]	3	3	4	4
Total employees (number)	7	7	8	8
Total salary employee cost ($)[3]	196,000	196,000	224,000	224,000
Manager's salary ($)[4]	51,000	51,000	51,000	51,000
Total salary expense ($)	247,000	247,000	275,000	275,000
Benefits (30% of salary) ($)	74,100	74,100	82,500	82,500
Total salary and benefits ($)	321,100	321,100	357,500	357,500
Incidental expenses (% of compensation)	28%	28%	28%	28%
Total manager and employee expense ($)	411,008	411,008	457,600	457,600

[1] Facility operates 24 hours/day and 7 days/week

[2] Each employee can handle 12,000 lifts per year

[3] Taken from website: http://salary.com/

[4] Taken from website: http://salary.com/

Table B4: Estimated Annual Costs for Alternate Terminal Sizes (12,000, 14,000, 16,000, and 18,000 Containers per Year)

Costs	Containers per Year (FEU) 12,000	Containers per Year (FEU) 14,000	Containers per Year (FEU) 16,000	Containers per Year (FEU) 18,000
Fixed cost				
Amortized cost ($)[1]	1,103,584	1,229,207	1,364,482	1,490,057
Depreciation ($)[2]	792,064	882,226	979,316	1,069,440
Insurance expense on infrastructure/ equipment ($)[3]	59,405	66,166	73,449	80,208
Taxes ($)[4]	158,413	176,445	195,863	213,888
Total ($)	2,113,466	2,354,044	2,613,110	2,853,593
Management and employee salary cost				
Managers salary ($)[5]	51,000	51,000	51,000	51,000
Employee salary ($)[6]	196,000	196,000	224,000	224,000
Manager/employee fringe benefits ($)[6]	74,100	74,100	82,500	82,500
Incidental expense ($)[7]	89,908	89,908	100,100	100,100
Total ($)	411,008	411,008	457,600	457,600
Other expenses				
Fuel and energy ($)[8]	53,040	61,880	70,720	79,560
Maintenance and repair expense ($)[9]	396,092	441,113	489,658	534,870
Total ($)	449,072	502,993	560,378	614,430
Total annual cost ($)	2,973,546	3,268,045	3,631,088	3,925,621
Total cost/container ($)	247.79	233.43	226.94	218.08
Total cost/bale ($)	2.815	2.65	2.58	2.48

[1] Total investment in infrastructure and equipment amortized at 7% interest rate over a 10-year time period

[2] Calculated by straight-line depreciation method with estimated life of 10 years and zero salvage value

[3] Calculated to be 0.75% of total investment in infrastructure and equipment. Based on Berwick (2007), with adjustments made for location, time period, and equipment complement.

[4] Estimated to be 2% of total infrastructure and equipment

[5] Taken from website: http://salary.com/

[6] Fringe benefits estimated to be 30% of total salaries

[7] Incidental expenses estimated to be 28% of salaries and manager/employee benefits

[8] Based on Berwick (2007), with adjustments made for equipment complement and time period

[9] Calculated to be 5% of total investment and equipment. Based on Berwick (2007), with adjustments for location, time period, and equipment complement.