EFFICIENT INTERFACING OF THE TRUCK-TO-SHIP INTERMODAL GRAIN TRANSFER SYSTEM: PORT OF HOUSTON

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Agricultural transportation is often characterized by seasonal and cyclical traffic flows that unfavorably affect the logistical efficiency of the marketing system. Congestion problems arise in the truck-to-ship intermodal grain transfer system at the Port of Houston. Seasonal peaks in truck-delivered grain receipts create problems with efficient interfacing of the port elevators' grain-receiving capacity and truck arrival patterns. During peak volume periods, the elevators' receiving capacity is inadequate; long truck queues develop and congestion or waiting occurs. Queues of 3-4 miles are common during the peak receipt periods, whereas the facility may be idle for extended periods of off-peak time.

The purpose of this article is to (1) quantify the magnitude of congestion cost associated with the seasonal surge in truck-delivered grain at the Port of Houston, (2) estimate costs of reducing this congestion to alternative levels, and (3) determine the least-cost level of congestion-reducing investment or, conversely, the optimum level of congestion to maximize efficiency.

The theory of queues provides a basis for calculating the nature and extent of congestion under conditions of fluctuating demands. Queuing models have been used by agricultural and transportation economists to examine a wide variety of problems. Cox, Glickstein, and Greene [3] applied queuing theory to determine necessary livestock unloading capacity at auction markets. Lu [10] used a queuing model to determine optimum checkout facilities for a major food store chain. Queuing analysis was used by Simmons [15] to resolve appropriate plant loading facilities for a fleet of milk distribution trucks operating in North Carolina. Recently, de Weille and Ray [4] and Wanhill [17] analyzed optimum seaport capacity with use of a queuing model. A recent Brookings Institution study employed queuing analysis to optimize intermodal transfer systems for the developing transportation network in Columbia [8].

BACKGROUND

Port elevators are an important link in the export grain marketing system. Currently, 66 port elevators operate in the U.S. and these facilities are responsible for exporting approximately 50 percent of the nation's annual wheat and soybean production and 20-25 percent of corn and grain sorghum output [14]. Because of the relatively small number of port elevators and the large volume of grain handled per unit of time, coordination with transportation is critical. When the port elevators' handling capacity and the arrival rate of the transportation agents are not synchronized, traffic congestion is rapidly generated. The truck congestion addressed in this article occurs at the Brownsville, Corpus Christi, and Houston ports and is a result of Texas producers' seasonal grain sorghum marketing practices.

During the past decade, Texas Gulf Coast grain sorghum production has stablizied at about 90 million bushels. Grain sorghum is harvested and marketed during July and August because of favorable foreign demand and associated price-storage cost relationships. Approximately 70 percent of the production is shipped immediately to Texas Gulf port elevators [5]. During peak activity periods, trucks must often wait 30 hours to unload because queues include as many as 275 trucks [5]. To attract truckers to this haul, rates are increased to compensate for waiting times, i.e., rates are bid up until truckers' return on the congested haul is equal to that earned on other available noncongested hauls. In spite of the increase in truck rates, they are lower than rail rates; primarily because of the proximity of the production region to port locations and the associated competitive advantage of trucks.

Annually grain elevators at the Port of Houston receive 44,000-46,000 truckloads of grain and soybeans or about 20 percent of the total Port inflow. Historically, about one-third of the truck receipts have been in July and August. Within this eight-week period, there are typically three to four consecutive weeks of

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extreme peaking [5]. Three port elevators operate at the Port of Houston; however, only two are actively involved in receiving truck-delivered grain sorghum during the peak period. Analysis is restricted to these two facilities.

CONCEPTUAL DECISION MODEL

The essential problem characteristics are: (1) during the seasonal surge, truck queues develop because of inadequate unloading capacity; accordingly, truck waiting or congestion costs are generated, and (2) additional unloading capacity can be obtained only through increased costs that are associated with new investment in capital and/or labor. Investment costs to alleviate the peak-period congestion must be recovered from that period's congestion cost reduction, i.e., port elevators' present unloading capacity is adequate for the nonpeak period.

The basic problem is one of tradeoffs: (1) increasing unloading capacity gives rise to additional capital and/or labor costs, and (2) congestion cost can be reduced only through increases in unloading capacity. The lowest total cost of unloading grain from trucks is achieved when unloading capacity is increased to the point that trucks' waiting cost plus the cost of providing the increased unloading capacity is at a minimum. A literature review indicates that this decision philosophy typically is used in optimizing a queuing system [3, 4, 10, 17].

Truck waiting cost is a nonlinear function of the number of unloading facilities and their unloading rates, value of time, and average number of trucks in queue. The negative-sloped total waiting cost function (TWC) decreases as unloading capacity is increased (Figure 1). In general, amortized new investment and labor costs increase in proportion to the amount of unloading capacity provided; accordingly, total unloading capacity costs (UCC) increase as capacity is increased (Figure 1). The lowest total cost of unloading grain from trucks is achieved when aggregated truck waiting costs (TWC) and unloading capacity costs (UCC) are at a minimum. The least-cost solution or the optimal level of unloading capacity (UC*) is identified in the conceptual decision model shown in Figure 1.

Aggregated costs (TWC + UCC) cannot be specified with a high degree of certainty because of the stochastic nature of truck arrivals and unloading or service times (Figure 1). Therefore, the stochastic characteristics must be incorporated through the use of queuing methodology.

TRUCK UNLOADING QUEUING SYSTEM AND MODEL

In queuing situations, six basic characteristics describe the system [12]. Sufficient information is provided for analysis of a queuing problem by specifying [10]: (1) frequency distribution of customer interarrival times, (2) number of service stages, (3) number of service channels at each stage, (4) frequency distribution of service times for each channel in each stage, (5) behavior of the customer in the queue, and (6) queue capacity.

Three separate *service stages* are involved in the truck unloading process (Figure 2). The initial stage is the collection of a grain sample, which is placed in a sack and delivered to a grader for identification of quality characteristics. After grade determination, a document which identifies the truck and associated grain quality is transferred to the unloading facility, where actual unloading of the truck is accomplished. The truck must wait for the three stages of service and each stage requires completion before the following stage is begun. If a truck encounters no queues, the total unloading process can be accomplished in 20 to 25 minutes. The number of *service channels* or servers per stage varies. Both elevators operate two sampling lanes or channels; one facility operates four grading channels and two unloaders and the other operates two grading channels and one unloader.

The manner in which trucks are taken from the queue(s) to be served is the queuing discipline or *behavior of queuing customers.* The truck queues were observed to follow a first in, first out (FIFO) discipline. *Queue capacity* refers to the number of waiting spaces available behind a server. The trucks waiting for the initial service stage, sampling, are assumed to

FIGURE 1. CONCEPTUAL DECISION MODEL

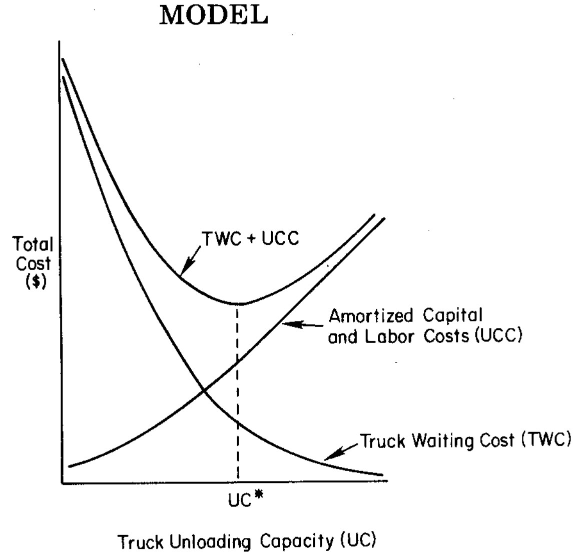
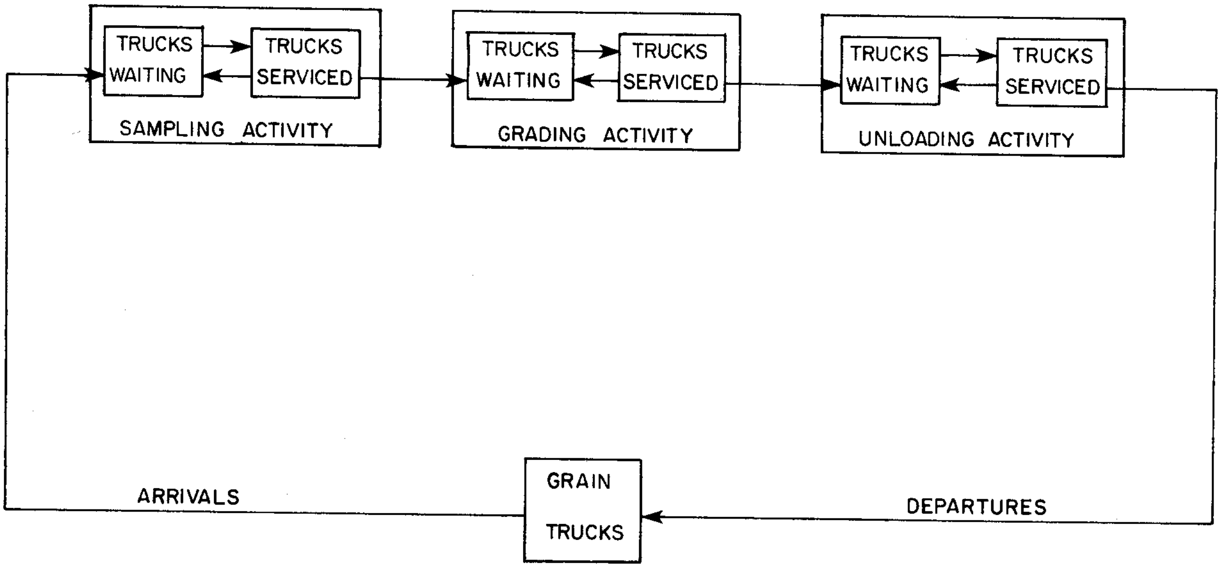


FIGURE 2. SCHEMATIC REPRESENTATION OF TRUCK UNLOADING SYSTEM



belong to a queue of infinite size, whereas the queue developing behind the unloader is finite or of fixed magnitude.

Data gathered during the peak activity period at the Port of Houston show the truck arrival pattern to be random, that is, the probability of an arrival occurring in an interval of time depends only on the length of the interval and not the interval's starting point. In such cases, the arrivals per unit of time generally represented best by a Poisson distribution [10]. When the number of arrivals per unit of time is approximated by a Poisson distribution, the time intervals between successive arrivals (*interarrival times*) can be represented by a negative exponential distribution of the following general form [16, p. 843].

$$f(t) = \lambda e^{-\lambda t}, \; t \geqslant 0$$

$$(\text{mean} = 1/\lambda, \text{ variance} = 1/\lambda^2)$$

where

$f(t)$ = density function for the time interval (t) between any two successive arrivals

λ = average number of customer arrivals per time period.

By the chi-square goodness-of-fit procedure, the collected data were determined to be described best by a Poisson distribution whose average number of truck arrivals per hour (λ) is equal to 13.83.[1] Accordingly, the frequency distribution of interarrival times was obtained by transformation into the foregoing negative exponential form.

The *service stage* distribution relates the time necessary to serve customers. Service times were collected for each channel at each stage of the truck unloading process. The data indicate that the time necessary for a truck to be served at any particular stage is best approximated by the exponential distribution. The data were subjected to a goodness-of-fit algorithm which determines the appropriate distribution using the chi-square and Kolmogorov-Smirnov test [11]. The results indicate that the sampling and grading activities are exponentially distributed with a mean of .06 and .33 hours, respectively. The truck unloading process is best described by an exponential distribution with a mean of .09 hours.[2] The exponential distribution is expressed in its general form as:

$$f(x) = \mu e^{-\mu x}, \; x \geqslant 0$$

where

$f(x)$ = density function for the time (x) necessary for service

μ = mean service time.

A stochastic network simulation model was constructed to represent each facility's queuing system [13]. The stochastic network model is composed of nodes and branches. Nodes represent points in the system where customers (trucks) are routed for service or to wait for service. In the model, each channel of

[1]These data were collected by placing Texas Highway Department traffic counters at the elevator entrances for a period of three weeks during harvest. The chi-square test was significant at the .05 level.

[2]Both test statistics for the service time distribution were significant at the .05 level.

the sampling, grading, and unloading stages is represented as a node. Branches connect nodes and include frequency distributions of service times. A source node is connected to the total queuing system via a branch that includes an interarrival time distribution of trucks. It is on this branch that truck arrivals into the system are generated. After the model has been calibrated to represent a specific unloading capacity, a series of simulations is carried out to generate necessary system statistics. These statistics include trucks' average waiting time; minimum, maximum, and average number of trucks in queue at each node; portion of time each server or node is busy; and maximum length of time that a server is idle and busy. Combining the average waiting time statistics with truck waiting cost per hour allows the truck waiting cost function (TWC) to be estimated for alternative levels of unloading capacity (Figure 1). This information, in combination with estimated costs of removing bottlenecks, provides the unloading capacity cost (UCC) relationship (Figure 1).

The simulation model's statistical output on magnitude of queue behind each node (server or channel) and portion of time server is busy identifies the location of system bottlenecks and provides information necessary to select that combination of server types which yields a heuristic least-cost solution. *Ex post* the simulation of the present system, one can discern which of the various stages represent the constraint. Accordingly, the next simulation represents a system that has been altered to alleviate the identified bottlenecks. This stepwise procedure was followed in subsequent simulations to identify the incremental system changes necessary to arrive at appropriate system modifications. Through this procedure the various number-of-server combinations are determined.

WAITING AND CONGESTION-REDUCING COSTS

Of the various methods for estimating waiting costs, the three most widely used are (1) the revenue approach, which equates waiting costs with losses in revenue [7], (2) the cost savings approach which equates nonmileage cost with waiting cost [9], and (3) the cost-of-time approach, which provides estimates of waiting cost based on the users' willingness to pay for time savings [18].

Because of an effort to provide a conservative estimate of truck waiting cost, the revenue method was rejected. This method often tends to overstate waiting cost because of the difficulty in estimating the portion of waiting time that can be converted into revenue-producing activity. The cost-of-time method was rejected for lack of a measure of grain truckers' willingness to pay for reductions in waiting times. Accordingly, to determine the value of truck waiting costs per unit of time, the cost-savings method was used. The cost-savings method generally follows the theory of the firm and the principle of cost minimization. The procedure is based on the assumption that time savings lead to a savings in resources required to perform a given volume of output. With this approach, per-hour waiting costs are assumed to be equal to the truckers' per-hour nonmileage costs.

To estimate per-hour nonmileage truck costs, a procedure developed by Adkins, Wiward, and McFarland [1] using ICC annual reports [6] was employed. On the basis of ICC reports, motor vehicle pricing index, a survey of grain truckers, and updated costs and procedures as outlined by Buffington and McFarland [2], per-hour truck waiting costs were estimated which included interest on invested capital, depreciation, property tax, drivers' wages and benefits, workmen's compensation, and social security. The value of time was estimated to be $12.39 per hour.

To reduce congestion, investment in additional unloading capacity is required. Unloading capacity is affected by altering the number of channels at the successive stages—sampling, grading, and unloading. Investment in an additional sampling channel involves new amortized capital and labor costs. Amortized capital cost is associated with investment in an open-sided metal building whose dimensions approximate those of the truck-trailer; an additional laborer is required to carry out sampling. To increase grading capacity, additional personnel and a modest investment in grading equipment are necessary. Substantial investment is required for an additional unloading channel—in particular, a building to cover the dump pit, a combination scale and lift platform for truck weighing and unloading, and grain-handling machinery to move grain from pit to elevator leg. Cost estimates were made in consultation with port elevator management and an elevator construction firm.

RESULTS

Previous analysis revealed the port elevators' unloading capacity to be adequate in all time periods except the three consecutive weeks associated with regional grain sorghum harvest. Both port elevators operate 24 hours a day during the congestion period; therefore, all capacity changes were simulated under this condition. Because the current system is appropriate for the nonpeak period, all amortized new capital costs were assumed to be incurred in the peak, i.e., the congestion-reducing costs (UCC) had to be recovered from the congestion cost savings associated with this three-week peak receipt period. On the basis of the historical volume of truck receipts at each elevator during the congested period, the queuing model's statistical output, and estimated waiting and congestion-reducing costs, the values in Table 1 were generated.

With the current system, congestion costs are substantial, particularly at the second elevator where they range up to $.13 per bushel (Table 1). This facility handles approximately twice the truck volume of the first elevator during this period. The least-cost organization at the second elevator involves the addition of one sampling, two grading, and one unloading channel. This organization reduces estimated congestion costs from $718,790 to $23,571 and increases the associated amortized capital and labor costs by only $66,987—a net cost reduction of $628,234. The optimal level of congestion cost is approximately $.005 per bushel.[3] The second elevator is operated by a major international grain trader and the first is operated by a regional cooperative. Relatively modest cost reductions are available at the first elevator.

SUMMARY AND IMPLICATIONS

This case study is an attempt to measure the cost of congestion in the truck-to-ship intermodal transfer system at the Port of Houston and to examine the economic feasibility of removal of this congestion. The analysis reveals congestion cost to be substantial and congestion-reducing investment in labor and capital to be economically feasible. That is, the

TABLE 1. PEAK-PERIOD TRUCK CONGESTION-REDUCING COSTS, PORT OF HOUSTON[a]

Port Elevator 1						
Channels	System Unloading Capacity (Trucks/hr.)	Average Waiting Time (hours)	Total Waiting Cost (TWC)[b] ($)	Amortized New Capital Cost (UCC)[c] ($)	Added Labor Cost (UCC)[d] ($)	Total Cost (TWC + UCC) ($)
2 sample* 4 grade 2 unload	12	3.78	127,904	N.A.	N.A.	127,904
3 sample 6 grade 2 unload	18	1.07	36,206	891	5,712	42,809**
4 sample 8 grade 2 unload	22	.99	33,499	1,782	11,424	46,705
5 sample 10 grade 3 unload	30	.90	30,453	56,673	19,488	106,614

Port Elevator 2						
Channels	System Unloading Capacity (Trucks/hr.)	Average Waiting Time (hours)	Total Waiting Cost (TWC)[b] ($)	Amortized New Capital Cost (UCC)[c] ($)	Added Labor Cost (UCC)[d] ($)	Total Cost (TWC + UCC) ($)
2 sample* 2 grade 1 unload	10	12.53	718,792	N.A.	N.A.	718,792
2 sample 2 grade 2 unload	12	10.01	574,231	54,000	3,528	631,759
3 sample 4 grade 2 unload	20	.41	23,571	54,891	12,096	90,588**
4 sample 5 grade 3 unload	30	.38	22,005	109,672	20,916	152,593

N.A. Not Applicable

*Current System

**Least-cost solution.

[a]Costs based on a three week period.

[b]Waiting time valued at $12.39/hour.

[c]Additional unloading channel initial investment estimated at $450,000; assumed to have 20 year life. Opportunity costs calculated at 12 percent. Additional sampling channel investment caluclated at $6,000; assumed to have 20 year life. Additional grading channel investment estimated at $1,000. Opportunity and maintenance costs included.

[d]Labor costs based on current wage scales paid to port terminal employees.

[3]The least-cost organizations reported in Table 1 are based on the truck waiting cost estimate of $12.39 per hour. Varying this estimate over a range of ±50 percent revealed no change in the least-cost organization.

additional cost of congestion-reducing investments would be less than the associated reduction in congestion cost. In a competitive environment, the congestion costs would be internalized and current unloading capacity increased because of anticipated decreases in truck rates. However, with current market organization, export terminals apparently are not internalizing congestion costs because there is little inclination to alter facilities.

It is hypothesized that most of the current congestion cost is borne by the farmer via lower grain prices. With current market organization, exporters appear to be price-setters and country elevators price-takers. That is, the price negotiated between exporter and country elevator is determined primarily by the exporter. Trucks will not participate in the country elevator to port terminal haul without additional compensation for waiting because noncongested hauls are available. Country elevators arrive at the farm price by subtracting their margin and the truck rate to port elevator from the exporter's purchase price. Consequently, farm price reflects the costs of congestion. The excessive congestion persists because of a market organization that allows this cost to be passed on or not internalized—a misallocation of resources.

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