McCormick
Northwestern Engineering
Northwestern University Transportation Center

Grain and Soybean Industry Dynamics and Rail Service

Analytical Models of Rail Service Operations

Executive Summary

Michael Hyland, Hani Mahmassani, Lama Bou Mjahed, and Breton Johnson
Northwestern University Transportation Center (NUTC)

Parr Rosson
Texas A&M University

To remain globally competitive, the United States' grain industry and associated transportation services underwent significant restructuring over the past fifteen years. New technologies, helped by weather changes, led to sustained yield volume increases in the Upper Midwest. To move larger volumes faster and at lower cost, the railroad industry introduced shuttle train service. Traveling as a unit to the same destination, shuttle trains save considerable time in transit and potential delay, bypassing intermediate classification yards. Grain shippers concurrently began consolidating and storing grain in larger, more efficient terminal elevators (shuttle loaders) instead of country elevators. This report examines the effectiveness of shuttle train service and the terminal elevators supporting the shuttle train system, under different demand levels, through the formulation of simple mathematical models. In order to compare shuttle and conventional rail service, this paper introduces three distinct models. The first model, referred to as the 'time model', determines the time it takes to transport grain from the farm to a destination (e.g. an export elevator). The second model, referred to as the 'engineering cost model', determines the aggregate variable costs of transporting grain from the farm to an export elevator. The third model, referred to as the 'capacity model', determines the maximum attainable capacity (i.e. throughput) of a rail network as a function of demand for rail transport and the percentage of railcars on the network being moved via shuttle service and conventional service.

Because the introduction of shuttle train service was accompanied by the prominence of terminal elevators, the scope of the analysis extends upstream of the rail transportation network to encompass the following three phases of the grain logistical supply chain:

- Transport from farm to local terminal or country elevator via truck
- Handling and storage of grain at terminal or country elevators
- Transport of grain from local elevator to export elevator via conventional or shuttle service

The 'time model' determines the total time to transport grain from farm to export elevator. The time model incorporates the following components:

- Travel time from farm to grain elevator via truck
- Truck unloading time at elevator
- (Short-term) storage time of grain at elevator
    - We assume that grain remains in storage until enough grain is consolidated to fill an entire shuttle train (110 railcars) or conventional train (24 railcars)
- Railcar loading time at grain elevators
- Rail transport time from local elevator to export elevator
    - Conventional service: we capture the time spent in classification yards
    - Shuttle service: we capture the time lost due to mandatory crew changes

The time to truck grain from farm to elevator and unload the truck is small compared with elevator storage time and rail transport time. The storage time of grain is a function of the demand for grain rail transport service in the region surrounding an elevator. The higher the demand, the more grain entering an elevator per unit of time, and therefore the shorter the time grains spend in storage. The results of the time model suggest that shuttle train service is significantly faster than conventional rail service at moderate to high demand levels. The reason for this outcome is due to the fact that shuttle trains bypass classification yards and transport grain directly from origination to termination point. In contrast, conventional rail service requires grain railcars to enter classification yards. At very low demand levels (<250 tons per day), conventional service is comparable to shuttle service in terms of total time due to the fact that it takes a longer time to consolidate enough grain to fill an entire shuttle train at a terminal elevator than a conventional train at a country elevator. However, as the demand rate increases, shuttle service quickly begins to outperform conventional service in terms of travel time. The model results suggest that at demand rates greater than 2,500 tons of grain per day, conventional service takes twice as long as shuttle service (12 days vs. 6 days) to transport grain from eastern North Dakota to the Pacific Northwest. We conducted a number of sensitivity analyses on the model results with respect to different parameter values. The sensitivity analyses strengthen the initial time model results: shuttle train service is faster than conventional service at moderate to high demand levels

The engineering cost model captures each of the variable logistical supply chain costs of moving grain between the farm and the export elevator. The model excludes the capital costs of country and terminal elevators, classification yards, and rolling stock equipment. Similar to the time model, the cost model components include: a trucking cost model, an elevator cost model, and a rail transportation cost model. Note that engineering costs are different from “accounting” costs, intended for tax and financial reporting, in that they refer to direct costs actually incurred in providing the service in question.

The cost to transport grains via truck from farm to terminal elevator is larger than the cost to truck the grain to country elevators due to the fact that there are fewer terminal elevators; therefore, on average the distance from farm to terminal elevator is greater than the distance from farm to country elevator. The storage, or inventory costs, of terminal elevators are higher than country elevators because terminal elevators need to store larger volumes of grain to fill 110 railcar shuttle trains. Despite the increased upstream logistics costs associated with shuttle train service relative to the upstream costs of conventional service, the cost efficiencies associated with shuttle train transportation over the rail network outweigh the increased upstream costs. Transporting the grain faster via shuttle service reduces in-vehicle inventory costs. Moreover, bypassing classification yards reduces labor costs, as does always having the optimal number of railcars on a train.

The results of the cost model suggest that at demand rates greater than 500 tons per day, shuttle service is approximately 16% cheaper than conventional service ($21 per ton vs. $25 per ton). These values include trucking and elevator storage costs as well as rail transportation engineering costs. A deeper analysis reveals that for both shuttle train service and conventional service, rail transportation costs account for a significant portion of the total logistical supply chain costs, approximately, 70% for shuttle service and 85% for conventional service. Once again we performed a number of sensitivity analyses on the cost model results with respect to model parameters including trucking costs, the price of grain and the handling costs of grain elevators.

The capacity model differs considerably from the time and cost models. The geographical scope of the capacity model is considerably larger than that of the time and engineering cost models. Rather than modelling the demand for a local terminal or country elevator, the capacity model incorporates all the demand for a rail classification yard. Additionally, the capacity model includes non-grain demand for rail service. Lastly, unlike the time and engineering cost models that compare shuttle service with conventional service as if the two service types could not exist simultaneously in the same region, the capacity model varies the percentage of demand served by conventional service and shuttle train service.

The capacity model is essentially a queuing model designed to evaluate the throughput of a section of track that includes a rail classification yard. All conventional service railcars, both grain and non-grain, enter the classification yard and are 'served' at a fixed rate. The shuttle trains, both grain and non-grain trains, bypass the classification yard unless the classification yard queue exceeds the capacity of the yard's receiving tracks and spills over onto the mainline.

As mentioned previously, we vary both the total demand for grain rail transportation and also the percentage of grain served via conventional and shuttle service. Demand is varied in small increments, whereas, we include four different percentages of demand served by shuttle service: 0%, 25%, 50% and 75%. We assume the number of non-grain railcars is fixed. A series of interesting results were obtained from the capacity model. First and foremost, if demand is low enough switching grain railcars from conventional service to shuttle service has no effect on throughput, as expected. As demand increases the throughput of the network is constrained by the service rate of the classification yard. The larger the percentage of grain served by shuttle service the higher the demand rate at which the classification yard constrains total throughput. In the 0% case and the 25% case, at high demand rates, the classification yard queue spills onto the rail network and prevents shuttle trains from bypassing the classification yard unimpeded. The results of the capacity model are quite clear, switching grain railcars to shuttle service from conventional service never decreases the throughput of the rail network and at high rail transport demand levels it can significantly increase the throughput of the rail transportation network.

The time, cost, and capacity models presented in this report allow for a comprehensive comparison of shuttle train service and conventional train service. The results of each model illustrate that shuttle train service offers meaningful advantages relative to conventional service under most realistic demand scenarios. The more grain demand that railroads can switch from conventional service to shuttle service the greater the overall operational and economic benefits. The cost, time and throughput advantages of shuttle train service all stem from its ability to bypass classification yards. Bypassing classification yards reduces travel time, decreases labor costs, and increases the capacity of rail transport networks. Each of these advantages benefit not only railroads but also grain shippers and grain producers. Grain producers and shippers require fast transport times and low transport costs to compete in global markets. Moreover, increased rail network throughput allows grain shippers (i.e. grain elevators) and producers to sell more grain when prices are at attractive levels.