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Analytical models of rail transportation service in the grain supply chain: Deconstructing the operational and economic advantages of shuttle train service

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ABSTRACT

This paper introduces conceptual and mathematical models of the domestic grain supply chain incorporating trucking, elevator storage, and rail transportation. We compare conventional rail service supported by country elevators with shuttle service supported by terminal elevators across three critical transportation service dimensions: travel time, cost, and capacity. Even after taking into account trucking and elevator storage, the time and cost model results indicate that shuttle service transports grain faster and reduces logistical supply chain costs, respectively, relative to conventional service. The rail capacity model results demonstrate that shifting grain from conventional to shuttle service significantly increases rail capacity.

1. Introduction

Grain production costs in the United States are significantly higher than in South American countries that compete on the global market (e.g., Brazil and Argentina); however, the United States' domestic (i.e., inland) transportation system is significantly more efficient in terms of cost, speed, and reliability (Frittelli, 2005). These efficiencies are the result of significant restructuring within the grain industry and its associated transportation services over the past twenty-thirty years. Maintaining a competitive advantage in terms of transportation costs and efficiency is crucial in order for the United States to continue selling grain to export markets. The analysis presented in this paper examines and quantifies the advantages and disadvantages of the restructured grain logistical supply chain. For context, the analysis is patterned on the Upper Midwest region (i.e., North Dakota, South Dakota, and western Minnesota) of the United States, though the models consider a highly idealized, and general, context.

The restructuring of the grain supply chain included the introduction of (1) shuttle train service by the railroads, and (2) larger, more efficient, storage elevators (henceforth referred to as terminal elevators) by grain shippers. The restructuring of the grain supply chain coincided with increased yield volumes, due to technological advances and weather changes, on the grain production side. Additionally, the railroads promoted and incentivized the construction of terminal elevators throughout the Upper Midwest.

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The motivation for providing shuttle and unit train service[1] lies in a simple realization – that freight rail transportation is most cost efficient when a large number of railcars move together on a single train. As the number of railcars on a train increases, the costs of rail transportation are spread over more railcars, resulting in a lower cost per railcar; hence, railroads aim to move as many railcars as possible on a single train. In order to obtain the cost efficiencies associated with large trains, railroads have historically consolidated railcars at classification yards. Under conventional rail service, single or multiple railcars are typically moved from their origin to a nearby classification yard where they are grouped with other railcars traveling to a similar destination. Railcars often travel through multiple classification yards before reaching their destination. The disassembly and reassembly of railcars at classification yards is a time and resource consuming process, subject to considerable variability, and hence is a source of unreliability in service times. Historically, railroads and shippers have accepted the inefficiencies of classification yards as the price of railcar consolidation (Keaton, 1991). However, the introduction of shuttle train service for bulk commodities, such as coal and grain, allowed railroads to move a large number of railcars directly from origin to destination, thus bypassing classification yards.

In order for the railroads to move 100 or more railcars directly from origin to destination, it is necessary for the grain storage elevators at the origin and destination to be able to load and unload 100 or more railcars in a reasonable time. Prior to the restructuring of the grain supply chain, most grain elevators either did not have enough storage capacity to fill 100 railcars with grain or it would take the elevators multiple days to load an entire shuttle train with grain. Hence, the railroads decided to incentivize existing elevator owners and other grain industry stakeholders to either retrofit their existing elevators or build new, terminal, elevators in order to efficiently load 100 or more railcars in a short period. Because of the incentives, larger, more efficient terminal elevators began popping up throughout the grain producing regions of the United States. These larger, more efficient terminal elevators handle the same volume of grain as multiple country elevators (U.S. Department of Agriculture, 2014). This shift from single and multi-railcar shipments originating at country elevators to 100 or more railcar shipments originating at terminal elevators increased the efficiency of grain transportation in many ways; however, it did result in two negative impacts: longer trucking distances between farms and storage elevators and potentially longer storage times at elevators. The longer trucking distances stem from the fact that each terminal elevator handles the same volume of grain as multiple country elevators. Hence, the draw areas of terminal elevators in the restructured grain supply chain are much larger than the draw areas of country elevators prior to restructuring. Moreover, many grain elevator cooperatives now truck grain from multiple country elevators, which act as feeders, to a single terminal elevator. The longer storage times at terminal elevators are due to the fact that shippers need to consolidate more grain to fill 100 railcar shipments than one-two railcar or even six-26 railcar shipments. Therefore, while it is clear that transporting grain over the rail network via shuttle service is more efficient than moving grain on mixed-manifest trains, previous studies have not explicitly examined whether or not the negative impacts that may occur upstream of the rail network outweigh the benefits on the rail network. The analysis presented in this paper aims to fill this gap, while providing a simple framework that helps convey the main trade-offs involved. The approach adopted is to present a stylized representation of the underlying system, capturing essential features without the clutter of non-essential detail.

This paper presents three analytical models to determine the advantages and disadvantages, from the perspective of global competitiveness, of the restructured grain collection and transportation system (shuttle service and terminal elevators) relative to the old system (conventional service and country elevators). The three mathematical models address three critical performance dimensions of grain transportation, namely time, cost, and throughput. The analysis explicitly takes into consideration the components of the grain supply chain upstream of the rail transportation network. Understanding the trade-offs associated with these two types of grain collection/transportation systems across the entire supply chain, not just on the rail network, is crucial to providing low cost, fast, and reliable transportation to the grain industry that allow it to compete in export markets.

The remainder of this paper is structured as follows: Literature related to grain logistics and transportation is reviewed in Section 2. Section 3 presents a conceptual model of a grain transportation network and lists the necessary model inputs and model outputs. Sections 4–6 present the time, cost, and throughput models, respectively. Each of these three sections presents mathematical models, base parameter values, numerical results, and sensitivity analyses. Lastly, Section 7 presents conclusions along with potential extensions to the capacity model.

2. Literature review

This section reviews the literature related to the grain supply chain. The integrated models of the grain supply chain presented in this paper are rooted heavily in the existing literature. In fact, many of the individual component models, model assumptions, and parameter values used in this paper to compare shuttle service/terminal elevators with conventional service/country elevators come from the existing literature.

Frittelli (2005) finds that between 1980 and 1998: considerable consolidation occurred in grain production, rail transportation, and grain storage. The number of farms decreased by 15% but farm size increased by 11%; the number of terminal

[1] Shuttle trains and unit trains are defined differently throughout the literature and in the rail industry. Consistent with most recent studies, the term shuttle train in this paper refers to 90–120 railcar shipments wherein the railcars and the locomotives that power shuttle trains are not detached from one another during normal service (Sparger and Prater, 2012); whereas, the term unit train refers to 50–55 railcar shipments that are often combined with other single railcar, multi-car, and unit train shipments (Frittelli, 2005).