Grains, Trains and Chains: An Agent-Based Model of the Western Canadian Grain Handling and Transportation Supply Chain

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for the Degree of
Master of Science

In the
Department of Bioresource Policy, Business & Economics
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by
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ABSTRACT


An open access policy will be explored to determine if it can restrain incumbent railway behavior and help ensure the continued timely delivery of Saskatchewan wheat to export markets. An agent-based simulation is developed to evaluate the feasibility of implementing competitive access applicable to grain movement. The simulation contains: all grain and oilseed farmers in Saskatchewan, in addition to all primary elevators and inland terminals in the province; both Class I railways; and the port of Vancouver. The model uses agent-based simulation to incorporate spatial and temporal effects into a dynamic supply chain, observing delivery penalty events. A competitive opportunity may be present for a potential rail entrant if the volume and frequency of delivery penalties are high enough and if the locations are sufficiently close enough to make entry feasible.

I found in the simulation that there are approximately one million tonnes of wheat that do not move in a timely manner on an annual basis within the province of Saskatchewan. Delivery penalty event volumes averaged approximately 85,000 tonnes per month or approximately 30 shipments across Saskatchewan per month. This delayed grain is not randomly distributed across the elevators in the province, but occurs in dense pockets. I find in the simulation that a potential rail entrant does not earn a profit. The return on investment for an entrant that transported all delivery penalty events to export position is -5.5%. If an entrant attempted “hit-and-run” entry and only transported the largest shipments, their return on investment would increase to -1.7%.
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Chapter 1
INTRODUCTION

1.1 Background

Modern supply chains are dynamic systems with multiple interactions and varying temporal patterns. The grain handling and transportation system (GHTS) of western Canada is an example of large scale supply chain dynamics. This consists of farmers harvesting and delivering a multitude of commodities in varying amounts throughout the calendar year via an extensive road network; a fixed infrastructure of elevator storage and grain handling facilities for transshipment of various commodities; and a rail network connecting the elevators to port facilities for transshipment to water vessels and delivery to final customers.

Western Canada is effectively landlocked from ocean ports, meaning primary transport of grain is done using the rail network that services those ports. Trucking of agricultural commodities takes place over traditionally short hauls of a few dozen kilometers as farmers transport grain from where it is grown to temporary storage at an inland grain terminal. Trucking rates are tightly linked to the price of fuel, a situation that was particularly noteworthy in 2008 as the price of crude oil climbed to record levels (Saskatchewan Trucking Association, 2008). The current economic environment has dropped fuel and subsequently transportation costs for the short term, but regardless of these cost decreases, it is still not feasible for western Canadian grain to be transported via truck into an export position.

In the case of western Canada, the only sector that can economically transfer grains to export position is rail. Goods transported by rail tend to be bulky commodities with a range of monetary
value, such as grains or coal, as well as dense finished products, such as those loaded into containers. Asset specificity can attenuate backhaul opportunities, effectively forcing shippers to pay for the movement of the railcar both when it is empty and when it is full (Clark & Easaw, 2007). In this case, shippers can be captive to rail transportation and the high asset specificity of the rail industry does not necessarily promote competition so as to alleviate these shipper concerns.

There is on-going regulation in Canada that seeks to ensure that the incumbent rail carriers, Canadian National (CN) and Canadian Pacific Railway (CP), are not taking advantage of Prairie farmers through exercise of market power because of the grain industry’s reliance on rail transport and the cost structure of rail transportation (Edsforth, 2010). There also is some question as to whether economic regulation in rail actually helps balance the situation. I offer that solutions to the regulatory puzzle of grain movement need to incorporate the spatial and temporal dependencies that are integral to the problem. The Canadian GHTS has contracted considerably in size from the 1960s, but is still remains large in scope and has a long history of missed marketing opportunities and shipper complaints (Canadian Transportation Agency, 2008). One approach that has been tried in other rail systems to enable more competition within the rail sector itself is a policy often referred to as ‘open’ or ‘competitive’ access (Carlson & Nolan, 2005). From a public policy perspective, implementing these kinds of changes in Canada without thorough analysis of their feasibility and industrial consequences carries potential uncertainty for both grain shippers and carriers.
1.2 Problem Statement

Given continued anecdotal evidence of rail market power in this sector, I will determine if an open access policy can restrain incumbent railway behavior and help ensure the continued timely delivery of Saskatchewan wheat to export markets. I will develop an agent-based simulation to evaluate the feasibility of implementing competitive access applicable to grain movement. A competitive opportunity may be present if there is an allocation of railway cars that are loaded and ready for transport from an elevator to export position, but the incumbent railway does not move the railcars in a timely manner. The opportunity cost of not moving the railcars represents a lost marketing opportunity for the shipper and is an opening for a potential railway entrant to move the wheat to Vancouver.

1.3 Objectives

In the grain supply chain, lost profit/marketing opportunities stem from the spatial distribution of the grain elevator network, as well as the temporal nature of grain deliveries. The data used to calibrate the simulation model are based on reality, so there are several factors that should emerge as critical to marketing and profitability. Areas that have relatively higher grain production volumes and a greater storage capacity within each elevator should be less likely to incur lost marketing opportunities because the rail network, as incorporated within the simulation, has evolved over time to handle that volume of crop. Conversely, production regions that have lower average annual grain production have a more dispersed elevator population and should thus have a greater likelihood of lost opportunities. It is also expected that the smallest elevators, or those with the smallest storage capacity, will experience the most frequent loss of marketing opportunity due to their lack of capacity necessary to accommodate temporal delivery
changes. I expect that there are frequent measurable volumes of wheat that are not moved in a timely manner, however, it is likely not possible for a potential entrant to be profitable transporting numerous small shipments of a single commodity to export position.

1.4 Thesis Organization

This thesis is composed of seven chapters. Chapter Two summarizes the broad and evolving literature on logistics, the structure of the grain handling and transportation system, the scope of rail regulation and a brief history of commodity movement. Chapter Three briefly explores the idea of dis-equilibrium modeling in contrast to standard methods used especially within the economics and competition literature. Chapter Four describes the basic simulation model of this supply chain and the data used to calibrate it. Chapter Five outlines the dynamics of the model and highlights key behaviour within the grain handling supply chain. Chapter Six explains and contextualizes the overall results of the simulation and using model output, develops an economic feasibility or contestability analysis for a potential entrant in this sector of the rail industry. The last chapter summarizes the results of the simulation and competition analysis as well as suggesting a number of future research directions.
Chapter 2

REVIEW OF LITERATURE ON LOGISTICS AND THE GRAIN HANDLING AND TRANSPORTATION SYSTEM

2.0 Introduction

This chapter gives an overview and history of the grain handling industry in Canada, plus provides the reader with a review of the relevant transportation and modeling literature. This is done to set the context for this thesis and familiarize the reader with the basic concepts of logistics and the grain handling supply chain. The chapter is also intended to give the reader an overview of the complexity and linkages between various parties in the grain handling supply chain as well as offer a sense of how these parties are assumed to interact within the simulation framework described later in the thesis.

2.1 Theory and Rail Economics: Logistics of Western Prairie Grain Handling

The grain growing regions of western Canada cover a significant area. Within the region farms are located either close to transportation links or choose a location because of the particular regional soil zones that can give greater potential yields. So-called grid roads connect the vast majority of farms to major roadways, while the major roadways typically follow rail corridors to the east and west. All told, the number of nodes within the grain transportation network plus the large volume of goods that move within it necessitate understanding of modern logistics.

2.1.1 Modern Logistics

Fundamentally, the objective of modern logistics is to get the right product to the right place at the right time. As defined, logistics is really the structured movement of parallel flows of information, physical goods, and finance. In the case of bulk commodities as modeled in this
thesis, this latter definition is a bit too broad, as the term “right product” is probably too encompassing. A more complete definition of logistics is not complete without some notion of getting the right quality or condition and at the right cost (Ballou, 1992; Katz & Shapiro, 1985). Getting those characteristics into the delivered commodity is essentially a combinatorial problem – this is complicated by multiple nodes within a supply chain as well as the movement between those nodes. Stochastic demand for commodities, quality variations beyond producer control, and varying farm output year to year can wreak havoc for a functional grain supply chain. All components of this supply chain, from storage and management to distribution and route scheduling can generate complications that prevent the right product from getting to the right place (Davidsson, Henesey, Ramstedt, Tornquist, & Wernstedt, 2005).

2.1.2 Grain Logistics and the Canadian Wheat Board

Along with farmers, grain companies and railways, layered on top of the grain handling supply chain at least for the moment is the Canadian Wheat Board (CWB). Currently, the CWB sells western Canadian wheat and barley on behalf of farmers through strategic overseas marketing that attempts to generate price premiums. As part of the legislation that created the CWB, the Board was granted rights to rail car scheduling in order to ensure they could meet delivery contracts they sold (Government of Canada, 1985). Today, the CWB exerts some power on the choice and direction of grain movement. Once done explicitly with face-to-face meetings with the railways over car allocation, today this is accomplished via incentive mechanisms such as the Freight Adjustment Factor (FAF) which functions as a spatial distribution mechanism for grain (Canadian Wheat Board, 2011; Quorum Corporation, 2006). The FAF accounts for an adjustment in the location of the eastern pooling basis point, the lower St. Lawrence, and for the
location advantage of shipments from delivery points in the eastern prairies (Quorum Corporation, 2005). FAFs are set before each crop year in order to incorporate variations in cropping patterns, and differences in seaway freight rates and sales opportunities.

2.1.3 Risk
Risk is present throughout the Canadian grain handling supply chain. The logistics literature typically focuses on the risk that the rail system adds to a supply chain, such as the unpredictable nature of rail car deliveries (both when and how many cars), and the rate of rail car unloading times, which is the time it takes for an assembled train to leave an elevator until that car is emptied into a ship (Wilson, Dahl, & Carlson, 1998). Risk also occurs in agricultural production, as seasonal variations in temperature and extreme weather events, such as drought or flooding, can affect production volumes. Weather events also pose a risk to rail movements, as very cold temperatures or heavy snow can hamper rail companies’ efforts to operate through the Rocky Mountains to access western Canadian ports.

2.2 Theory and Rail Economics: Elevators and Delivery

2.2.1 Elevator Catchment Areas
A catchment area is the region from which an elevator draws its grain deliveries from farmers. Typically larger elevators have larger catchment areas, while smaller elevators have smaller catchment areas, leading to a variety of sizes of inland terminals. Catchment areas can increase in radius through the use of trucking premiums (or subsidies) that reduce or remove the truck cost. This is essentially the Hotelling-Bertrand spatial pricing model, meaning that farmers who deliver grain receive the same gross revenue for their product, and are charged an amount for
trucking which depends on location, effectively increasing the offered price at a location (Hotelling, 1929; Sharkey and Sibley, 1993). Within production areas on the Prairies, there are areas where large concrete facilities are present, but smaller elevators still attract sufficient volume in many cases to be viable. This situation occurs because of the varied sizes of catchment areas for grain in the region (see Figure 2.1).

![Figure 2.1. Elevator catchment areas](image)

### 2.2.2 Trucking Rates

Each elevator is at least a partial monopsonist in a particular region because of the spatially distributed nature of elevators and farmers (Davis & Hill, 1974). However, typically, trucking rates decrease per unit distance. Once a load is on a truck, the actual distance it travels, up to several hundred kilometres, does not have much effect on the total cost of the movement (Weyburn Inland Terminal, 2011). With decreasing costs per unit transported, it is reasonable for
a farmer located in one catchment area to haul grain a considerable distance in exchange for a more favorable price. Such an expanded delivery radius opens the possibility of many more delivery points for an individual farmer.

When grain companies offer financial incentives to farmers to transport their crop to specific locations, it changes the relationship between road and rail transportation, as well as the distance over which trucks are competitive with railways.

2.2.3 Truck Transportation
The grain trucking sector has several unique characteristics. Farm level grain supply is distributed throughout a region and is typically trucked to one or two delivery points located within a given area. Instead of setting free-on-board (FOB) prices, buyers may be able to spatially price discriminate. For example, buyers may compete for grain by signing ex ante production contracts. In this case, the price is set at the farm gate and the buyer absorbs the trucking expense. Discriminatory pricing also results in cross-hauling. An elevator company may transport grain to multiple other elevators after taking delivery to realize shipping advantages. Many forms of trucking subsidies are common in Saskatchewan. Farmers commonly choose to deliver to distant delivery locations because, as compared to a closer point, they are offered a better grade or price, or are offered a trucking cost incentive, both of which improve profitability (Vercammen, 2001).

2.2.4 Trucking Premiums
Trucking premiums offer elevators a way to effectively charge different tariffs to different farmers. This allows elevators to offer an incentive for those farmers that are farther from the
delivery point, or it allows closer elevators to be more competitive by offering a higher price for equivalent grain. Trucking premiums have emerged because branch line abandonment in the region has meant more farmers are forced to truck their grain further distances. Potential catchment areas for terminals have increased because trucking premiums lower the cost per tonne of freight, essentially yielding a net increase in the price received for the grain being delivered (Park, Wilson, & Johnson, 1999). Railways also offer discounts in freight rates to elevators that can spot large numbers of cars and elevators may choose to pass on those discounts to farmers in the form of trucking premiums. For example, the reduction in the grain freight rate on 50 car blocks from CN and 56 car blocks from CP are $3.64 and $4.55 per tonne respectively. The reduction for 100 car blocks from CN and 112 car blocks from CP are both $7.28 per tonne (see Table 2.1). The freight rate discounts treated as an expense within the revenue cap formula, allowing the railways to increase freight rates while still remaining within the revenue cap.

2.2.5 Road Damage
The rail system serving grain handling was set up to export western Canadian bulk products. Primary rail lines run east and west across the country, with a number of branch lines spurring north and south to access terminals in between. The system was built with product flows going to the east (Thunder Bay) and west coasts, not to other locations on the prairies. Today, moving grain to processors costs less if done by truck because of the comparatively short distances hauled. And trucking rates still closely reflect costs because the trucking industry is very competitive with many firms. However, if road damages from trucking use were reflected in trucking costs, trucking services would be used less, and there would be greater incentive for farmers to use local delivery points as rail would be more competitive over a shorter distance.
While not typically accounted for in regulatory discussions of the grain handling system, road damage from grain transportation is part of the cost of operating the grain handling system (Gray, 1996; Babcock, Bunch, Sanderson, & Witt, 2003).

2.3 Theory and Rail Economics: Elevator Storage and Management

Elevators in western Canada are used for storage and can take in thousands of tonnes of grain to a fixed location so that the railways can take delivery of the grain and transport it to an export position. In order for the grain companies who operate the elevator to make money, they have a strong incentive to turn over as much grain as possible. The profitability of operating an elevator is directly related to the volume of grain the elevator purchases (Whitacre & Spaulding, 2007; Johnson & King, 1998; Fulton, 1996). For every tonne of grain handled, the elevator charges farmers a tariff. The basis is how the elevator is compensated for receiving, handling, and loading of rail cars to get the grain into an export position. The basis also reimburses the elevator for the removal of dockage (i.e. waste), and when the costs are all added up, the tariff is an important source of revenue for elevator companies, representing a sizeable cost to grain producers (Vercammen & Fulton, 1996). The basis levels are used as signals by the grain companies to tell farmers when to deliver their open market crops and when to hold off on delivering grain.

2.3.1 Price Variation over a Region

“If grain markets [have perfect information], then prices should differ between locations by no more than the cost of transportation, among time periods by no more than the cost of storage, and among product forms by only as much as the cost of product transformation” (Davis & Hill,
1974). But many of the significant variables that explain price variation over geographical space are out of the elevator’s control (Davis & Hill, 1974). If there is a short supply of grain, then the elevators will be competing to handle the grain and the price will subsequently rise. During the harvest rush, the most valuable place for farmers to spend their time is harvesting the grain, not hauling it to market, unless there is insufficient on-farm storage. During this time, the cost of transportation increases because of the high opportunity cost of time. Because farmers do not have all of the time that they would ideally have to make a delivery decision, this effectively decreases the number of delivery points the farmer can look at as potential delivery sites and creates a spatial problem that yields an elevator some market power (Davis & Hill, 1974).

2.3.2 Discriminatory Pricing

Elevators can use discriminatory pricing as long as farmers can be kept separate and pricing can be based on marginal cost pricing or differences in demand (Cobia, Wilson, Gunn, & Coon, 1986). As elevators compete more vigorously for the patronage of some farmers, differences in demand arise from the perspective of the elevator. Elevators have a strong incentive to attract additional volume because of economies of size. Once a facility is built, total average costs are almost entirely a function of volume because even costs normally classified as variable react like fixed costs to changes in volume.

2.3.3 Tariff Impacts

Grain producers in the Canadian prairies have always faced long distances to markets and have been effectively tied to a few shippers. A producer’s decision of when and how to market their crop can have a big impact on net profit. By understanding the local tariff, the producer can
compare futures prices with cash and forward contract price quotes. Besides qualitative differences, non-Board grains and oilseed location tariffs reflect arbitrage between different locations. The two components of the local tariff are the freight costs to the destination and the elevator handling fees.

2.3.4 Storage

There is value in storing grain and that means trying to identify a base level of ideal capacity in a terminal at a given time. Most grain storage is not priced directly; the price of storage is embedded in the basis. The short run price of storage includes more than just the cost of storing commodities, it also includes shrinkage and damage, excess drying effects, and the benefits from owning, known as convenience yields (Paul, 1970). A convenience yield occurs when there are more benefits to storing grain than there are costs associated in doing so, and in this case, the price of storage is said to be negative. Grain companies have desires to keep a certain amount of their capacity used up for storage (Johnson & King, 1988). Bin space is used not only for storage, but also to handle a crop. This will influence marketing and purchasing decisions because any buying and selling will alter capacity percentages.

2.4 Theory and Rail Economics: The Importance of Transportation

Ultimately, western Canadian farmers are reliant on an efficient rail service to export their grain. The long distances from the prairies to major ports and the bulky nature of grains give rail transportation an inherent advantage over trucking. Canadian grain shippers have been treated differently than other Canadian shippers because of the relatively low value of the product, the lack of alternative modes of transportation such as barges, distributed shipping points, and the presence of a single rail carrier at many locations (Park, Wilson, & Johnson, 1999).
2.4.1 Captive Shippers

On the whole, grain shippers do not have many options when they attempt to get their grain into an export position because of the land-locked nature of western Canada. West coast ports are between 1,000 and 2,600 kilometers from grain production, excluding truck transportation as an option of getting western grain into export position (DMTI Spatial, 2008). Railways have the ability to extract monopoly rents on low value products that are shipped long distances because of limited options of alternative transport modes (Garrod & Mikilius, 1987). Demand considerations aside, in this supply chain, transporting grain to the east through the ports of Thunder Bay and Montreal has its own additional costs. Non-trivial waterway fees apply to grain movements through the canal system of the Great Lakes and transfer fees are incurred when transloading grain from a lake vessel to an ocean vessel.

2.4.2 Transportation as a Bottleneck Input

Rail lines are a bottleneck within the grain supply chain, meaning they often determine the rate of flow of products moving through the supply chain. To alleviate this situation, allowing additional rail carrier entry would be considered efficient if the total welfare in the system increased to an amount greater than the extant monopoly case. In order for welfare to increase, the marginal cost of the new competitor will have to be lower than the incumbent.¹ Opening up access to existing rail lines for a fee should be welfare improving compared with the current standard of a monopoly railway; however, a regulator granting non-discriminatory access could lead to inefficient entry (Guatier & Mitra, 2008). In the latter case, inefficient entry may occur when too many potential new competitors come and go in which ever markets they choose and

¹ The marginal cost of the new competitor would include an access fee that would be sufficient to cover the cost incurred of the use of the incumbent’s infrastructure.
whenever they choose, including peak load times, whereas the incumbent railways are obliged to serve all customers at all times.

2.5 Theory and Rail Economics: Rail Transportation

CN and CP operate nearly 1,000 trains per day serving hundreds of customers using approximately 2,000 train crews, 3,000 locomotives, and 200,000 rail cars (QGI Consulting, 2009). CN and CP’s strategic focus is to operate long trains across their mainline network while carefully managing their service on lighter density lines to focus on those that can profitably support their business (QGI Consulting, 2009). For all railways, a major preoccupation of car distribution managers is the prediction of future car demand and future car supply. The ‘pipeline’ management process requires grain car planners at the railways to take account not only of the car demands placed by shippers, but of the network demands and constraints that must be managed in the movement of the empty grain cars as well as the current and expected performance of the affected railway network in the loaded and empty cycle. When railways face restrictions on their capacity, how they manage their networks may be dependent on the competitive characteristics of the affected traffic. In turn, railway capacity is a function of track structure, traffic control systems, rolling stock assets, and human resources (crews), which are all fixed for the short term. Railway planning in the long term offers more flexibility, such as demand smoothing (QGI Consulting, 2009).

2.5.1 Seasonal Variations in Demand

Grain demand peaks from October to December and through April and May. If the Canadian railways invested in enough rail car capacity to handle all of the traffic offered during these peak
periods, they would have surplus rail car capacity through most of the year. If the railways desire that peak grain demand can be deferred, they will invest in capacity that intentionally pushes some demand beyond the grain customer’s peak demand period. In this way, the railways have an incentive to provide capacity for those elements for which demand cannot be deferred, and where there is the highest level of competition. The application of this demand smoothing process creates the potential for disagreements between railways and shippers over the appropriate level of capacity that should be available to handle peak transportation demand. Because of the uneven impact of demand smoothing on railway and customer, the parties may not evaluate the risks of investment in capacity to handle traffic peaks in the same way and this can make railways and shipper disagreements in this area very difficult to resolve (QGI Consulting, 2009).

2.5.2 Demand-Pull vs. Supply-Push

The quantity of grain shipped and sold is a function of the port demand for the product. A “demand-pull” system has contracts filled and grain cars ordered in anticipation of a ship’s arrival in port, ensuring the right grain fills the right ship. “Demand-pull” is characterized by different demands throughout the year as a result of the seasonality of grain production. A “supply-push” system, the one favored by the carriers, operates on a strict delivery process in anticipation of demand and maximizes railroad asset utilization. “Supply-push” works well for non-perishables like coal and potash because the railways typically employ unit trains travelling from a single origin to a destination. Applying a “supply-push” strategy to grain is more difficult because grain production has multiple origins, is highly seasonal, can degrade over time, and production varies considerably from year to year (Canadian Transportation Agency, 2008).
2.5.3 Rail Car Allocation

Rail car allocation is a complex optimization problem because of the number of shippers who all wish to have their particular interests served. There is a staggering array of commodities to be moved as well as different grades within those commodities, including both Board and non-Board grains and corridor management priorities that all need to be considered by the railway in their car allocation decisions (Estey, 1998). As of 2009 in the grain handling sector alone, there were 318 elevators in western Canada, as well as 252 producer car loading facilities (Canadian Grain Commission, 2009; Canadian National, 2009; Canadian Pacific, 2011). As mentioned earlier, rail lines are spread across a vast area, those serving the major portion of the grain handling system run approximately 1,600 kilometers east and west and 600 kilometers north and south. Overall, there are approximately 35,000 kilometers of Class 1 railroad track across Canada (Natural Resources Canada, 2011).

It is important to note that from 1996 to 2000, rail car allocation for the grain sector was done by the Car Allocation Policy Group (CAPG). The committee consisted of one representative from each of the following groups: the CWB; producers; the Western Grain Elevator Association; and the railways. This group established corridor priorities throughout the year, and divided cars among Board and non-Board commodities. In 2000, the group was abolished. Now elevators, acting as agents of the CWB, negotiate directly with railways, while other producers negotiate with railways for the delivery of producer cars (Canadian Transportation Agency, 2008; QGI Consulting, 2010).
2.5.4 Rail Car Ordering Programs

CN and CP now have different programs for car ordering to serve the variety of bulk commodity shippers across the Prairies. Both railways offer financial incentives to shippers to load cars in large blocks through advanced ordering programs. Larger car volumes reduce the operating costs for the railways and those savings can be passed on to the grain companies. Eventually some of these discounts reach farmers in the form of trucking premiums. The incentives offered to elevators by the railways are greater than the actual cost savings (Producer Car Shippers of Canada, 2011). In addition to the advanced car ordering programs, there is a general allocation of rail cars that are sent to the shipper with the highest bid. At the start of the 2007-2008 crop year, CN discontinued its advanced ordering program and opted for a general distribution model, basing orders on historical statistics (Canadian Transportation Agency, 2008).

Table 2.1. Incentives used by CN and CP on a per rail car basis

<table>
<thead>
<tr>
<th>Railway</th>
<th>Commodity</th>
<th>Origin</th>
<th>Destination</th>
<th>Single Car Rate / Tonne</th>
<th>50 Car Block Rate / Tonne</th>
<th>100 Car Block Rate / Tonne</th>
<th>50 Car Discount / Tonne</th>
<th>100 Car Discount / Tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>CN</td>
<td>Wheat</td>
<td>Aberdeen, SK</td>
<td>Thunder Bay</td>
<td>$30.10</td>
<td>$26.46</td>
<td>$22.82</td>
<td>$3.64</td>
<td>$7.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vancouver</td>
<td>$32.23</td>
<td>$28.59</td>
<td>$24.95</td>
<td>$3.64</td>
<td>$7.28</td>
</tr>
<tr>
<td>CP</td>
<td>Wheat</td>
<td>Blackie, AB</td>
<td>Thunder Bay</td>
<td>$39.64</td>
<td>$35.09</td>
<td>$32.36</td>
<td>$4.55</td>
<td>$7.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vancouver</td>
<td>$26.18</td>
<td>$21.63</td>
<td>$18.90</td>
<td>$4.55</td>
<td>$7.28</td>
</tr>
</tbody>
</table>

(QGI Consulting, 2010)
2.5.5 Priority Rail Pricing and Congestion

An externality of rail infrastructure usage is the incremental effect of additional trains: as the line approaches full capacity utilization, it is inevitable that delays to existing services will increase. The railways operate a system that is often pushed to capacity. At these times, there is the incentive to move higher valued goods so that higher rates can be charged, and grain goes to a lower priority. Congestion occurs with little ability for remedial incremental capacity expansion to immediately accommodate lower valued goods as they will be moved later (Australian Government: Bureau of Transport and Regional Economics, 2003).

2.5.6 Freight Rates

Rates set for service to rail customers are theoretically determined by the marginal cost of the shipment and the shipper’s elasticity of demand. Marginal cost is specific to the grain being hauled, and incorporates the underlying value of the commodity. Typically rates to transport canola are higher than other crops as it is higher valued than feed barley or oats. In addition, certain delivery locations are located on mainlines and see more trains in a given month, opening the possibility for decreased rail rates.

2.5.7 Demurrage

Demurrage is the name applied to the charges incurred when an elevator does not fill rail cars in a timely manner or if the shipper is not able to fill a ship waiting in port in sufficient time (Ronen, 1986). In effect, the elevator or the shippers are paying for additional use of the respective railcars or vessel. The opposite of demurrage is despatch. For example, if the shipper delivers grain to a vessel in a shorter amount of time than was originally contracted, they are paid a premium for the time saved (Parker, 1974). The railways do not credit elevators for despatch of
loaded rail cars. Demurrage does not cover charges where rail cars were not moved in a timely manner by the railways and a marketing opportunity was lost.

2.5.8 Short Lines
Short lines have provided continued operation of rail lines for many communities that otherwise would have lost service through line abandonment. A short line railroad is a small railroad company that controls a short distance of track. They strive to offer improved customer service because of a more concentrated focus and aim to provide lower rail rates. Short lines provide a means for rural shippers, located on light density lines, to haul their product to long distance markets using a low cost form of transportation (Bitzan, VanWechel, Benson, & Vachal, 2003).

2.5.9 Dual Monopolies
The rail industry in western Canada is not perfectly competitive as there are large barriers to entry. Locomotives and track are highly asset specific investments that require very high freight costs to cover investment expenditures (Fulton & Gray, 1998). The majority of grain movements from elevator delivery locations are captive to one rail line. The railways operate in two geographically distinct regions, so Canada is served by a dual monopoly (Tougas, 2006; Fulton, 2006). Although this may appear to be a poor situation for competition, a Cournot-Nash equilibrium outcome requires only two competitors to achieve a competitive outcome (Brennan, 2000). The geographic diversity means that the railways have market power in their respective regions and are closer to a monopoly. However, they are not true monopolies because trucks can get grain to other terminals and farmers could also reduce the amount of grain they choose to export (Eley, Fulton, Gray, & Perlich, 1996).
2.6 Theory and Rail Economics: Regulation Overview

The Class I railways operate under a revenue cap for grain movement only and can freely increase the rates they charge and reduce the volume of grain they transport because they do not face the threat of entry of competition. Given this latitude, they can discriminate on price because they have some market power (Tougas, 2006).

2.6.1 Natural Monopoly

Economic theory says that a good or service should be provided up to the point where the marginal benefit that the good or service yields the company is equal to the marginal cost the company incurs to provide it. Natural monopolies are an exception to this rule because of the large costs that are associated with running the firm, and the economies of scale that they operate with as the only provider of a good or service. The average costs the firm faces could be declining throughout the entire range of the demand curve (see Figure 2.2). A single rail firm that owns a rail line and provides service on it creates excess capacity because of the lumpy nature of the infrastructure (Australian Government: Bureau of Transport and Regional Economics, 2003). Natural monopoly regulation was essentially the method under which the Canadian railways were historically regulated, until deregulation.
In a competitive environment, price is set equal to marginal cost. In a natural monopoly, this pricing method sets the price below the average cost and the rail firm would lose money. At the prevailing demand levels in the rail industry, marginal cost pricing makes it very difficult to offer rail infrastructure without some kind of subsidy (Australian Government: Bureau of Transport and Regional Economics, 2003). If the rail firm was left to act as a monopolist, it would set price equal to $P_m$, and transport the inefficient output $q_m$. That quantity is much lower than in a competitive scenario, so regulation is required to force the rail firm to provide a quantity of service that is closer to the levels that a competitive industry would provide. As a compromise between production at $q_m$ and $q_c$, the government may regulate the railway to provide $q_r$ level of service and price to be set when the average cost crosses the demand curve. The level of service is sub optimal to a competitive environment, but it means the railway only breaks even. The implication of this pricing structure is that the railway does not have much incentive to innovate.
compared to a competitive firm (Australian Government: Bureau of Transport and Regional Economics, 2003).

2.6.2 Canada and Rail Regulation

Today, the rail industry in Canada is primarily rate deregulated, with the exception of grain movements. For all rail movements in Canada, a series of regulations are instituted in an attempt to restrict carriers believed to be exploiting market power over shippers. The CTA includes provisions that were designed with the intention of stimulating competition such as confidential contracts, interswitching, competitive line rates and final offer arbitration, but they all assume that the railways will actively compete with one another (Fulton & Gray, 1998). In addition, the railways are obligated to give regulated access to their proprietary track to another competing railway if they cannot provide the service requested (Skotheim & Nolan, 2008). However, if the railways simply do not choose to compete with one another, the regulation will have limited effectiveness.

2.6.3 Other Models of Network Competition

Network industries (railway, electricity, telecommunications) have traditionally been vertically integrated with both infrastructure and operations managed by the same entity. This is because of the economies of scope from minimizing transaction costs and economies of scale of having a single operator (Jensen & Stelling, 2007). However, this has been challenged on the grounds that the benefits of competition can more than offset the higher costs arising from the loss of economies of scale and scope. Many countries, such as the UK, Sweden, and Argentina, have vertically separated infrastructure from operations in some network industries (Campos &
Cantos, 2000). Longer distance, lower volume traffic, which uses resources distributed along the line, can be served most economically by combining flows. This is a natural monopoly since it requires a system to operate it effectively and there would be a loss of economies of scale if it was broken up (Drew, 2009).

2.6.4 Vertical Separation of Infrastructure

The introduction of various competition elements in the railway sector, which was made possible by the vertical separation of infrastructure from the operation of trains, have had a significant positive impact on cost efficiency in the production of train services in the European context (Jensen & Stelling, 2007). The impact is expressed as cost elasticity of competitive pressure on the whole vertical production process of the sector (Jensen & Stelling, 2007). The short term reduction in cost efficiency, likely a result of the temporary costs of restructuring the sector and to a more permanent change of cost level from the vertical separation, is more than compensated for by the increased cost efficiency of operator’s production of train services due to increased competitive pressure (Jensen & Stelling, 2007).

Sweden provided an example where vertical separation of infrastructure in rail yielded overall reduced costs (Jensen & Stelling, 2007). The cost decrease was a positive net result of competitive pressure, even though there were losses in economies of scale. In comparison, Great Britain did not adopt a complete vertical separation of infrastructure; instead opting to keep the most congested portion of the network vertically integrated, as it was concluded that reduced congestion was more important than increased competition. The introduction of entrants was initially restricted by information flows within the network, such as obtaining access to the
network at a specific time and accessing the information about which corridors were available (Drew, 2009).

2.6.5 The US Model of Rail Competition

Upon the implementation of the Stagger’s Act of 1980 in the US, rates declined as a result of competition. The service provided drastically changed as well, as the number of single car movements declined significantly and was replaced with multiple car and unit train shipments that offered a much lower cost per unit (MacDonald, 1989). The shift to low cost transport spurred productivity gains, decreased rates, and carrier profits subsequently grew (MacDonald & Cavalluzzo, 1996). The use of unit trains has lowered the costs for rail carriers, but it imposed a different ordering and delivery structure onto the shippers that the railway serves. The preference for multiple and unit car orders is manageable for shippers that already have a large capacity, but for those that do not have the ability to spot large car numbers, they either have to make significant capital investments in order to do so or risk not being able to get rail cars in a timely manner or at all.

2.6.6 Deregulation

Deregulation is argued to provide systemic economic benefits through various cost savings and reduced bureaucracy. Throughout the 1970s there were multiple studies done in the United States of the outcome of deregulation. One argument was that transportation rates would decline. Deregulation would allow for an increase in competition and this in turn would result in carrier’s management strategies being forced to be more innovative in terms of the service provided and rates offered (Johnson & Harper, 1975). The other argument was that rail deregulation would
lead to increased rates as a result of productivity, profit and quality improvements (MacDonald and Cavalluzzo, 1996). Industry costs decreased in response to deregulation and rates subsequently decreased, while railway profits increased with an increase in traffic.

2.6.7 The United States Rail Regulator

In the US, the Surface Transportation Board is responsible for rail regulation concerns, and they use what is known as a Stand-Alone Cost test as a freight relief method for shippers if market power can be shown to exist in a given market. In order to establish the degree of market power, rail revenues derived from the contested freight shipment are compared with the computed variable costs of transportation. If the ratio of revenue to variable costs exceeds 180%, then a condition of excessive market dominance is established, and a shipper can prove that the freight rate is unreasonable and appeal the rate they are charged (Morgan, 1998).

2.7 The Rail Sector in Canada: Rail Regulation Policy in Canada

2.7.1 Service Provisions

The regulated rail duopoly includes level of service provisions, at a minimum providing “adequate and suitable” service as a means to ensure the railways are still moving all of the grain shippers would like moved (Canadian Transportation Agency, 2011). It also requires that the service is provided “without delay, and with due care and diligence” (Canadian Transportation Agency, 2011). With the variety of shippers spread across the Prairies, there have been a number of complaints brought to the CTA where the railways were challenged on the service they provided. The cases are documented on the Canadian Transportation Agency’s website (Canadian Transportation Agency, 2011). In September 2007, level of service complaints were
filed against CN and the CTA ruled in favor of the complainants as a result of CN changing its car ordering program (Canadian Transportation Agency, 2008). Great Northern Grain Terminals and the CWB successfully challenged CN’s car supply policies that differentiated against smaller grain handling companies (Canadian Transportation Agency, 2007; Canadian Transportation Agency, 2008). Naber Seed and Grain Company launched a case against CN for inadequate provision of service during the 2000-2001 crop year, and their complaint was upheld (Annand & Nolan, 2003). Not every case brought before the CTA is ruled in favor of the complainants, as a recent case dismissed the argument regarding CN delisting certain producer car loading sites (Canadian Transportation Agency, 2010).

2.7.2 The Revenue Cap
The railway revenue cap provides a statutory limit on the amount of revenue the two major railways can earn from the movement of regulated grain in western Canada. The revenue cap is a dynamic revenue regulating mechanism based on the estimates of each carrier’s total tonnage, average length of haul, and revenues from the prior year (Quorum Corporation, 2006). The cap was established in an attempt to ensure rail carriers do not overcharge farmers for freight. If too much revenue is generated, those excess gains are returned to farmers through a financial contribution to an endowment fund held by the Western Grains Research Foundation, in addition to a five percent penalty fee (Western Grains Research Foundation, 2011; Teamsters Canada Rail Conference, 2009). The revenue cap applies to CN and CP, and affects all export shipments from western Canada handled through the west coast ports, Churchill, Thunder Bay, and Armstrong.
The revenue cap formula:

\[
= \{ \frac{A}{B} + \left[ (C - D) \times 0.022 \right] \} \times E \times F
\]

where:

- A is the carrier’s revenue for the movement in the base year
- B is the tonnage moved by the carrier in the base year
- C is the carrier’s average length of haul for the movement of grain in the crop year
- D is the carrier’s average length of haul for the movement in the base year
- E is the tonnage moved by the carrier in the crop year
- F is the Volume-Related Composite Index determined by the Agency

The revenue cap does not penalize the railways for handling more grain than originally expected in the current crop year or for the incursion of additional costs arising from inflation (Quorum Corporation, 2006). The Volume-Related Composite Index is an inflation factor that reflects forecasted price changes for railway labor, fuel, material, and capital purchases by the railways. In the course of establishing the index, the CTA collects information from parties in the grain handling and transportation industries including producer representatives, the CWB, shipper organizations and other government departments.

2.7.3 Canadian National and Canadian Pacific

The rail industry has seen revenues steadily increase over the past decade. In 2000, CN had total revenues of $5.4 billion, and that number has steadily increased through to 2010, with recorded revenues of $8.3 billion (Canadian National, 2000; Canadian National, 2011). Over those years, the revenue earned from grain freight has oscillated somewhat, with grain contributing $863 million in 2000, then decreasing to $790 million in 2004, and increasing to $1.2 billion in 2010 (Canadian National, 2000; Canadian National, 2004; Canadian National, 2011). As a percentage of the total revenue, grain accounts for an average of 13% of the total per year. Over the same time period, CP’s revenues also increased, but not by the same amount as CN. Total revenue for
CP in 2000 was $3.5 billion, while 2010 closed out with $4.9 billion (Canadian Pacific, 2000; Canadian Pacific, 2011). Grain revenue amounts for CP were lower than for CN, with amounts less than $1 billion for the years 2000 to 2007, and increasing to $1.1 billion in 2010 (Canadian Pacific, 2000; Canadian Pacific, 2001; Canadian Pacific, 2002; Canadian Pacific, 2003; Canadian Pacific, 2004; Canadian Pacific, 2005; Canadian Pacific, 2006; Canadian Pacific, 2007; Canadian Pacific, 2011). Grain revenue accounts for a larger percentage of the total for CP than CN, with grain contributing an average of 20% of revenues in a given year.

Figure 2.3. Grain and total rail revenue from 2000 to 2010

(Canadian National, 2000 - 2011; Canadian Pacific, 2000 - 2011)
2.8 The Rail Sector in Canada: Access Provisions

Regulated access provisions into a network industry can be difficult to enforce and monitor. Efficiency improvements occur when entrants are given the flexibility to develop access contracts and negotiate with incumbents (Carlson & Nolan, 2005). Access fees are an option to potentially open up existing track infrastructure to new competition, in an effort to provide the socially optimum level of rail service (Freebairn, 1998). However, the form that the regulators determine the fee takes and the value it is set at should be cautiously considered. The price cannot be set too high, as it would be cost prohibitive for potential competitors and would discourage entry even from those with low marginal cost. Alternatively, the price cannot be set so low that the fees do not compensate track owners for the use of their infrastructure. An access fee that will sustain the goal of competition needs to provide incentive for the current track owners to continually invest in the infrastructure they have, perform continual track maintenance, and account for congestion price effects, yet be low enough that entrants can afford it (Carlson & Nolan, 2005; Clark & Easaw, 2007).

2.8.1 Access Pricing

A number of different systems have been suggested for setting access fees to infrastructure. In 1938, Hotelling offered the marginal cost rule. Additional users of a fixed resource, such as roads, bridges, and railroads are given access to the good upon payment of the extra costs that the usage causes. The marginal cost includes the additional resources and labor needed for the facility in use, but not the fixed costs (Hotelling, 1938). In 1946, Coase suggested a two-part pricing method for monopolists to capture more consumer surplus. A consumer is charged one lump sum to pay the cost of carriage, or the fixed costs, as well as a per unit charge to cover the marginal costs (Coase, 1946). Later, in 1970, Coase disputed the marginal cost assumptions
regarding overhead costs that were not financed, saying that taxes or other revenue sources would be non-distorting (Coase, 1970). The Ramsey-Boiteux principle uses markups on marginal cost. The price markup is inversely related to the price elasticity of demand. If the demand for a product is very elastic, then the smaller the price markup should be. During times of low demand elasticity, such as peak loading, congestion pricing would occur. However, physical limits to the number of trains that can run on a set of tracks means that congestion pricing may require additional tracks, increasing the marginal costs and flawing the Ramsey-Boiteux principle of keeping a flat access charge (Poletti, 2005). The Efficient Component Pricing Rule (ECPR) can be used to price a bottleneck input operated by a monopolist. The charge calculated using the ECPR adds the incremental cost of offering access, such as the additional maintenance of the tracks that will be required through increased use, and sums it with a calculation measuring the opportunity cost of providing access due to entry as well as the costs of providing access (Armstrong & Doyle, 1998).

2.9 The Rail Sector in Canada: History

Canada has had a long and storied relationship with railways throughout its history. Rail was the primary form of long distance land transportation at the time of confederation, and the rail industry was a key component in determining the landscape that comprises Canada today.

2.9.1 Confederation to the Completion of a Transcontinental Railway

In the years just after confederation, Prime Minister John A. MacDonald believed that Canada’s success would best be realized in the form of a united nation from the Pacific to the Atlantic coasts. The American west had closed, and there was upward pressure from settlers looking
north to Western Canada as the last best west. Although the expressed National Policy was a protective tariff on Canadian goods, the national policies were not only the tariffs, but also population growth through immigration and the completion of the transcontinental railway (Conrad & Finkel, 2002). It was the combination of the three that would protect Canada from the expansion of the United States. It was only with a set of strong incentives that persuaded CP to take on the task, as construction through the bogs of the Canadian Shield in northern Ontario and the passes of the Rockies made construction very difficult. A land grant of 25 million acres, track already completed from earlier attempts at a coast to coast railway, and a $25 million cash grant and a guarantee of a 20 year monopoly on western rail traffic were all a part of the package that CP received (Conrad & Finkel, 2002).

2.9.2 Railways as a Lifeline
Through the latter decades of the 19th and early part of the 20th centuries, CP and the Grand Trunk Railway (now CN) laid thousands of kilometres of track. The railways did more than just transport grain out of the three Prairie Provinces; they moved in people, building supplies, and machinery for a growing regional economy. The growing track network served hundreds of towns that were mostly between seven and ten miles apart, as that distance was considered the farthest a farmer should have to haul their grain to market (Conrad & Finkel, 2002).

2.9.3 Crow’s Nest Pass Rate
In 1897, the so-called Crow’s Nest Pass rate was enacted when the Canadian government wanted the Canadian Pacific Railway to build track through the Crow’s Nest Pass to Kootenay, BC. At

2 A railway pass through the mountainous region of the BC interior.
the time, Canadian Pacific was paid $3.3 million to build the railway, but in exchange, they were obligated to maintain regulated shipping rates for Prairie grain (Kulshreshtha & Devine, 1978). As part of the agreement, joint running rights were also defined (Government of Canada, 1897).

The extensive rail network that dominated the western provinces faced competition after the Second World War with the emergence of highways and trucks as a means of freight transportation. In Canada, the 1950s saw the creation of thousands of kilometres of roads and highways across the Prairies, giving farmers with trucks the newfound ability to move their grain beyond the nearest elevator (Waiser, 2005). In addition, while the railways were gradually allowed to increase their regulated rates in the Prairies due to the results of costing reviews, through the 1950s and 60s it was recognized that much of their track infrastructure was out of date as newer rail cars could not be supported over the older track.

Over time, the Crow Rate policy gradually fell into disfavor with the Class 1 railways. They argued with government to the effect that they continually lost money on grain movement because of the low regulated freight rates (Doan et al, 2003). The historic Crow Rate policy was modified with the implementation of the National Transportation Act of 1967. Canadian railways obtained updated but still regulated grain freight rates as well the ability to abandon track infrastructure that did not generate sufficient profit (Baldwin, 2011).

2.9.4 Legislation from 1967 to 1995
With the passing of the National Transportation Act in 1967, rail movements and pricing were fully deregulated with the exception of grain. One key part of the legislation was that it also
contained new provisions for protecting so-called captive shippers, a situation that can often be
the case with dispersed prairie delivery points. *The Report of the Task Force on Rates*, released
in November 1982, maintained that the scale used for setting freight rates was biased because it
was developed from a list of single point rates and a coincidental geographic accident that set the
rates for all movements over 2,051 kilometres (Heads, 1982). In 1983 an updated policy called
the Western Grain Transportation Act (WGTA) was introduced. The WGTA was intended to
ensure that the railways earned a fair return as determined by a review panel and thus tried to set
equitable freight rates. It also developed a mechanism where farmers and the federal government
shared the cost of grain freight (Fulton & Gray, 1998).

The WGTA allowed grain shipping costs to gradually increase while the federal government
agreed to share the cost of transporting grain. The Crow Benefit was the federal share of the cost,
initially set at $659 million, but further cost increases were shared by farmers and the federal
government (Storey, 2006). In reality, the WGTA provided a subsidy to farmers to increase the
price received for their grain. In 1995 the WGTA was repealed under pressure from competing
export nations because it was determined that it acted as an export subsidy. The federal
government compensated farmers directly affected by the replacement of the WGTA with a one-
time payment of $1.5 billion (Storey, 2006).

2.9.5 The Canadian Transportation Act of 1996

The Canadian Transportation Act of 1996 replaced the subsidy regime for grain movement with
a distance based cap on freight rates. Departing from the convention of regulated freight rates,
the Canadian Transportation Act instead capped freight rates by establishing the maximum
allowable amount for a given rate. This allowed the railways to set their grain rates at any value at or below the maximum rate. The rates were set by the rail regulator, the Canadian Transportation Agency, who tried to also ensure that the railways’ volume dependent and line dependent costs were covered (Vercammen, 1996). Finally with the implementation of the 1998-1999 Estey/Kroeger grain handling and transportation system review process the system is now governed by a revenue cap for grain movement, meaning that the Canadian Transportation Agency no longer sets maximum rates for western Canadian grain movements (Estey, 1998; Kroeger, 1999).

2.10 The Rail Sector in Canada: The Grain Handling System

The GHTS today is a network of a few centrally located high throughput terminals on the remaining rail network, connected via the road network that facilitates truck transportation to terminals. Western grain is primarily bound for export through the ports of Vancouver, Thunder Bay, Churchill, and Prince Rupert. The grain handling system consists of on farm storage, competitive trucking companies, inland elevators and terminals, railways, and export ports. Some grains are processed within the prairie region, while some is also shipped to the United States and Mexico. While the system is now designed to gain economies of both scale and scope, there still exist a number of smaller sites that handle grain. These are often called ‘producer car’ loading sites and the following tables list relevant sites located in Saskatchewan. The producer car loading sites are listed in Table 2.2 and 2.3 for CP and CN respectively.
Table 2.2. CP producer car loading locations in Saskatchewan as of 2011

<table>
<thead>
<tr>
<th>Location</th>
<th>Car Spot</th>
<th>Location</th>
<th>Car Spot</th>
<th>Location</th>
<th>Car Spot</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Indian Head</td>
<td>3</td>
<td>Redvers</td>
<td>5</td>
</tr>
<tr>
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<td>5</td>
<td>Kelvington</td>
<td>9</td>
<td>Regina</td>
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<tr>
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<td>Rose Valley</td>
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</tr>
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<td>Rosetown</td>
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</tr>
<tr>
<td>Bredenbury</td>
<td>2</td>
<td>Lloydminster</td>
<td>4</td>
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</tr>
<tr>
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(Canadian Pacific, 2011)
Table 2.3. CN producer car loading locations in Saskatchewan as of 2011

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(Canadian National, 2011)

2.10.1 Industry Overview

From a planning perspective, the grain handling system is not as streamlined or efficient as possible mostly due to how the system developed. Over the course of settlement in Western
Canada and as new areas were opened up, the existing railways tended to pick geographically distinct regions to set their branch lines and thus only their trunk or main lines ended up being built in proximity to each another. As a result, before the many advances in road building and trucking, many Prairie farmers were served effectively by a single rail carrier because of the distances required to move grain to an alternative elevator on a competing rail line. The original network of elevators was built to accommodate horse drawn wagons, not the large Super B trucks that are commonly used now (Conrad & Finkel, 2002). The result is a grain elevator system with multiple origins and destinations, often making management and timely commodity deliveries difficult to co-ordinate.

Grain companies order and receive rail cars based on grain deliveries, world prices, and the railway’s ability to move goods. Loaded rail cars are moved as a complete train or can be combined with other rail cars in the system to build a full length unit train. Rail cars must be emptied directly into ships, or into terminal elevators for later ship loading, or into adjacent rail yards to be emptied when a ship arrives and if rail yard space is available. Once unloaded, the cars are reassembled and returned to the prairies (Canadian Transportation Agency, 2008). For example on average in the 2008-2009 crop year, it took 13.4 days for rail cars to cycle from the country elevator to the terminal and back (Quorum Corporation, 2010). In the same year, it took an average of 50.1 days for Canadian grain to get from an elevator to port position, an amount consisting of: 5.7 days of loaded transit time; 27.7 days in store in country; 16.7 days in a terminal elevator; and 4.6 days of vessel time in port (Quorum Corporation, 2010).
2.10.2 Efficiency Constraints

There have been an increasing number of interruptions in the grain market supply chain in western Canada in the past ten years. Foremost among these are west coast port capacity constraints, as Vancouver and Prince Rupert are able to handle approximately 27 million metric tonnes of grain per year, assuming that all elements of the system work efficiently without interruption (Prince Rupert Port Authority, 2011; Colley West Shipping, 2011). The increased number of grades that end users of Canadian grain have demanded and the Canadian Grain Commission tests for grade further complicates the process since no individual port specializes in handling specific grains or grades, thus increasing the demands on terminal operations. With an increase in the number of grades, there is more opportunity for market segmentation. At the same time, however, transaction costs within the system are growing as those different grades need to be segregated and this alters capacity usage. In addition, the marketing season for grain is not spread out evenly throughout the year. Sellers all try to accelerate their rate of sales in nearby months in an attempt to capture premiums, while at the same time; buyers try to defer purchases to capture discounts (Wilson, Dahl, & Carlson, 1998). The multiple interests that all attempt to be served put additional strain on the grain handling and transportation system, potentially limiting its ability to reliably serve its underlying purpose.

2.10.3 Elevator Market Concentration

Elevators, or inland terminals, are the wood, concrete or steel collection facilities that clean and store all types of grain for transport to export position. They are almost always located adjacent to a rail line, taking delivery directly from farmers or cross hauled from another elevator. The primary grain handling capacity on the prairies is reasonably concentrated. In August 2009, the
four largest grain companies held over 70% of the primary storage capacity in Saskatchewan (Canadian Grain Commission, 2009). This level of concentration, along with a lack of excess capacity, suggests that the grain handling firms have the potential to exert some degree of market power. The lack of sufficient capacity within the system to take all of farmers intended deliveries leads to delivery delays and a further increase in market power to those facilities than can handle more grain. To encourage greater competition among the grain companies, the CWB has operated a tendering process for rail car allocation, with approximately 16% of Board shipments to port in the 2005/2006 crop year allocated through tenders (Informa Economics, 2008). Under the tendering process, grain companies have to provide bids to the CWB for grain cars and then the CWB selects the best bid.

2.10.4 Vancouver Terminals

Vancouver is the port of destination for not only my study, but one of the primary destinations for the GHTS. There are five terminal grain elevators in Vancouver. Cargill owns a 240,000 tonne terminal in North Vancouver, while James Richardson International also owns a 108,000 tonne terminal at that location. Alliance Grain Terminal is a group composed of Paterson Global Foods, Parrish & Heimbecker, Prairie West Terminal, Weyburn Inland Terminal, Great Sand Hills Terminal Marketing Centre, and North West Terminal (Competition Bureau, 2007). Alliance’s terminal on the north shore of Vancouver’s downtown eastside operates a 102,000 tonne facility. Pacific Elevators, operated by Viterra, and located just to the east of Alliance’s terminal, has a 200,000 tonne terminal. Cascadia is the largest terminal with a capacity of 282,000 tonnes, and is also operated by Viterra. The total capacity at Port Metro Vancouver is 932,000 tonnes (Port Metro Vancouver, 2011).
2.10.5 Terminal Ownership

Ownership at the terminal effectively determines competition in the country. Terminal charges can be expected to be set above the cost of providing the service. Through car allocation policies, the CWB is able to ensure that all grain companies have access to terminal facilities (Fulton, 2006).

2.10.6 Elevator Numbers Since 1971

Since 1971, elevator numbers have dropped dramatically in western Canada, from 4,800 to 318 in August 2010 as a rapid centralization rationalized the system (Canadian Grain Commission, 2010; Martin, 1976). The fixed costs of concrete elevators are high, while the marginal cost of operating them are low, giving the grain companies that operate them the incentive to move a large quantity of tonnes.
2.11 Summary

This chapter has described both the history and structure of the Canadian grain handling and transportation system. As a modern and complex supply chain with many players, to date the GHTS has not been accurately modeled on a system level. Thus, it is the goal of my thesis to simulate the GHTS in enough detail to validate both information and grain flows within the supply chain. Once completed, I will use the operational model of the GHTS to examine the

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3 The sudden drop in elevator numbers from 1983 to 1984 was a result of a change in the method for reporting elevator numbers. If there were two elevators in a town owned by the same company, it was recorded as one for the purpose of registration.
critical issue of whether or not open access or entry in the rail portion of the system is a viable policy alternative to help bolster overall competition and efficiency within the system.
Chapter 3

EQUILIBRIUM VS. DIS-EQUILIBRIUM MODELING

3.0 Introduction

In contrast to traditional equilibrium models used in economics, agent based modeling (ABM) relies on individually programmed agents to collectively search for convergence or stability in the appropriate economic context. Agent based modeling is not intended to replace traditional econometric modeling; rather it provides a controlled laboratory setting for testing dynamic characteristics of a system and a method of empirical examination (Gintis, 2007). ABM allows for the incorporation of spatial and temporal dependence within a model that traditional operations management and system dynamics models ignore.

3.1 Micro-Simulation

Related models known as micro-simulation models are based on a bottom-up approach which creates larger structures from the base components. The basic individual elements of the system are specified in detail, creating heterogeneous actors which are equipped with behavior rules (Leidtke, 2009). Micro-simulation approaches fall short for our purposes because these models try to replicate characteristics of an ‘average’ population. Agent based modeling uses heterogeneous individuals who act independently yet are permitted to interact on some prescribed level. Unlike micro-simulation, the recursive and heterogeneous nature of the agents means in many cases, collective behavior is sometimes not readily predictable from the sum of individual behavior (Tesfatsion, 2006). Once the initial conditions and agent behaviors have been specified, there is no further interference or input by the modeler.
3.2 Benefits of Agent Based Modeling

Agent based modeling is designed to generate solutions to complex problems by distributing them to a number of local decision makers each performing discrete decisions (Parunak & VanderBok, 1998; Bocker, Lind, & Zirkler, 2001; Franklin, 1997; Mes, van der Heijden, & van Harten, 2007; Tesfatsion, 2006; Berger, 2000). Through communication with one another, the autonomous decision makers, or agents, can solve whole problems by way of co-operation. In the context of this research, grain companies in Saskatchewan often operate in many locations, but the business decisions they make on a day to day basis are all a direct function of elevator capacity in a unique spatial area at a particular point in time. Solving this complex problem can be done with agent-based simulation since not all of the relevant information needs to be known by all agents beforehand and some of the key factors of the grain supply chain may emerge as a result of individual interactions. Elevators do not know what production will be in a particular year, but by working to achieve an individual objective of a target capacity percentage, the system reaches equilibrium where all grain can be handled. Using modern computational hardware and software, all of these interacting decisions can be simulated simultaneously.

3.3 Breadth of Possibilities

When using agent based simulation models, instead of observing the system to see if an equilibrium state is achieved, the goal is modified to watch and see if some form of equilibrium develops over time, running the model through hundreds of iterations to generate a distribution of outcomes (Franklin, 1997). An agent based model has many agents with many decision variables and a variety of possible behaviors. Certain variables, such as the number of trains delivered to a location, do not have a wide range of possible values but can offer widely different
outcomes with a modest change. Within those possible behaviors, some can be enabled while others are selectively disabled to observe the effects of lack of information or what happens when there is improved information. Running the model enough times to observe the spectrum of all possible outcomes yields simulated data that shows the breadth of possible scenarios.

3.4 Walrasian Equilibrium

Walrasian equilibrium is a precisely formulated set of conditions under which allocations of goods and services can be price-supported. It assumes that there are a finite number of private firms, homogenous goods for sale, a finite number of consumers, and a Walrasian auctioneer that determines prices to ensure the market clears (Tesfatsion, 2006). These assumptions are made in order to decrease the degree of complexity that the market presents for economists trying to model social behaviors. However, a lot of the intricacies of the market are forgone with these assumptions, one of the most important being the dismissal of transaction costs (Berger, 2000). The interaction of distinct individuals and the interactions of two individuals who possess the same average characteristics yield different results when behaviors are observed. The traditional modeling sense is still valuable as there will always have to be assumptions made about unknowns; however, ABM provides a way of improving the traditional toolkit.

3.4.1 Distinction between ABM and Walrasian Equilibrium

The difference between ABM and traditional Walrasian representations they seek to complement is that they assist in the study of system processes at the level of their basic components by providing an experimental analysis into the dynamics of a system (Crooks et al, 2008; Gintis, 2007). The traditional modeling is a top down approach where macro level results are observed
and the micro level components are derived from the macro level. ABM looks to build a model in the opposite manner, building a system up from the smallest elements of its structure in a detailed manner such that the observations of the ABM match those observed in the real system. It allows for certain assumptions to be relaxed in order to achieve the desired outcome, which also incorporates more realism into the model by allowing for heterogeneity. A highly decentralized market economy has a stable state in which the economy is close to Pareto efficient. The stability of a market system depends on the fact that prices are private information. When even a small fraction of agents are assumed to use public prices, price becomes volatile and does not converge to equilibrium (Gintis, 2007).

3.5 Complexity
A complex system has many interwoven parts that rely on one another through a network of interactions, but is also capable of change given information concerning its environment (Miller & Page, 2007). Within the confines of this thesis, this refers to the variety of agents and their objectives. A result of complex behavior is self organization and emergence. Self organization is when a behavior appears within a system without external influence to guide the system to a result (Paranuk & Brueckner, 2001). Emergence is the way patterns and results arise out of a combination of relatively simple behaviors (Miller & Page, 2007). For example, ants trying to find food and leaving a pheromone trail to that food source results in the emergence of an ant expressway to a food source. Computability, or the ability to solve a problem in an effective manner, is an interesting discussion in light of self organization and emergence. Just because a problem is complex, it does not necessitate a complex answer. Using agent based modeling to
examine a complex system allows for modeling of relatively simple interactions in an effort to explain a system through emergence and self organization.

3.6 Validity of a Modeling Style

Ideally given a good theoretical foundation, a model would be constructed which would then be validated and if acceptable, used in decision making. However, many of the systems being modeled using ABM are very complex problems that have not been modeled before and there is only speculation as to how they really function. ABM is more generic, rather a style of modeling than a type of model (North & Macal, 2007). Whether or not ABM is appropriate for the theory, its applications, the policies involved or the design of systems that the model might be built to inform, cannot be guessed in advance (Crooks, Castle, & Batty, 2008).

3.7 NetLogo

NetLogo© is an ABM environment that can be used for simulating social and natural phenomena. It is particularly well suited for modeling complex systems over time, and with the use of a GIS extension, landscapes that are spatial can be accurately modeled. It was pioneered by Uri Wilensky in 1999 and has been in continuous development at the Center for Connected Learning and Computer-Based Modeling (Wilensky, 1999).

3.8 Geographic Information Systems and ABM

GIS enables scientists to model geographic space, but does a poor job of representing time and behavior. Agent based models, on the other hand, observe the behavior of agents within geographic space and make use of sophisticated representations of time and behavior (Brown,
Riolo, Robinson, North, & Rand, 2005). If GIS and ABM are integrated together, there is the potential to overcome both their limitations and to build an even stronger representation of a system. Combining GIS and the simulation capability of ABM in order to achieve a hybrid model can be realized in two ways. Dynamic coupling is where the access to geographic data is made during the execution of the model (Goncalves, Rodrigues, & Correia, 2004). As the simulation runs, agents have access to the underlying information and can read and write different spatial data into the database as the model progresses. Static coupling is when the geographic data are previously imported into the simulator before the simulation (Goncalves, Rodrigues, & Correia, 2004). This approach is much less resource intensive in terms of computing capacity, yet it delivers a much more realistic representation of space than would otherwise be obtained by just using the relative space capabilities of NetLogo©.

3.9 Relevant ABM Application

3.9.1 Commuter Responses to Travel Information

Agent based modeling has a variety of applications because of its distributed nature of problem solving, individuality, and spatial capabilities. A behavioral study of drivers and commuter’s responses to travel information demonstrated the feasibility of the approach and the potential to develop more complex driver behavior dynamics based on the belief-desire-intention agent architecture (Dia, 2002). The study was able to systematically test different behaviors of drivers to determine the responses that they were making to certain traffic problems and could compare those results to answers obtained in a survey. Often, doing a full scale test of all of the drivers in a city is not possible or too expensive to complete, so ABM offers an alternative. The same holds true for evacuation planning. Real exercises in evacuation planning are very expensive and
sometimes not realistic as they cannot take into account each individual behavior as the panic effect and initial response to an evacuation in a dangerous area (Nabaa, Bertelle, Dutot, & Olivier, 2009). However, treating human responses like agents and incorporating GIS into the system provides a very realistic simulation of what it would be like, without having to actually do a trial run.

3.9.2 Grids and Networks
By their very nature, ABMs provide benefits to understanding human choice and decision making in movements within grids or networks (Branting, Wu, Srikrishnan, & Altawheel, 2007). As part of their inherent structure, any grid or network problem can be readily addressed with an agent based model. All model environments operate on a grid that is normally meant to be a simple representation of space, but in the case of downtown city cores and rural setting, the grid pattern is the actual representation of space. Because of each agent’s ability to communicate with one another, they can easily create networks with one another and stop relationships with one another.

3.9.3 Networks
Analytical concepts of network economics are based on getting marketing information, which takes time and has an opportunity cost. That is why economic agents generally try to establish a stable set of partners, or so-called relationship networks. Exogenous conditions, as well as the strategic intention of market participants, influence the establishment of the network and its structure. A bottom up model may show a way of mapping the emergence of complex collaboration patterns such as carrier networks with exchange of cargo as well as inner and
intermodal transport chains. A multi-agent architecture is well suited for simulating inter-regional transportation (Leidtke, 2009).

3.9.4 Transportation Networks
A transportation network needs to be flexible, stable, and robust. Flexible transportation networks may consist of multiple independent organizational units. These individual players may not be willing to share all of their information, like their cost structure, so that traditional centralized approaches are not applicable. ABM allows for individual players to negotiate based on available information in an attempt to realize a global objective (van Dam, Lukszo, Ferreira, & Sirikijpanichkul, 2007). Little is known about the performance of agent based transportation control compared with more traditional methods (Davidsson, Henesey, Ramstedt, Tornquist, & Wernstedt, 2005). A key research issue is the relative performance in matching available capacity with incoming orders using operations research heuristics or agent based approaches. A distributed agent based solution applied to real time dynamic transport scheduling problems will be more robust in the sense that it is less sensitive to fluctuations in demand or available transport methods than more traditional transportation planning heuristics (Mes, van der Heijden, & van Harten, 2007).

3.10 Summary
Disequilibrium modeling allows for the dynamic spatial and temporal relationships of the western Canadian grain supply chain to be accurately captured and modeled. This model is not a new application of agent based software, but an extension of existing work with grids,
information networks, and transportation networks that incorporate distributed organizations into one system.
4.0 Introduction

This chapter describes the physical characteristics of the agent based simulation of the grain handling and transportation system in Canada. It begins by outlining the features of the landscape, and defines the agents and the assumptions they operate under.

4.1 Model Overview

The GHTS simulation model developed in this thesis is a scaled reproduction of the grain handling system in the province of Saskatchewan. GIS shapefiles\(^4\) were obtained for the province that contained the outlines of the 20 Census Agricultural Regions (CARs) (University of Saskatchewan, 2007). The dimensions of the simulated area are 630 kilometres east and west, and 631 kilometres north and south (see Figure 4.1). This spatial information was added to the simulation environment such that all agents that populate the simulation operate within the boundaries of the simulated world, and in effect, operate within a landscape similar to the real world. Farmers, with an average starting inventory of 300 tonnes, were distributed randomly within each CAR and stayed in their initial locations for the duration of each replicate. All active rail lines were placed in the simulation in their real locations. The number of trains that move on the rail lines was randomized as railway behavior was not explicitly modeled. Elevators, with no starting inventory, were positioned with the aid of a shapefile that located all of the towns within

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\(^4\) A shapefile is a geospatial vector data format developed by Esri for use in GIS software. A shapefile offers a spatial explanation of a geometry, and includes attributes such as names or characteristics of objects such as provincial boundaries or road networks.
Saskatchewan, as well as the rail network. The combination of the two shapefiles allowed for the most accurate placement of the elevator.

(Government of Saskatchewan, 2005)

Figure 4.1. Census Agricultural Regions (Crop Districts), rural municipalities, and soil zones of Saskatchewan
Farms do not increase in size over the timeline of the simulation, nor is there an explicit modeling of acreage of specific crops. The simulation assumes a monoculture of wheat across the province, direct seeded on all arable acres of each farm every year. There is no summer fallow management, and there is not a specific modeling of adverse weather events.

Figure 4.2. A 30,000 foot view of the grain handling supply chain in western Canada
4.2 Initialization

In the initialization phase, all of the bounding physical starting information is loaded into the simulation environment. The shapefiles that contain the location of the physical characteristics are loaded first, including all elevator locations, the placement of the rail lines, and the CAR boundaries. As part of the shapefile, there is projection information that gives the simulation a reference to the dimensions of each file in physical space. This information is used as a conversion factor so each agent in the simulation can convert the simulated landscape to the real environment, particularly for the use of distance measurements. Agents within the landscape can only measure simulated distances. However, once they are given a conversion factor, they can convert simulated distance to real distances and their decision making behavior then closely replicates a real process.

4.3 Physical Boundaries

Once the above information has been initialized, the CAR boundaries are visualized and the rail lines are placed. Train sizes are set according to the tonnage spot capacities of a 100 car train, a 50 car train, and a 25 car train, with capacities of 10,000 tonnes, 5,000 tonnes, and 2,500 tonnes respectively, assuming 100 tonnes per rail car.

4.4 Production Information

The production information that each farmer uses is uploaded during the initialization phase. Each individual CAR has a text file containing yearly production information that each farmer will access in the respective year of the simulation and is divided equally among each of the farmers in the CAR because all farmers are the same size in this simulation (Agriculture
Division, Crops Section, 2006). The text file contains production values, in tonnes, for all wheat produced in Canada, by Province and CAR (see Appendix D). The data was used from the calendar years 1977 to 2006 inclusive. The production information was not detrended because there is not enough carryover to affect the network in the simulation.

4.5 Price Information

Price information from 1977 to 2006 was obtained from the CWB, given in Canadian dollars per metric tonne (Canadian Wheat Board, 2010). Total payments for wheat and durum were averaged across the three grades offered: 1, 2, and 3 Canadian Western Amber Durum (CWAD), and 1, 2, and 3 Canadian Western Red Spring (CWRS) wheat. Elevators do not offer forward contracts, production contracts, basis contracts, or futures contracts; the only offering is cash prices.

Production numbers were considered for Saskatchewan and used to determine the percentage, by tonnage, of each grain produced for each year. That percentage was applied as a weighted average to determine an average final price offered to producers. Finally, the price was adjusted according to the Farm Product Price Index for Saskatchewan grains to ensure the prices were indexed and relative to another (see Appendix D). The price modification was to account for the different growing regions across the province and the different growing conditions. For example, durum is typically grown in the southern portion of the province, with northern growers not having the ideal growing conditions for durum production. However, farmers in the northern part of the province also typically have higher yields than those in the southern parts, so any price
disadvantage they may be exposed to as a result of not being able to grow durum are negated by higher yields.

4.6 Synthetic Farmer Population

The number of farmers initialized within each CAR was determined from the 2006 Census of Agriculture. The number of farmers used to populate the landscape was 25,422, as determined by the North American Industry Classification System for Oilseed and Grain farming (Statistics Canada, 2006). The farmers in each CAR are placed across the landscape within the bounds of the specific shapefile and are randomly distributed within it. Although the number of farms in 2006 is significantly less than the number of farmers in 1977, the decision to use the number of farmers as of 2006 was made as the production distribution was more significant than the number of farmers (Hay, 2007).

In the case of planting intentions, all that is important is gross margin. For this model, it is assumed that farmers only plant wheat (CWRS and CWAD combined as one), and all of their acreage is seeded every year. In the case of marketing a crop, almost all of the costs are sunk by the time the grain is harvested and accordingly, producers do not need to take their cost of production into account when pricing their grain (Schoney, 2011). Every farmer within each CAR is identical in size and harvests the same amount of grain as every other farmer in the same CAR. Yields will vary across the region; however, this model captures yield variability with the randomized location of farms for each replicate.
4.6.1 Grid Calculation

A grid calculation (around the outside of a triangle) is used to determine road distance for trucking grain to an elevator. Grid distance more accurately represents distances in comparison to straight line distances, considering the extensive grid road network of the province (see Figure 4.3).

![Diagram of grid distance]

Figure 4.3. Grid distance

4.6.2 Trucking Rates

Trucking rates are a function of distance (Weyburn Inland Terminal, 2011). Once grain is on a truck, the cost to move it a short distance may be high in terms of dollars per tonne, but the per unit cost decreases as the distance increases. The average variable cost of trucking will increase over distances of hundreds of kilometers because of the relatively low volume of grain being transported (see Figure 4.5). Rail transportation is less expensive over comparatively long hauls of thousands of kilometers (see Figure 4.4).
4.7 Elevator Locations

As of August 2009 in Saskatchewan, there were 185 elevator locations (Canadian Grain Commission, 2009). They are owned by 37 companies, of which 22 have primary facilities, which predominantly take grain for the purpose of exporting it out of the province. There are 157
primary elevator delivery locations available to farmers in 120 towns. The total capacity of all of the delivery locations in the province is 3.23 million tonnes. For this model, the processing facilities will not be included because they do not buy grain for the purpose of exporting the raw commodity. The capacity of the primary delivery facilities is 2.91 million tonnes, or 90% of the total elevator storage capacity in Saskatchewan (Canadian Grain Commission, 2009) (see Table 4.1). A complete list of primary and process elevators by company and total capacity is listed in Table A.1. in Appendix A.

Table 4.1. Primary elevators in Saskatchewan as of August 2009

<table>
<thead>
<tr>
<th>Company</th>
<th># of Locations</th>
<th>Capacity</th>
<th>Sum of Primary Capacity</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Served by CN</td>
<td>Served by CP</td>
<td>Served by CN</td>
<td>Served by CP</td>
</tr>
<tr>
<td>ADM Agri-Industries Company</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>15,000</td>
</tr>
<tr>
<td>Bunge Canada</td>
<td>2</td>
<td>0</td>
<td>57,600</td>
<td>0</td>
</tr>
<tr>
<td>Canada Malting Co. Limited</td>
<td>2</td>
<td>0</td>
<td>13,420</td>
<td>0</td>
</tr>
<tr>
<td>Cargill Limited</td>
<td>11</td>
<td>2</td>
<td>234,610</td>
<td>44,450</td>
</tr>
<tr>
<td>CMI Terminal Joint Venture</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>27,220</td>
</tr>
<tr>
<td>Fill-More Seeds Inc.</td>
<td>1</td>
<td>3</td>
<td>5,100</td>
<td>12,320</td>
</tr>
<tr>
<td>Gardiner Dam Terminal Joint Venture</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>17,000</td>
</tr>
<tr>
<td>Great Sandhills Terminal Marketing Centre Ltd.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>20,800</td>
</tr>
<tr>
<td>Louis Dreyfus Canada Ltd.</td>
<td>2</td>
<td>2</td>
<td>62,680</td>
<td>94,040</td>
</tr>
<tr>
<td>Mission Terminal Inc.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3,760</td>
</tr>
<tr>
<td>Mobil Grain Ltd.</td>
<td>2</td>
<td>0</td>
<td>8,560</td>
<td>0</td>
</tr>
<tr>
<td>North East Terminal Ltd.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>35,920</td>
</tr>
<tr>
<td>North West Terminal Ltd.</td>
<td>1</td>
<td>0</td>
<td>63,000</td>
<td>0</td>
</tr>
<tr>
<td>Parrish &amp; Heinbecker, Limited</td>
<td>7</td>
<td>3</td>
<td>146,920</td>
<td>94,980</td>
</tr>
<tr>
<td>Paterson Grain</td>
<td>2</td>
<td>16</td>
<td>14,430</td>
<td>134,250</td>
</tr>
<tr>
<td>Prairie Heritage Seeds Inc.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1,290</td>
</tr>
<tr>
<td>Prairie West Terminal Ltd.</td>
<td>1</td>
<td>4</td>
<td>12,420</td>
<td>50,750</td>
</tr>
<tr>
<td>Richardson Pioneer Limited</td>
<td>19</td>
<td>15</td>
<td>211,340</td>
<td>272,120</td>
</tr>
<tr>
<td>RW Organic Ltd.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>7,390</td>
</tr>
<tr>
<td>South West Terminal Ltd.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>52,000</td>
</tr>
<tr>
<td>Viterra Inc.</td>
<td>27</td>
<td>25</td>
<td>506,980</td>
<td>579,390</td>
</tr>
<tr>
<td>Weyburn Inland Terminal Ltd.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>105,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>77</strong></td>
<td><strong>80</strong></td>
<td><strong>1,337,060</strong></td>
<td><strong>1,568,180</strong></td>
</tr>
<tr>
<td><strong>Percentage</strong></td>
<td><strong>49%</strong></td>
<td><strong>51%</strong></td>
<td><strong>46%</strong></td>
<td><strong>54%</strong></td>
</tr>
</tbody>
</table>

(Canadian Grain Commission, 2009)
4.7.1 Elevator Capacity by Company

The four largest companies, with respect to total capacity, were treated as independent companies (see Table 4.2 and Figure 4.6). The remaining 18 companies were grouped together and treated as a single company. Viterra has 37.4% of the total capacity, Richardson Pioneer has 16.6%, Cargill Ltd. has 9.6%, and Parrish & Heimbecker has 8.3%, totalling 71.9% of the total capacity in Saskatchewan. The remaining elevators account for 28.1% of capacity (Canadian Grain Commission, 2009).

Table 4.2. Elevator capacities by company within Saskatchewan of August 2009

<table>
<thead>
<tr>
<th>Company</th>
<th># of Locations</th>
<th>% of Capacity</th>
<th>Sum of Primary Capacity (tonnes)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Served by CN</td>
<td>Served by CP</td>
<td>Served by CN</td>
<td>Served by CP</td>
</tr>
<tr>
<td>Cargill</td>
<td>11</td>
<td>2</td>
<td>8.1%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Parrish &amp; Heimbecker</td>
<td>7</td>
<td>3</td>
<td>5.1%</td>
<td>3.3%</td>
</tr>
<tr>
<td>Richardson Pioneer</td>
<td>19</td>
<td>15</td>
<td>7.3%</td>
<td>9.4%</td>
</tr>
<tr>
<td>Viterra</td>
<td>27</td>
<td>25</td>
<td>17.5%</td>
<td>19.9%</td>
</tr>
<tr>
<td>Remainder</td>
<td>13</td>
<td>35</td>
<td>8.2%</td>
<td>19.9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>77</strong></td>
<td><strong>80</strong></td>
<td><strong>46.0%</strong></td>
<td><strong>54.0%</strong></td>
</tr>
</tbody>
</table>

(Canadian Grain Commission, 2009)
4.7.2 Elevator Population

There are three sizes of grain elevator used within the simulation: small, medium, and large. Values of less than 7,000 tonnes, between 7,000 and 25,000 tonnes, and greater than 25,000 tonnes were applied to the 157 primary elevator locations as of August 2009 to capture different scales of operation, and grouped accordingly (Canadian Grain Commission, 2009). The category limits generated 51 small elevators, 57 medium elevators, and 49 large elevators, which had average capacities of 4,076 tonnes, 13,829 tonnes, and 38,961 tonnes respectively. Total capacity of grain storage of the 157 locations is 2,905,240 tonnes. Approximately 7.2% of the actual
capacity of Saskatchewan was held in small elevators, 27.1% was held in medium elevators, while 65.7% of the actual capacity was held in the remaining large elevators. From a rail perspective, CN serves approximately 46% of the capacity while CP serves the remaining 54% (Canadian Grain Commission, 2009). Each elevator in the simulation is served by a single railway.

4.7.3 Synthetic Elevator Population

Using the average capacities as starting points and the actual number of facilities from each category, a synthetic population of elevators was created to match this capacity distribution. All small elevators have a capacity of 4,000 tonnes, all medium elevators have a 14,000 tonne capacity, and all large elevators have a 39,000 tonne capacity. Seven percent of the simulated capacity in the province is held in small elevators (a 0.2% difference); 27.4% of the simulated capacity is held in medium sized elevators (a 0.3% difference); and 65.6% of the simulated capacity is held in large elevators (a 0.1% difference) for 2009. The simulated elevator capacity is 2,913,000 tonnes, 0.27% greater than in 2009 (see Table 4.3).

Table 4.3. Simulated elevator capacities in Saskatchewan by company

<table>
<thead>
<tr>
<th>Company</th>
<th># of Locations Served by CN</th>
<th>% of Capacity Served by CN</th>
<th>Sum of Primary Capacity (tonnes)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargill</td>
<td>11</td>
<td>8.9%</td>
<td>312,000</td>
<td>10.7%</td>
</tr>
<tr>
<td>Parrish &amp; Heimbecker</td>
<td>7</td>
<td>4.7%</td>
<td>255,000</td>
<td>8.8%</td>
</tr>
<tr>
<td>Richardson Pioneer</td>
<td>19</td>
<td>7.4%</td>
<td>496,000</td>
<td>17.0%</td>
</tr>
<tr>
<td>Viterra</td>
<td>27</td>
<td>20.7%</td>
<td>1,103,000</td>
<td>37.9%</td>
</tr>
<tr>
<td>Remainder</td>
<td>13</td>
<td>8.0%</td>
<td>747,000</td>
<td>25.6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>77</strong></td>
<td><strong>49.7%</strong></td>
<td><strong>2,913,000</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>
4.7.4 Elevator Visualization

Individual elevators are defined based on their elevator shapefiles. The shapefiles provide each elevator’s location in the landscape, as well as the capacity of each location, the company name, the railway that services it, and the rail distance to the port of Vancouver. Once an elevator is created, a rail siding belonging to the respective railway that serves the elevator is added to the elevator location. The rail siding is initialized to meet the requirements of the specific elevator location\(^5\).

There are four locations that are not served by CN or CP, but are served by a short line railway. In each of the four cases, it has been assumed that the locations are served by Canadian National, which was the prior rail service provider in all instances\(^6\).

4.7.5 Elevator Handling Fees

Elevators set their handling fees according to historical data. Each elevator calculates a storage cost that is a function of its available capacity and its handling fees. If an elevator has 15% or less of its capacity filled, it incurs a negative storage cost. The elevator will pay a premium to not be in an inventory-short position.

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\(^5\) In CAR 2A (south east segment of Saskatchewan), Fillmore Seeds Inc. operates three elevator locations at Fillmore, with individual capacities of 1,100 tonnes, 3,700 tonnes, and 1,420 tonnes. These three elevators and their capacities were summed into one location with a capacity of 6,220 tonnes. A similar situation exists in CAR7A (west central Saskatchewan) with Prairie West Terminal at Plenty, with individual capacities of 7,340 tonnes and 31,740 tonnes. The Prairie West elevators were combined into a single location with 39,080 tonnes.

\(^6\) The locations are the Pioneer elevator at Northgate in CAR1A; the Mobil Grain locations in Bethune and Chamberlain in CAR6A; and the Pioneer in Shellbrook in CAR9A.
4.7.6 Supply of Storage

Storage capacity varies across Saskatchewan as there is not only the physical cost of infrastructure to provide ample room for commodities, but also the maintenance of that capacity and management of its best use. There is value in having commodities in storage as the price may increase over time, but there is a trade off as there is also value in having available capacity in order to take delivery of more grain should more favorable market conditions arise (Paul, 1970). The supply of storage is conceived as a continuous curve, relating quantity and price (see Figure 4.7). It rises steeply in the negative region, and then as stocks become more abundant the curve becomes positive and flat. The segment extends over a wide range of capacity levels – up until there is an actual shortage of storage space. The curve is log-like in shape, being nearly asymptotic to the y-axis when its capacity is near 0%, crossing the x-axis at 15%, and remains positive to 100%. For grains as a whole, I suggest there is a positively sloping supply curve in the short run, and that this curve shifts in response to changes in demand for handling grain (Paul, 1970). The storage cost is added to the elevator handling fees to determine the basis. The port price is the same for all elevators, obtained from a text file to ensure accuracy among the elevators. The price offered to farmers by the elevators is determined by subtracting the rail rate of the railway that serves a particular location and the elevator basis from the port price.
Figure 4.7. Price of storage

4.7.7 Elevator Wheat Tariff Rates

For the years 1997 to 2006, wheat tariff values for Cargill, Viterra, Parrish & Heimbecker, and Pioneer were obtained from the CGC website (see Appendix A). The tariffs for North West Terminal, North East Terminal, South West Terminal, Paterson Grain, and Weyburn Inland Terminal were averaged to obtain the value used for the remaining elevators. The average time one farmer’s grain is assumed to be in storage is 21 days (Quorum Corporation, 2010) (see Appendix A).
Figure 4.8. Distance to Vancouver in kilometres by rail, Study Area

4.8 Rail Freight Rates

Rail freight rates were obtained from the Saskatchewan Ministry of Agriculture (Saskatchewan Ministry of Agriculture, 2009) (see Appendix C). The grain prices were derived from the CWB with respect to the final price of 1CWRS 12.5% protein wheat in store\(^7\). The freight rate was the producer rate offered to the same locations for the same years (see Figure 4.10 for rail rates). The data obtained from the Saskatchewan Ministry of Agriculture only referenced Saskatoon as delivery point; however, it did not specify whether those rates were for rail transport on CN or CP lines (see Figure 4.9 for a map of rail lines). Additional data from the Government of Alberta’s Agriculture and Rural Development website was used to determine that the data was for CN rail transport (see Appendix C). All rail freight rates were calculated with Vancouver as the only port destination.

\(^7\) Thunder Bay used from 1974 to 1994 and St. Lawrence/Vancouver used from 1995 to 2008.
CN & CP Rail Lines in Saskatchewan

(DMTI Spatial, 2008)

Figure 4.9. CN and CP rail lines in Saskatchewan
Figure 4.10. Average CN and CP freight rates in Saskatchewan, 1977 to 2006
4.9 Delivery Penalty Description

A delivery penalty is that grain which does not move in a timely fashion from an elevator into port position – reflecting a loss in marketing opportunity. A delivery penalty is similar to demurrage fees (Section 2.5.7), however a delivery penalty is calculated in tonnes instead of a dollar amount, and is the spot capacity of a single train that an elevator can take delivery of. The

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8A screen shot of the model in the NetLogo© modeling environment after it is initialized but prior to starting. All CARs are visualized in the simulation; however, only CAR 1B is shown here to show detail. CAR 1B is in the southeast segment of the province. Elevator locations and size are represented by country elevator shapes and respective sizes, while different colors indicate different companies. Small railroad track icons are a visual reference to ensure proper initialization. The line running northwest to southeast connecting the elevators in the top third of the CAR is the CP mainline, while the line below it is a CN branch line. The small triangles within the CAR boundaries are individual farmers.
value of the tonnes that do not move in a timely manner can be much greater than any demurrage fees that are paid. For example, if the market price for wheat increases dramatically, there is opportunity cost lost if the wheat does not move to an export position quickly because the price of wheat may drop before it is sold if transportation to port is delayed. The cost is not only the direct charges of the associated demurrage fees, but the opportunity cost of not being able to sell wheat at a desired price. Hence the reason for summation of the total tonnes, as the value of the shipment that did not move could be large, depending on the price.

4.9.1 Calculation

A delivery penalty is calculated for elevators based on a heuristic, or rules of thumb, depending on the capacity of the individual elevator. All elevators must have a basis greater than zero. If the basis was zero or negative, the elevator is at fault for any grain that moves slowly. The elevator increased its own offering price to farmers and was essentially overdrawning grain in an attempt to remove itself from a low percent capacity condition. The practice of a negative basis is done in Saskatchewan; however, the model does not allow for elevators to change their behavior within the time period of one month, creating the potential for the elevator to draw in more grain than it needs to in order to not be in an undesirable state. A negative basis is typically used for a very short amount of time to draw in grain before an elevator updates its price (Baldwin, 1986). The capacity of the elevator must be 75% or greater if the elevator is large or medium, while small elevators must be at 85% capacity or greater. The different percentages reflect the different relative train car spot capacities among the different sized elevators (See

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9 This heuristic was chosen based on the author’s knowledge of the industry as well as knowledge of basic inventory optimization models.
The elevator percent capacity at which a delivery penalty accumulates is the critical factor driving the amount of tonnes that are recorded in the simulation.

Table 4.4. Percent at which delivery penalties accumulate

<table>
<thead>
<tr>
<th>Elevator Size</th>
<th>Total Capacity (tonnes)</th>
<th>Train Spot Capacity (tonnes)</th>
<th>Spot Capacity as a % of Total Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>4,000</td>
<td>2,500</td>
<td>63%</td>
</tr>
<tr>
<td>Medium</td>
<td>14,000</td>
<td>5,000</td>
<td>36%</td>
</tr>
<tr>
<td>Small</td>
<td>39,000</td>
<td>10,000</td>
<td>26%</td>
</tr>
</tbody>
</table>

If the small elevators had their percent capacity cut off point at 75 or greater, the amount of delivery penalties in every month is very high as a result of the structure of the system, and not as a result of the behavior of the trains that serve the location. In a given month, a small elevator will take deliveries from farmers, but only has a 50% chance of receiving a train spot from the railway that serves it. A single train takes away 63% of the volume within the small elevator, so when a train is not delivered, it does not take very long for the elevator to accumulate a volume greater than 75%. The extra 10% difference allows for one more month of deliveries to take place, and in that time, the elevator adjusts its price to reflect increased storage costs.

The final component to allow for delivery penalties to be summed is that the railway serving the elevator location must not have delivered a train in that particular month. An elevator that is at maximum capacity and has a positive basis cannot claim a delivery penalty event against the railway if they received at least one or two spots of railcars. A listing of the data used in the initialization of the model and the number of farmers by CAR is provided in Table 4.5.
4.9.2 Recording

If an elevator satisfied the three conditions necessary for its size class to claim a delivery penalty event, it recorded the tonnage capacity that did not move, the location of the elevator, the elevator company, and the month it occurred in.

4.10 Validation

Validation of the model will be done by comparison of carryout stocks of wheat\textsuperscript{10}. Carryout stocks were chosen as these are independent of datasets used in the simulation and will provide an accurate indication of the ability of this model to replicate real world behaviour. With the importance on the accuracy of carryout stocks, a heuristic was added to the farmer marketing behaviour to ensure farmers were able to deliver all of the wheat they wanted to deliver.

\textsuperscript{10} Carryout stock is the amount of wheat left over once all demand is satisfied.
Table 4.5. Initialization information summary

<table>
<thead>
<tr>
<th>Elevator Size</th>
<th>Number of Elevators</th>
<th>Total Capacity (Tonnes)</th>
<th>Percent Capacity at Initialization</th>
<th>Train Capacity (Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>49</td>
<td>4,000</td>
<td>0%</td>
<td>2,500</td>
</tr>
<tr>
<td>Medium</td>
<td>57</td>
<td>14,000</td>
<td>0%</td>
<td>5,000</td>
</tr>
<tr>
<td>Large</td>
<td>51</td>
<td>39,000</td>
<td>0%</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Farmer Starting Inventory $N \sim (300, 50)$

The above table is a summary of the data used in the initialization of the simulation. All farmers are given a starting inventory that is less than an average year’s wheat production in order for deliveries to start entering the supply chain prior the first harvest. Also note that the number of farmers is not evenly distributed across the province; see Figure 4.1 to observe that the CARs with the largest population of farmers are located in the more productive dark brown and black soil zones.
4.11 Summary

This chapter has provided the initialization information that will be used in the simulation of the supply chain that transports Saskatchewan wheat to export position. This information will be utilized in the next chapter which details the model’s flow, agent behaviour, and each agent’s use of the information in order to achieve their objectives.
Chapter 5

ELEVATOR AGENT BEHAVIOR

5.0 Introduction

This chapter will describe in some detail how the grain handling and transportation agent based simulation model is set up and run. Due to the relative lack of prior research on this topic, to that end much of what is detailed here comprises a set of heuristics, whereby I use relevant literature, personal experience and industry knowledge to try to realistically re-create the very complex process that is the grain handling and transportation system supply chain. To help the reader visualize the simulation, Figure 5.1 provides an overview of the flow of the model and categorizes for the reader the key variables and decisions made within the model by type and class. The runtime procedure in the simulation is where all of the individual agent’s behaviours are realized. The runtime procedures in NetLogo© occur within the span of one tick, which in this model is one month (see Appendix E). Most variables are cleared at the start of the month, with the exception of inventories of elevators and farmers.
5.1 Elevator Agent Overview

Figure 5.1. Elevator agent overview
5.1.1 Time period

The simulation is replicated for 360 months, with 12 months equating to one calendar year and each replicate proceeding for 30 years. It is repeated for a total of 1,024 iterations, yielding 368,640 months of data.

5.2 Railways

The railways set freight rates from historical data. The railways obtain the rates from text files containing the freight rate in dollars per tonne per kilometer. Historical freight rates were obtained for the Parrish & Heimbecker terminal located in Saskatoon (Saskatchewan Ministry of Agriculture, 2009). With the aid of freight rate information from the Alberta Agriculture and Rural Development website, the price spread between CP and CN was calculated and applied to the known freight rates obtained for the Saskatoon location serviced by CN (Mah, 2010). The actual historical rates could not be obtained for all elevators in the model at the time of simulation. The dollars per tonne per kilometer values were calculated by using the respective distances over CP and CN track to the Port of Vancouver. Over CN track, it is 1,700 kilometres to Vancouver, while over CP track it is 1,740 kilometres.

5.2.1 Rail Car Allocation

The car allocation to each elevator is randomized, with draws from a uniform distribution. Given the large scale of the rail network that covers Saskatchewan, and the number of complaints regarding adequate level of service provided by the railways, the allocation of cars, although organized, is an approximation of random. Large elevator locations receive 21 trains per year on average (see Figure 5.2). Medium elevators accept delivery of 12 trains per year on average,
while small elevators are allotted six trains in an average year (see Figures 5.3 and 5.4 respectively). The average number of trains randomly delivered in a year to each elevator size was determined by calculating the average total wheat production over the years 1977 to 2006, which was 13.3 million metric tonnes (Statistics Canada, 2007). The number of rail cars delivered to elevators on a yearly basis was allocated such that the average wheat production would be transported to port within one year (see Table 5.1). Using the number of large, medium, and small elevators, car spots of 100, 50, and 25 were assigned to each of the respective elevator capacities.

<table>
<thead>
<tr>
<th>Elevator Size</th>
<th># of Elevators</th>
<th># of Rail Cars per Train</th>
<th>Average # of Trains per Year</th>
<th>Average Total Tonnes Transported per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>49</td>
<td>25</td>
<td>6</td>
<td>735,000</td>
</tr>
<tr>
<td>Medium</td>
<td>57</td>
<td>50</td>
<td>12</td>
<td>3,420,000</td>
</tr>
<tr>
<td>Large</td>
<td>51</td>
<td>100</td>
<td>21</td>
<td>10,710,000</td>
</tr>
</tbody>
</table>

**Total** 14,865,000

(Statistics Canada, 2007)

There is a calibration within the rail car allocation that allows elevators to reject one spot of trains if the elevator has a: large capacity and its capacity is less than 15%; medium capacity and its capacity is less than 25%; or small capacity and its capacity is less than 50%.

11 This was done based to better approximate the real world delivery conditions. Shippers’ receipt of cars approximates random. If a shipper has a low volume of inventory, they will not call for rail cars. If the shipper does make a call for cars, the number of cars they receive is approximately random as they may or may not get all of the rail cars they requested in the time they specified.
Figure 5.2. Example train allocation to a large capacity elevator

Figure 5.3. Example train allocation to a medium capacity elevator
5.3 Elevators

Elevator capacity changes every month with the number of trains that are allocated to it. The more trains that are received, the higher the capacity of the elevator as the railway acts as potential storage for the elevator within the time period of one month.

5.3.1 Capacity vs. Effective Capacity

Overcapacity is built into every elevator because the simulation is bound to a time period of one month, while the real world operates on a weekly schedule. Overcapacity allows for the elevator to have the same capabilities of grain handling that it would if the simulation was run on a weekly basis (52 ticks per year), but it can be simulated on a monthly basis (12 months per year), which uses one quarter of the computing time (see Appendix B).
5.4 Farmers

5.4.1 Marketing

Farmer marketing decisions are fixed for all months of the year, and are the same in each year of the simulation. In September, farmers do not make any deliveries unless they are asked by an elevator that is short. In every period, each farmer chooses a set percentage of their total inventory that they will deliver (see Table 5.2). In October, farmers are assumed to set their delivery to 10% of their total inventory. The amount the farmer has in inventory will be highest in October because the last harvest will have been added to the carryout inventory, so the percentage each farmer wants to deliver needs to be small. In November, the percentage increases to 20 because to achieve a ten percent delivery amount of the original inventory volume, the percentage allocated to potential delivery has to increase every month in order to stay on the same relative scale.

Table 5.2. Farmer delivery volumes by percentage of inventory by month

<table>
<thead>
<tr>
<th>Month</th>
<th>Delivery Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>40%</td>
</tr>
<tr>
<td>February</td>
<td>40%</td>
</tr>
<tr>
<td>March</td>
<td>40%</td>
</tr>
<tr>
<td>April</td>
<td>50%</td>
</tr>
<tr>
<td>May</td>
<td>50%</td>
</tr>
<tr>
<td>June</td>
<td>80%</td>
</tr>
<tr>
<td>July</td>
<td>90%</td>
</tr>
<tr>
<td>August</td>
<td>100%</td>
</tr>
<tr>
<td>September</td>
<td>0%</td>
</tr>
<tr>
<td>October</td>
<td>10%</td>
</tr>
<tr>
<td>November</td>
<td>20%</td>
</tr>
<tr>
<td>December</td>
<td>30%</td>
</tr>
</tbody>
</table>
If the farmer was not able to deliver their potential delivery volume in the prior period because the elevator was full, the absolute value of the delivery size will increase, making it more difficult for a specific farmer to deliver. For example, if the farmer had 1,000 tonnes in inventory and was unable to deliver ten percent of their inventory in October, then their potential delivery will be 200 tonnes for November. The elevator may have room for 100 tonnes, but it cannot communicate that information to the farmer. The elevator can only tell the farmer if it does or does not have room for the volume the farmer wants to deliver.

As the percentages of the total intended delivery volume increase, there is a check performed in the months of April to August to ensure a farmer is attempting to deliver a reasonable amount of grain (see Table 5.3). When a farmer’s inventory increases, their ability to deliver all of it declines as the volume they intend to market becomes larger. Larger volumes are more difficult to supply if the intended delivery location is a small or medium sized elevator or an elevator that is at the end of the delivery cycle (when available elevator capacity is already filled). If the farmer’s inventory is greater than 7.5 semi-truck loads, the farmer lowers the intended delivery percentage by 25% so the total volume allocated to delivery decreases. This method delivers approximately 98% of production in a given year.
Table 5.3. Farmer delivery percentages April to August

<table>
<thead>
<tr>
<th>Month</th>
<th>Intended Delivery Volume</th>
<th>Adjusted Delivery Volume if Inventory &gt; 300 tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>50%</td>
<td>38%</td>
</tr>
<tr>
<td>May</td>
<td>50%</td>
<td>38%</td>
</tr>
<tr>
<td>June</td>
<td>80%</td>
<td>60%</td>
</tr>
<tr>
<td>July</td>
<td>90%</td>
<td>68%</td>
</tr>
<tr>
<td>August</td>
<td>100%</td>
<td>75%</td>
</tr>
</tbody>
</table>

5.4.2 Potential Elevator Delivery Options

Prior to farmers determining the elevator they would like to deliver to, a subset of elevators is derived from all elevators according to the ability of each elevator to take delivery of grain. An elevator may have a good price, but if a farmer cannot deliver to it because the elevator has a limited capacity available for deliveries, then the offered price is not accessible. If an elevator is less than 50% full, it is set as one of the elevators that can accept deliveries. The subset is divided into three smaller subsets consisting of large, medium and small elevators. Ten thousand randomly chosen farmers try to deliver to the closest (via a straight line) large elevator, regardless of the price it offers. Twenty five hundred random farmers try to deliver to the medium sized elevator that they are closest to. Two thousand farmers try to deliver to the closest small elevator. The farmers that are not chosen to try to deliver to a set location operate on a

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12 In order to render the delivery problem tractable, I had to divide the full set of farmers into subsets that approximately correspond to the demand and catchment areas of the different elevator sizes. This implies a large subset for the large elevators with large catchment areas, and so on down to the smallest elevators with the smallest catchment areas.
spatial equilibrium solution defined by delivery to the elevator with the largest differential between price and marginal (transportation) cost to that elevator (Hoover & Giarratani, 1985).

5.4.3 Harvest

Once delivery information, prices and rates have been set, farmers check the tick counter to determine if it is time to harvest their grain. If it is September, then farmers harvest their crop. Each farmer produces an equal share of the total production of the CAR they are located in. This distributes the production evenly to ensure that the spatial characteristics of delivery will be accurate. Farm locations are randomized across simulation runs so that the distance to elevators is randomized.

5.4.4 Delivery

Prior to attempting to deliver, each farmer updates a record keeping variable to hold their current inventory amount. An elevator logging variable is used so the elevator resets its values from the delivery of the last farmer that delivered to it. The elevator then checks to see how much space it has and stores that value. The elevator determines its space at the start of the delivery sequence because the elevator is not able to update its inventory within a farmer delivery sequence (only one type of agent can perform behaviours at one time). The elevator then determines if it was to add the delivery of the current farmer to all of the other deliveries it has already received from other farmers, would it be less than the elevator space it has. If it would fit, then the elevator adds the farmer’s delivery to its elevator delivery amount for the period. Individual farmer deliveries cannot be divided; farmers can only deliver all or none of their intended delivery volume.
If the farmer was able to deliver, then the farmer updates all of the variables associated with delivery. The truck distance and rate are calculated and are used to determine the price the farmer receives. This pricing method is a combination of Bertrand and Hotelling (Sharkey & Sibley, 1993; Hotelling, 1929; Stigler, 1949). The price may be different than the original price in which the farmer used to make their delivery decision. The amount delivered is removed from the farmer’s inventory. For visualization purposes in the simulation, the farmer changes its color to the color of the elevator company that it last delivered to.

5.5 Elevator Delivery Behaviour

Once all farmers have attempted delivery, all elevators take delivery of the grain. This is done in different steps because of the circular reference nature of farmer deliveries and elevators accepting deliveries. Once all deliveries have been made, the elevator then compares its inventory against the amount the railway serving it is scheduled to pick up in that particular month. If the elevator has sufficient inventory to fill what the railway will transport in that particular month, then the elevator allocates the amount the railway will need and subtracts that allocation from its inventory. If the elevator will not have enough to cover what the railway will take away, the elevator calls for more grain (in a manner similar to Bunn & Oliveira, 2001).

5.6 Elevator Shortage

If elevators are in a short position, they need farmers to deliver more grain to avoid costs associated with demurrage\(^{13}\). Elevators encourage delivery by offering a price premium. The

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\(^{13}\) This is a calibration exercise based on the author’s knowledge of the industry. It is not uncommon for a spot of railcars to be delivered that the elevator does not have the ability to fill with its current inventory volume. In those cases, elevator managers contact a number of their
elevator adjusts its basis to equal its storage cost at the beginning of the month, but removes a charge for handling fees. The elevator resets its offering price to reflect a narrower basis. The elevator asks a pre-determined number of farmers for 10% of their total volume of grain. If an elevator is small, it asks 50 random farmers within a 42 kilometre radius of its location to deliver. If the elevator is medium in size, it asks 100 random farmers within a 105 kilometre radius of its location to deliver. Finally, if the elevator is large, it asks 200 random farmers within a 210 kilometre radius of its location for immediate delivery. Larger elevators have larger catchment areas. Farmers then perform the same delivery procedure that they did with the first delivery procedure, except in this instance they will all be allowed to deliver because the elevator needs the inventory and has available capacity to take all of the grain.

Once all farmers that were called as part of any elevator shortage have delivered their grain, the elevators that were short add up their inventories again. If the elevator’s inventory is large enough to cover what the railway will take away, then it allocates the amount the railway will require and subtracts the amount from its inventory. If the elevator is still short of grain, it delivers whatever grain it has in inventory to the railway and calculates how many tonnes of grain it was short in meeting the full delivery amount.

5.7 Demurrage

A demurrage agent exists to record inland demurrage, while a port agent manages the volume of grain accepted and sent via ship from Vancouver. Inland demurrage is delivery penalty that the best customers that are close and can deliver on very short notice. The elevator managers will offer a premium and will contact as many farmers as they need to in order to ensure the railcars are all full when they leave as they have a small window in which to fill the railcars and not incur demurrage charges.
elevator incurs because it was not able to collect enough from farmers when the railways did deliver an allotment of car. The demurrage agent and the port agent do not exhibit goal seeking behaviour because they are agents that are only used to manage specific data of other agents in the simulation.

5.8 Railways Take Delivery
The railway accepts delivery of the grain from the elevators. Once the railway has taken delivery of the grain, the elevator updates its final inventory and determines what percentage capacity is filled.

5.9 Port Delivery
The final action is for grain to be delivered to port. Deliveries at port are assumed to have been called in. Ship tonnage is allocated as a function of inland capacity. Viterra is allocated 38% of a given ship; Pioneer is allotted 17%; Cargill receives 11%; Parrish & Heimbecker are assigned 9%; while the remaining elevators use the remaining 25%. Total port delivery is summed according to company and compared to the percentage allocated to each firm. The number of ships is determined after the total port deliveries are tallied. Variability is added such that only a discrete number of ships can dock in a given month, while deliveries from each of the companies is continuous, allowing for demurrage to occur at port.

5.10 Summary
This chapter has outlined both the information flows and the decisions faced by the agents in this simulation model. Each agent in the supply chain uses information drawn from their local
environment as well as from other agents to try to perform in an individually rational manner. Pertinent to the next chapter, I have also described how delays and penalties in this simulated supply chain occur and are recorded. This is the performance metric that will be used to evaluate the feasibility of rail competition policy options in the next chapter.
Chapter 6

SIMULATION RESULTS AND POLICY IMPLICATIONS – THE ISSUE OF RAIL COMPETITION

6.0 Introduction

This section discusses the results generated by the 1,024 runs of the simulation. Initial model parameters were set as outlined in Chapter 4. By virtue of its size and scale, the simulation has produced an enormous volume of data that could be used to address a variety of research questions about the grain handling and transportation system. However, due to the goals of the research I will focus the following discussion of the simulation results on the critical rail competition and access question.

6.1 Validation of Results

An approximate validation of results was done to determine if the model was consistent with real world results. I decided to use the actual volume of wheat stock in Saskatchewan for validation. Unfortunately, data could not be obtained on carryout stocks of wheat for the years 1977 to 1980, but Figure 6.1 illustrates the comparative data series after that date up to the final year of the model run (2006). While the simulation consistently overestimates carryout stocks of grain, the carryout stocks generated by the simulation track actual carryout stocks closely (see Figure 6.1). The model overestimates carryout stocks because the number of trains that are delivered are determined by a random distribution that is aimed to transport the long run average wheat production. The volume of grain that the railways move to export position is approximately the same year over year. The railways can adjust for years where production is less than the long run average by reducing the number of cars that are delivered, but have limited...
ability to increase car deliveries in years of higher than average production in this model (see Figure 6.2). A large production year, or three of them, as in the case of 1989 to 1991, means that carryout stocks remain high until wheat production decreases towards the long run average. The gap in carryout stocks between the actual and those in this simulation is not closed until wheat production drops significantly during the drought in 2002.

(Statistics Canada, 2006)

Figure 6.1. Total wheat stocks in Saskatchewan, 1981 to 2006
6.2 Delivery Penalty Events\textsuperscript{14}

The amount and depth of data allowed me to compute approximate likelihood or odds of delivery penalty events occurring within the system both through space and time. This representation is a measure of system ‘failure’ (from a logistics perspective) and is essentially a way to track overall system efficiency. Over all simulation runs 57,139,200 elevator delivery events were generated, at which 11,770,396 delivery penalty events occurred\textsuperscript{15}. Each location had an average of 98,087 events over all runs, equating to 96 delivery events per run (see Figure 6.3). The total tonnage associated with delivery penalties over all runs averaged 85,061 tonnes per month, translating into approximately seventeen 50 car unit trains. Overall, the odds of a delivery penalty, occurring at any given time at any given location, were marginally greater than one in five. The delayed

\textsuperscript{14} Also see Section 4.9.
\textsuperscript{15} The data for Year 1 is lower than all other data points because all elevators in the model start without inventory.
grain tonnage generated by the simulation breaks down by likelihood in the following manner, according to the train size required to move it. The probability of a 2,500 tonne spot occurring at any given time was 19.3%, while the probability of a 5,000 tonne spot occurring at any time was much lower at 1.25%. Finally, the probability of a 10,000 tonne spot was very small at 0.01%. Overall, delivery penalty events occurred most often at small elevator locations and rarely at medium and large elevator locations.

![Simulated Average Delivery Penalty Accumulation by Year in Tonnes (1,024 Runs)](image)

Figure 6.3. Simulated average delivery penalty accumulation by year in tonnes

6.3 Untimely Deliveries per Year

The average volume of grain that did not move in a timely manner within the supply chain in any given year was just over one million tonnes (1,017,893). However, delivery penalties were distributed unevenly across the province and through the months of the year. Delivery penalty events occur in every year of the simulation, indicating a consistent situation of disequilibrium within the Canadian grain handling supply chain. The delayed grain varies in size, but there is a
noticeable temporal effect as to when the events occur (see Figure 6.4), as well as a spatial effect\(^\text{16}\). The simulation initialization process means that the average delivery penalty volume is reached by the third year and remains consistent after that time.

![Selected Simulated Average Delivery Penalty Accumulation by Month](image)

**Figure 6.4.** Selected simulated average delivery penalty accumulation by month

As shown in Figure 6.4, average delivery penalties by month are highest in March, as farmers’ focus in the simulation shifts from grain marketing to seeding. Through March, farmers attempt to sell their remaining inventory to concentrate on the next growing season and deliver more grain, leading to higher percentage capacities within the elevator network. Other trends include that June delivery penalty events decrease as elevator percent capacities decrease, lowering the likelihood of a missed marketing opportunity. In addition, December averages are typically lower than the mid-winter months, with some exceptions in years of greater production. Finally,

\(^{16}\) Note that there are no reported deliveries in the first year of the simulation and fewer delays in year 2 as it takes some time year for the supply chain information to pass through the system.
October is the lowest month for delivery penalties as farmers are wrapping up harvest and only selling a small percentage of their grain.

6.4 Individual Delivery Penalty Events

The individual events that make up the total delivery penalty tonnage are important to analyze in a little more detail because they help determine the feasibility of introducing an entrant or third party railway that can attempt to pick up delayed tonnage that has been left in the elevators. Figure 6.5 summarizes some of this information on a temporal level, but further analysis needs to be done to determine the spatial characteristics of delayed grain in the supply chain.

Figure 6.5. Selected simulated average delivery penalty event size by month
6.5 Mean Spot Tonnage

To gain some understanding of the spatial nature of these problems, I note that the mean tonnage spot at any given location, including multiple spots in those locations with more than one elevator, is 2,645 tonnes. Of the 11,770,396 delivery penalty events, 93.87% of the events were 2,500 tonnes; 6.06% of the events were spots of 5,000 tonnes; the remaining 0.07% was 10,000 tonne spots, so that smaller elevators are the most likely locations of a delay or missed marketing opportunity. In this simulation, since rail deliveries are randomized any delay or demurrage event can also be the result of the smaller storage capacity of an elevator, and not just untimely rail service. If a given elevator was larger, the likelihood of a missed marketing opportunity is lower because it is more likely to receive a train allocation in any given month and have the highest valued goods moved to export position.

6.6 The Location of Delivery Penalties

The amount of grain that does not move in a timely manner appears to be a significant amount, but given the nature and size of this supply chain the location of that delayed grain will be critical in determining the viability of a potential rail entrant. GIS mapping tools were used to determine the likelihood of a demurrage or delay event occurring at any particular location for each month in the simulation. Given the volume of data generated by the simulation, the following probability maps have been created in an attempt to allow the reader to easily see where the delivery delays occur with greatest frequency. And to maintain tractability, I will only illustrate data for the final year of the simulation (2006). Every month in 2006 was analyzed in detail to find the locations that generated the highest probability of a delivery penalty event occurring. This information is summarized in the stylized map of the region in Figure 6.6.
For 2006, the average total tonnage delayed in the system was 981,121 tonnes. As indicated, the white areas are associated with a low probability of a delivery penalty event occurring, while the darker areas indicate a greater likelihood of such an event occurring. Thus, in the simulated year 2006 there was a 65% chance of a delivery penalty event occurring at the Pioneer elevator in Shellbrook that is served by CN. The Pioneer elevator at Tribune, which has train service from CP, fares marginally better, but there is still a 52% chance of a delivery penalty event occurring there. The Viterra elevator locations at Wadena, with service from both railways, had a 38% chance of a delivery penalty event, while the Viterra elevator at Maple Creek, with service from
the CP mainline had a one in 100 chance of experiencing a delivery penalty event. Centers with smaller elevators have poor connectivity to a rail network that prioritizes high volume unit trains. Smaller elevators have a greater likelihood of receiving lower levels of service.

Figure 6.7. Map of delay probabilities for March 2006

Within the year, there are significant differences in specific months that also show the variation in delivery behaviour of farmers. Figure 6.7 is a map generated for March of 2006 with the Pioneer elevator at Shellbrook and the Pioneer elevator at Tribune highlighted. Numerically, the probability of a delivery penalty occurring at these locations was 71% and 61% respectively,
higher than the average for the year. Through March, farmers are looking to decrease inventory levels to help finance a new crop.

Figure 6.8. Map of delay probabilities for October 2006

Finally, assessing the same locations six months later (October of 2006) shows a change in the delay probabilities as farmers in the simulation have recently harvested their crops (shown in Figure 6.8). The likelihood of a delivery penalty occurring in the two highlighted locations has dropped significantly, with Tribune having a 26% chance of a delivery penalty event, while
Shellbrook’s probability is slightly higher at 32%. Note as well that the delay probability map from March has significant areas of higher probability spread across the province, with particularly large areas of comparatively lower probability in regions served by remaining branch lines, while elevators located near the main lines have comparatively lower probability. In addition, the image from October 2006 indicates a low probability of a delivery penalty in the south eastern portion of the province as well as in the north central region. Likely there is a relationship between the number of elevators, their capacity, their density and the average production volume of the region that reduces the probability of a delivery penalty event.

6.7 Potential Rail Entry in the Grain Handling Supply Chain

In 2005, Carlson and Nolan explored the costs of rail access for a potential entrant to the Canadian rail system who wanted to move grain. Using the access pricing scheme developed in that paper, I increased their computed access charges by a rate of two percent inflation for 10 years since the data used in that study came from 1998, while the prices used in the following calculation are derived from 2008 data (except for the average freight rate which is from 2006). This leads to a total charge for access of $0.016 per tonne kilometre, consisting of $0.009 per tonne kilometre for compensation for use of infrastructure, and $0.007 per tonne kilometre for track access (Carlson & Nolan, 2005). In addition, rail cars are assumed to have a tare weight of 20 tonnes and can transport 100 tonnes of grain. A single commonly used EMD SD40-2 locomotive, weighing 120 tonnes, has an approximate value of $225,000 and can be leased for $250 per day (Simmons-Boardman Publishing Corporation, 2008). The locomotives may not be used every day of a given year, but a potential entrant would need to have access to them all year round because of the uncertain nature of when and where a delay or demurrage event will occur.
A crew of three is needed to operate each train and I assume they are compensated $65,000 per year. Twenty five and 50 car spots need two train locomotives and one crew, while 100 car spots need three train locomotives and one crew.

A single competing railway handling this delayed volume is assumed to require a 15% rate of return on their investment\(^{17}\). I also assumed that the entrant has perfect information - this implies several points: an entrant knows the probability of each elevator location not receiving rail car spots in a timely manner; the entrant is informed immediately if and when those events occur; where those events are located; and also that there is available track capacity for purchase on the incumbent’s infrastructure to transport the grain to Vancouver in an expedited manner. With perfect information, the rate of return can be decreased as some of the risk associated with the ability to operate an open access railway has been reduced through information access of where delivery penalty events are most likely to occur. In fact, potential entrants in this industry may consist not only of other American or short line railways, but also the grain companies themselves. Their elevators would be best placed to know information about where a potential delivery penalty event is occurring.

6.7.1 Potential Entrant Feasibility: All Delivery Penalty Events

A financial income statement was generated using the above assumptions and the simulated data on delivery delays to determine if rail entry would be feasible or profitable. An accounting breakeven threshold with a net income of zero was used with assumptions of a freight rate of

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\(^{17}\) The rate of return was set at 15% through an estimation of average venture capital rates of return and potential cost savings that a potential rail entrant would have access to with perfect information (Nolan & Rosaasen, 2011).
$41.85 per tonne\textsuperscript{18} and a distance to port of 1,857 kilometres\textsuperscript{19}. As I will show, economic breakeven was found by adjusting the freight rate to an amount that generated a return on investment of 15\textsuperscript{20}. In an average year, there were 1,017,893 tonnes of grain delayed or not moved in a timely manner. Approximately 957,500 tonnes (94\%) of this total will be moved in 25 rail car spots, while the remaining 60,000 tonnes (6\%) will be moved in 50 car spots (recall that the likelihood of a 100 car spot is very small at 0.07\%). I assumed the average railway car cycle for all car spot sizes was 14.7 days, which was the average for tendered grain in the 2006-2007 crop year (see Table 6.1 for a summary of assumptions) (Quorum Corporation, 2007).

Table 6.1. List of assumptions used in determining potential rail entrant profitability

| Assumptions used for Determining Revenues and Expenses for Potential Rail Entrant |
|-------------------------------|------------------|
| Average Distance by Rail to Vancouver (Km) | 1,857 |
| Inflation | 2\% |
| Operating Charge ($ / Tonne) | 0.009 |
| Access Charge ($ / Tonne) | 0.007 |
| Total Charge ($ / Tonne) | 0.016 |
| Empty Railcar Weight (Tonnes) | 20 |
| Loaded Railcar Weight (Tonnes) | 120 |
| Locomotive Mass (Tonnes) | 120 |
| Lease Cost of EMD SD40-2 ($ / Day) | 250 |
| Cost of One Labourer ($ / Year) | 65,000 |
| Average Car Cycle Length | 14.7 |
| Number of Sets* | 16 |

*The number of locomotive sets needed to move all of the delivery penalties.

\textsuperscript{18} Average freight rate from 2006
\textsuperscript{19} Average distance to Vancouver of all elevator locations used in the simulation
\textsuperscript{20} Return on Investment was calculated as: Net Income / Expenditures
Table 6.2. Income statement of potential railway entrant for 2006

Income Statement for Potential Railway Entrant for 2006

<table>
<thead>
<tr>
<th>REVENUE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight Rate ($ / Tonne)</td>
<td>41.85</td>
</tr>
<tr>
<td>Tonnes</td>
<td>1,017,500</td>
</tr>
<tr>
<td>Total Revenue</td>
<td>42,582,375</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EXPENSES</th>
<th></th>
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<tbody>
<tr>
<td>Fixed Cost</td>
<td></td>
</tr>
<tr>
<td>Locomotive Cost</td>
<td></td>
</tr>
<tr>
<td>Lease Cost / Day ($ / Day)</td>
<td>250</td>
</tr>
<tr>
<td>Number of Sets</td>
<td>16</td>
</tr>
<tr>
<td>Locomotives / Set</td>
<td>2</td>
</tr>
<tr>
<td>Days / Year</td>
<td>365</td>
</tr>
<tr>
<td>Total Fixed Cost</td>
<td>2,920,000</td>
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</table>

<table>
<thead>
<tr>
<th>Labour</th>
<th></th>
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<tbody>
<tr>
<td>Wages / Month ($)</td>
<td>65,000</td>
</tr>
<tr>
<td>Members / Crew</td>
<td>3</td>
</tr>
<tr>
<td>Number of Sets</td>
<td>16</td>
</tr>
<tr>
<td>Total Labour</td>
<td>3,120,000</td>
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<table>
<thead>
<tr>
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<th></th>
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<tbody>
<tr>
<td>Access</td>
<td></td>
</tr>
<tr>
<td>Locomotive Mass</td>
<td></td>
</tr>
<tr>
<td>Mass / Locomotive</td>
<td>120</td>
</tr>
<tr>
<td>Locomotives / Set</td>
<td>2</td>
</tr>
<tr>
<td>Number of Sets</td>
<td>16</td>
</tr>
<tr>
<td>Trips / Year</td>
<td>24</td>
</tr>
<tr>
<td>Total Access</td>
<td>92,160</td>
</tr>
<tr>
<td>Railcar Mass (Tonnes)</td>
<td>1,221,000</td>
</tr>
<tr>
<td>Dist to Vancouver (km)</td>
<td>1,857</td>
</tr>
<tr>
<td>Tonne-km</td>
<td>2,438,538,120</td>
</tr>
<tr>
<td>Total Expenses</td>
<td>45,056,610</td>
</tr>
</tbody>
</table>

| Net Income        | -2,474,235|
| Return on Investment | -5.5%    |
A potential entrant incurs significant costs not only in the form of access fees, but also leasing costs of locomotives in order to move the grain (see Table 6.2). If this is the case, a single entrant does not earn a positive rate of return. Sixteen sets of two locomotives are needed to transport all of the wheat that gets delayed because it takes, on average, 14.7 days to move a train from elevator to port and back. Recall that here are 395 events that compromise the approximately one million tonnes of delayed grain, and this consists of 12 – 50 car trains and 383 – 25 car trains. The movement to the port of Vancouver is assumed to be without a railcar management process that assembles trains into longer unit trains, for example: if a 25 rail car spot was moved by the entrant, it remained as a 25 rail car train to its final destination.

Table 6.3. Critical control variable analysis

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Break Even</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accounting</td>
<td>Economic</td>
</tr>
<tr>
<td>Freight Rate ($/T)</td>
<td>$41.85</td>
<td>$44.28</td>
</tr>
<tr>
<td>Distance to Vancouver (km)</td>
<td>1,857</td>
<td>1,740</td>
</tr>
<tr>
<td>Car Cycle Length</td>
<td>14.7</td>
<td>~ 10</td>
</tr>
</tbody>
</table>

An analysis of the critical control variables (see Table 6.3) yield interesting information for potential competitors. For example, an entrant would need to increase the freight rate it charges to $44.28 per tonne to achieve a net income of zero, or it might decrease its average length of haul to below 1,800 kilometers. Either of these changes would be very difficult for an entrant to implement. If this railway could instead decrease car cycle length to approximately 10 days, it could also achieve the zero net income result, although network access and switching costs may increase.
Extending this analysis further, an entrant could achieve a 15% return on investment if it could convince its shippers of the value of timely transport in spite of a 22% increase in freight rates to $50.92 per tonne. An alternative option would be to decrease the average length of haul of the entrant by 21% to 1,475 kilometers. Perhaps not surprisingly, by charging either higher rates than the incumbent railways or by focusing exclusively on those hauls located closer to port that happen to get delayed in the Canadian grain supply chain, I find that a potential entrant could be viable. But attempting to decrease the average car cycle length independently of other factors will not achieve the required rate of return for an economic break even.

6.7.2 Potential Entrant Feasibility: Large Delivery Penalty Events

If the potential railway decided to operate with a “hit-and-run” entry approach, using the same assumptions as in the case of transporting all delivery penalty events, they would be slightly better off. Over 1,024 iterations, there were 8,247 delivery penalty events where the rail car spot volume was 10,000 tonnes, or approximately 8 events per year. The events occurred at 37 locations across the province, with the highest probability at Moose Jaw, with one event occurring approximately every two years.
The large elevators that have the highest likelihood of a delivery penalty event are most commonly located in the western half of the province (see Figure 6.9). As was found earlier with transporting all delivery penalties, the distance traveled to port is a critical control variable in determining the success of a potential entrant. Figure 6.9 also outlines those large elevators that are closest to Vancouver with the use of isolines, with elevators within the narrow isolines the most likely location for entry. See Table 6.4 for the income statement of an entrant moving only 100 rail car spots.
Table 6.4. Income statement for potential railway entrant transporting 100 rail car spots for 2006

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>REVENUE</strong></td>
<td></td>
</tr>
<tr>
<td>Freight Rate ($ / Tonne)</td>
<td>41.85</td>
</tr>
<tr>
<td>Tonnes</td>
<td>80,000</td>
</tr>
<tr>
<td>Total Revenue</td>
<td>3,348,000</td>
</tr>
</tbody>
</table>

**EXPENSES**

**Fixed Cost**

Locomotive Cost

- Lease Cost / Day ($ / Day) | 250
- Number of Sets              | 1
- Locomotives / Set           | 3
- Days / Year                 | 365

- 273,750

Labour

- Wages / Month ($)           | 65,000
- Members / Crew              | 3
- Number of Sets              | 1

- 195,000

**Variable Cost**

Access

Locomotive Mass

- Mass / Locomotive            | 120
- Locomotives / Set            | 3
- Number of Sets               | 1
- Trips / Year                 | 8

- 2,880

Railcar Mass (Tonnes) 96,000

Dist to Vancouver (km) 1,857

Tonne-km 183,620,160

- 2,937,923

**Total Expenses**

- 3,406,673

**Net Income**

- 58,673

**Return on Investment**

- 1.7%

108
If the potential entrant used a “hit-and-run” approach, they would require three locomotives and would make 8 return trips to Vancouver. The entrant does not earn a positive return using a “hit-and-run” approach to transport only large rail car shipments. The potential entrant would be profitable if they increased the freight rate $7.12 per tonne to $48.97 per tonne.

Using the spatial and temporal data generated by the simulation, I found that the return on investment for a single potential entrant transporting all delivery penalty events is approximately -5.5%, yielding a loss. In fact, the grain that does not move in a timely manner is widely dispersed across Saskatchewan, both through time and space. “Hit-and-run” entry, in the classical contestable markets sense, yields a ROI of approximately -1.7%. However, moving all of this grain would require a wealth of timely information throughout the year. An entrant possessing a set of locomotives has the potential to move delayed shipments from specific locations, such as those in the western half of the province, through specific time periods and achieve profitability.

6.8 Summary

This chapter provided an analysis of the delivery penalty events that occurred within the replicates of the simulation of the wheat supply chain located within the province of Saskatchewan. The simulation provided detailed summaries of delivery penalty events by location and time, allowing likelihood estimations to be calculated which show the locations offering the greatest competitive opportunity for a potential entrant. On a system basis, an economic breakeven analysis using this data showed that the potential for a third party rail entrant to be profitable is limited by space and time. I conclude that economies of scale and
space matter in rail movement. As in reality, I find that the simulated grain supply chain works well most of the time in most places. Further analysis using my simulation data leads me to conclude that even if open or competitive access in the sense as has been implemented in Australia or the EU is adopted as competition policy in the Canadian rail sector (as suggested by Estey, 1998), there would likely be very limited entry and that entry would be contestable or “hit-and-miss” at best.
Chapter 7

CONCLUDING COMMENTS

7.1 Summary

The primary purpose of this research was to simulate the enormous grain handling and transportation supply chain in Canada all the way from individual farms to port position. All of this was achieved by constructing an agent based model of the grain handling system within the arable portion of the province of Saskatchewan. Spatially, the model is bounded by the 20 CARs in the province, and includes all primary elevator locations, active rail lines, and grains and oilseeds producers. For tractability, wheat is the only commodity moving through the supply chain as it is grown across the province, and until recently, was a dominant cash crop in this region. Once the supply chain simulation is operational, I then located over both time and space those instances where Saskatchewan wheat does not move in a smooth and timely manner. By recording where and when these events occur, I determined if a potential railroad entrant can earn enough profit in either the short or long run to justify entry. The results may help settle long-standing but heretofore impossible to answer questions about the future of rail regulation within the grain handling and transportation system in Canada.

The contribution of this thesis is related mostly to the scale of the problem being modeled. Built upon the broad Prairie landscape, I simulated the supply chain moving Saskatchewan wheat hundreds of kilometers into an export position via the port of Vancouver. The model incorporates spatial distribution, feedback, and dynamic temporal relationships within an agent-based modeling (ABM) framework to ultimately test the viability of rail competition within the grain handling supply chain. In so doing, I generated realistic spatial and temporal delays at the
grain elevator level, delays that might be mitigated through access to expanded railway service in
the form of inter-rail competition. To the knowledge of the author, this model generates a level
of system detail that has not often been attempted in either the regulatory, industrial organization,
or transportation literature. In the simulation, any wheat that does not move in a timely manner is
tracked, and the actual locations of any delays are mapped to help identify the greatest potential
opportunities for rail entry to be profitable.

While the scope of the study is unique, the actual modeling approach is founded upon prior
research in both the social sciences and in the economics of competition. Simulated competition
has been used to examine the effect of coordination effects of mergers (Davis & Garces, 2010),
while on a more dynamic level, intra and intermodal competition has been modeled by
simulating a game theoretic approach (Ivaldi & Vibes, 2008). And agent based simulation has
been used previously to aid intermodal container transport handling schedules, exploring the
inland exchange between road and rail transportation (Gambardella, Rizzoli, & Funk, 2002).
Finally, Preston et al. built a much smaller numerical simulation model that examined the
potential for on track rail competition in the UK. Their work is most similar to the potential for
rail competition I ultimately evaluate in this thesis (Preston, Whelan, & Wardman, 1999).

7.2 Conclusion

I found in the simulation that there are approximately one million tonnes of wheat out of a
possible average of 13 million tonnes that do not move in a timely manner on an annual basis
within the province of Saskatchewan. Delivery penalty event volumes averaged approximately
85,000 tonnes per month, with an average spot size of 2,645 tonnes, or approximately 30
shipments across Saskatchewan per month. This delayed grain is not randomly distributed across the elevators in the province, but occurs in dense pockets. In fact, there is a 94% probability that these shipments will be found at small elevators located in pockets, such as in the southeast part of the province south of Melville, in addition to locations south and west of Prince Albert, south of Moose Jaw, and north of Swift Current. Those areas are all located on branch lines, and are most often located in areas with lower production volumes on a per farmer basis. I found that there is a 6% probability that the delay will consist of a 50 rail car spot, while the chance of a delay at a large elevator with a rail car spot capacity of 100 cars is negligible. The capacity of medium and large elevators with respect to their rail car spot sizes dramatically decreases the likelihood of wheat not moving in a timely manner.

The freight rate used for the analysis of the potential entrant came from 2006 and rates will undoubtedly increase, yielding a higher potential for return on investment, ceteris paribus. In spite of such an increase, a marginal rise in freight rates charged by a new entrant may be a reasonable alternative for farmers in situations where very timely movement of grain could yield financial gain. If there is a ship waiting in Vancouver for a grain buyer that is willing to pay a premium to have the ship filled as soon as possible, the new rail entrant could charge a premium to transport wheat in a time critical event. In such a case, farmers would still obtain a net benefit in spite of an increased cost of shipping because a high price premium could more than offset increased rail transportation costs. It also implies that there could be returns for vertical integration between elevators and railways.
If a potential entrant marginally increased freight rates while simultaneously being selective of which locations it hauled from, it could also potentially obtain economic profitability. This simulation assumed all wheat in the province was transported to the port of Vancouver. In fact, most wheat from the eastern portion of the province is exported through the ports of Churchill and Thunder Bay, effectively decreasing the average length of haul. While not hauling wheat from one part of the province will necessarily decrease the total volume of grain to be transported, it will also decrease the average length of haul, meaning subsequent potential for entrants to have low enough access fees to return a potential profit. The use of GIS to determine the spatial distribution of the delayed grain allowed locations to be identified where an entrant has the greatest likelihood of having a profitable “hit-and-run” competitive opportunity.

Open rail access may also lead to improved rail service as has been seen in other countries such as Sweden and Great Britain. Vertical separation of infrastructure to provide increased competition is not a defined methodology of decreasing rail transportation cost; in this case the costs may increase but service would increase as well. The transaction costs, or the information flows, that are necessary as part of any open access regime is a significant cost to the industry. In Sweden and Great Britain, increased transaction costs have been a deterrent to lowering overall costs within rail (Drew, 2009). A simulation framework, such as the one used in this thesis, allows the researcher to model the information flows that an open access regime will require in order to operate with minimal transaction costs before the desired policy is executed. This method also allows for a more thorough analysis of feasibility and consequences that open or competitive access would impose on a rail system prior to implementation, potentially reducing
the risks that shippers and carriers would be exposed to. This thesis represents one of the first efforts to run a simulated rail access experiment in a well-defined and extensive rail market.

Looking forward, while not explicitly considered in this thesis, the end of the CWB’s monopoly on wheat and barley marketing would have an effect on the transportation of grains into export position. The CWB operates as a transportation coordinator of the western Canadian grain handling system, organizing grain handling companies and negotiating rail car deliveries from the railways, and advocating for farmers as part of its role in selling western Canadian wheat and barley. The removal of the CWB may eliminate a mechanism that farmers have available to them to ensure the railways provide grain cars in a timely manner.

This simulation is a very stylized representation of the Saskatchewan grain handling supply chain. The grain supply chain handles more grains than just wheat and those grains are transported to ports other than just Vancouver, but an examination of simulated wheat delays provides valuable insight into the problems with rail transportation because wheat is grown across all of Saskatchewan and western Canada. The difficulty in modeling a supply chain in this manner is that it is really a model of information flows, subject to physical constraints of the commodity or product that is moving. Future studies can build on the results and structure of this agent based model to include wheat production across western Canada; the inclusion of more grains; delivery to more ports; the real physical capacities of elevators; and train assembly and management by corridor. The model can also be extended to examine how concentrated the elevator network can get before this starts to generate massive inefficiencies for producers. This thesis has been able to show that agent based modeling allows researchers to effectively manage
the spatial and temporal relationships that are critical to competition policy, especially within the rail industry.

7.3 Limitations
This model has limitations as to its application because of the assumptions that were necessary to make the model tractable in size. Transportation technology from the farm gate to the elevator terminal has evolved from transportation in two axle trucks capable of transporting three tonnes at a time to highway tractors with up to eight axles that can transport up to 40 tonnes in one load. The 40 tonne super B trucks cost much less on a per tonne kilometer basis, and are not only owned by commercial carriers, but farmers themselves, allowing them to seek out new delivery points much farther from their production areas. In addition, presumably there was a systemic acreage shift in the data covering the years in the simulation in two respects: from summerfallow as a predominant tillage practice to direct seeding; and the introduction and widespread adoption of pulses and oilseeds. Summerfallow was historically the dominant tillage method and has slowly been replaced with direct seeding that allows for continuous cropping and for farmers to more easily increase farm size as they can seed and harvest more acres with less time and effort. The effect is that more acres produce crops in a given year, broadening the spatial distribution of where grains are produced. A shift in the crop portfolio from predominantly wheat to pulses and oilseeds means that in the regions where those alternatives thrive, there will be less wheat grown. Pulses typically thrive in the drier and warmer southwest corner of the province, while oilseeds do better in the typically wetter central and northeast portion of Saskatchewan. Acreage shifts to pulses and oilseeds act to decrease the spatial distribution of wheat yields closer to the central areas of the province.
Examining one province imposed artificial boundaries on farmers within the simulation, as those farmers would under normal circumstances be able to haul to delivery points in Alberta and Manitoba. This boundary decreased the total catchment area of elevators near the periphery of the simulated area, increasing the likelihood of a delivery penalty event. Vancouver is not the only port farmers typically have access to; there are also ports in Prince Rupert, Thunder Bay, and Churchill. Two of the ports, Churchill and Thunder Bay, are located to the east of the study area, which would decrease the total distance by rail to an export position, providing farmers on the eastern side of the province with lower freight rates.

Farmers grow more commodities than just wheat, it is sold by more methods than just cash, and there are many grades offered for each of the commodities. Railways transport multiple commodities and products within each train as it moves across the country, and they will manage cars and rearrange trains such that the highest valued products will move first.

7.4 Future Research

This model provides a look at an entire supply chain, giving policy makers a tool to examine total welfare effects of all stakeholders within an industry prior to implementation of the policy, and not being restricted by traditional models that do not have the ability to incorporate the spatial and temporal components that are critical to the grain handling and transportation system. A continuation of this work would be the addition of more commodities and more grades, in addition to expanding the research area to include all of western Canada. Further exploration of farmer delivery behaviour would possibly provide insight to road usage characteristics. Restrictions on farmers’ ability to increase in size and exit the industry, combined with elevator
company entry and exit may provide an inside look as to which branch lines may vulnerable for abandonment by the railways. The inclusion of port behaviour could provide new insight into the economics of all supply chains, as bottleneck effects could be priced across the entire chain, and optimized through time and over distance for all within the chain to benefit. The incorporation of GIS data files into a functional supply chain allows for any jurisdiction and any commodity to be modeled, from corn in Illinois to coal in West Virginia. This model provides a model of a scalable supply chain that can be applied to those applications where time and distance are critical factors that simply cannot be overlooked.
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# APPENDIX A

## Primary and Process Elevators

**Table A.1. Primary and Process Elevators in Saskatchewan as of August 2009**

<table>
<thead>
<tr>
<th>Company</th>
<th>License</th>
<th>CN (tonnes)</th>
<th>CP (tonnes)</th>
<th>NONE (tonnes)</th>
<th>Other (tonnes)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADM Agri-Industries Company</td>
<td>Primary</td>
<td>15,000</td>
<td>3,400</td>
<td>15,000</td>
<td>3,400</td>
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</tr>
<tr>
<td>Bioriginal Food &amp; Science Corp.</td>
<td>Processor</td>
<td>57,600</td>
<td>18,750</td>
<td>57,600</td>
<td>18,750</td>
<td></td>
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<tr>
<td>Can Pro Ingredients Ltd.</td>
<td>Processor</td>
<td></td>
<td>3,420</td>
<td></td>
<td>3,420</td>
<td></td>
</tr>
<tr>
<td>Canada Malting Co. Limited</td>
<td>Primary</td>
<td>13,420</td>
<td></td>
<td>13,420</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CanMar Grain Products Ltd.</td>
<td>Processor</td>
<td></td>
<td>230</td>
<td></td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>Can-Oat Milling, a Division of Viterra Inc.</td>
<td>Processor</td>
<td>9,500</td>
<td></td>
<td>9,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargill Limited</td>
<td>Processor</td>
<td>234,610</td>
<td>44,450</td>
<td>279,060</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMI Terminal Joint Venture</td>
<td>Primary</td>
<td>27,220</td>
<td></td>
<td>27,220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fill-More Seeds Inc.</td>
<td>Primary</td>
<td>5,100</td>
<td>17,000</td>
<td>17,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gardiner Dam Terminal Joint Venture</td>
<td>Processor</td>
<td>7,530</td>
<td></td>
<td>7,530</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain Millers Canada Corp.</td>
<td>Processor</td>
<td></td>
<td></td>
<td>7,530</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Sandhills Terminal Marketing Centre Ltd.</td>
<td>Primary</td>
<td>20,800</td>
<td></td>
<td>20,800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Husky Oil Limited</td>
<td>Processor</td>
<td>8,500</td>
<td></td>
<td>8,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDM Yorkton Trading LP</td>
<td>Processor</td>
<td>39,000</td>
<td></td>
<td>39,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louis Dreyfus Canada Ltd.</td>
<td>Primary</td>
<td>62,680</td>
<td>94,040</td>
<td>156,720</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milligan Bio-Tech Inc.</td>
<td>Processor</td>
<td>1,080</td>
<td></td>
<td>1,080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mission Terminal Inc.</td>
<td>Primary</td>
<td>3,760</td>
<td></td>
<td>3,760</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobil Grain Ltd.</td>
<td>Primary</td>
<td>8,560</td>
<td></td>
<td>8,560</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mustard Capital Inc.</td>
<td>Processor</td>
<td>1,000</td>
<td></td>
<td>1,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North East Terminal Ltd.</td>
<td>Primary</td>
<td>35,920</td>
<td></td>
<td>35,920</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North West Terminal Ltd.</td>
<td>Primary</td>
<td>63,000</td>
<td></td>
<td>63,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parrish &amp; Heinbecker, Limited</td>
<td>Primary</td>
<td>146,920</td>
<td>94,980</td>
<td>241,900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paterson Grain</td>
<td>Processor</td>
<td>1,500</td>
<td></td>
<td>1,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paterson West Terminal Ltd.</td>
<td>Primary</td>
<td>14,430</td>
<td>134,250</td>
<td>148,680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paterson West Terminal Ltd.</td>
<td>Processor</td>
<td>3,990</td>
<td></td>
<td>3,990</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pound-Maker Agventures Ltd.</td>
<td>Processor</td>
<td>4,500</td>
<td></td>
<td>4,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prairie Heritage Seeds Inc.</td>
<td>Primary</td>
<td>1,290</td>
<td></td>
<td>1,290</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prairie Mill Limited</td>
<td>Processor</td>
<td>107,380</td>
<td></td>
<td>107,380</td>
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<td></td>
</tr>
<tr>
<td>Prairie West Terminal Ltd.</td>
<td>Primary</td>
<td>12,420</td>
<td>50,750</td>
<td>63,170</td>
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<td></td>
</tr>
<tr>
<td>R Young Seeds Inc.</td>
<td>Primary</td>
<td>8,000</td>
<td></td>
<td>8,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Richardson Nutrition Holdings Limited</td>
<td>Processor</td>
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(Canadian Grain Commission, 2009)
Elevator Tariff Rate Distribution

Elevator wheat tariffs were collected for the years 1997 to 2006 from the Canadian Grain Commission. For 1977 to 1996, all elevator wheat tariff rates were assumed to be from the same distribution. A single variable regression was performed on P&H elevator data from a Saskatoon location located on a CN line, regressing tariff rates on years. The regression was applied to every elevator, including Parrish & Heimbecker locations, for the years 1977 to 1996. The wheat tariffs used for the years 1997 to 2006 were the collected values.

Elevator Wheat Tariffs at Parrish & Heimbecker Saskatoon (CN) 1977 - 2006

(Saskatchewan Agriculture and Food, 2009)

Figure A.1. Elevator wheat tariffs at Parrish & Heimbecker Saskatoon (CN) 1997 to 2006
Figure A.2. Elevator wheat tariffs by company, 1997 to 2008

Table A.2. Parrish & Heimbecker wheat tariff rates regressed against years

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<th>Parrish &amp; Heimbecker Wheat Tariff Rates Regressed Against Years</th>
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<td><strong>Multiple R</strong></td>
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<td><strong>R Square</strong></td>
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<tr>
<td><strong>Adjusted R Square</strong></td>
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<td><strong>Observations</strong></td>
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**ANOVA**

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<th>Pioneer Grain</th>
<th>Parrish &amp; Heimbecker</th>
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<td>18.35</td>
<td>18.90</td>
<td>18.28</td>
<td>17.97</td>
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</tbody>
</table>

*Italicized* Estimated from regression

*Normal* Collected data

(Canadian Grain Commission, 2010)
APPENDIX B

Overcapacity Factor

Take an example of an elevator with a capacity of 39,000 tonnes. It collects 39,000 tonnes of grain in one month and at the end of the month, it is allotted two spots of 10,000 tonnes each. The ending percent capacity of the elevator is 19,000 tonnes (39,000 tonnes maximum minus 20,000 tonnes in rail car spots) divided by 39,000 tonnes, or 48.7% capacity. The assumption of this calculation is that the trains come at the end of the month; overcapacity is used to simulate deliveries at other times of the month.

For example, the month could have started with no inventory; in Week 1 there was 39,000 tonnes of deliveries; in Week 2 there was a single 10,000 tonne spot; and in Week 3 there was another single 10,000 tonne spot. After three weeks, there would be 19,000 tonnes in inventory. It means that in Week 4, there is capacity for an additional 20,000 tonnes of deliveries, and the total tonnes handled in the month would be 39,000 plus 20,000, or 59,000 tonnes. With this in mind, there needed to be an overcapacity factor, and that factor would change each month depending on the number of trains that are delivered to a specific location. Elevators are allowed to look at the variables of the railway that serves it, and are able to determine how many trains they will receive in a given month and can calculate the overcapacity factor.
Rail distance to each port is different depending upon the railway that is used to transport the grain, and using CN and CP rail rates interchangeably would not be accurate. The Alberta government’s site was accessed to observe the 2004 – 2009 Western Canadian Rail Rates & Deductions information. From that page, a variety of locations from within Saskatchewan were recorded and a regression ran to determine how distance affected the offered rail rate. This was done for each of the years of 2005, 2006, 2007, and 2008 for both CN and CP. It was found from these values that CP often charges a rail rate that is higher on a per kilometer basis than CN. Regressions were conducted on all locations within each of the years 2005 to 2008 to obtain the following estimated rail rates in dollars per tonne per kilometre:

Table C.1. Regression output of coefficients for use in determining freight rates

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<thead>
<tr>
<th></th>
<th>CN Adj. R²</th>
<th>$ / tonne / km</th>
<th>CP Adj. R²</th>
<th>$ / tonne / km</th>
</tr>
</thead>
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<td>0.981</td>
<td>0.0218</td>
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<tr>
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<td>0.0228</td>
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<td>0.0244</td>
<td>0.981</td>
<td>0.0260</td>
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</table>

Using the rail line shapefile information, I was able to measure the shortest distance, by rail from Saskatoon to Vancouver and from Saskatoon to Thunder Bay by CN and CP rail. It is 1,515 kilometres from Saskatoon to Thunder Bay, and 1,700 kilometres from Saskatoon to Vancouver over CN track. Comparatively, it is 1,444 kilometres from Saskatoon to Thunder Bay and 1,740 kilometres from Saskatoon to Vancouver over CP track. Using these distances and the
corresponding years where the prices were either based on an in store price of Thunder Bay or Vancouver, I was able to derive the price, in dollars per metric tonne per kilometer, how much it costs to move grain for the Saskatoon location on the CN line. I used the Government of Alberta’s information to derive the data for an equivalent Saskatoon location if it was located on a CP line. I then observed the average price differential between the CN and CP prices for the years 2005 to 2008, and then applied that average difference to all of the years to obtain two independent lists of freight rates, per kilometer, for the years 1974 to 2008 for both rail lines. There are 53 CN locations and 59 CP locations used for calculating the regression and corresponding coefficients.
<table>
<thead>
<tr>
<th>Station</th>
<th>Rwy</th>
<th>Rail Rate to Vancouver ($/tonne)</th>
<th>Distance to Vancouver (km)</th>
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<td>39.76</td>
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<td>45.68</td>
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<td>40.31</td>
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<td>44.17</td>
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<td>Booth</td>
<td>CN</td>
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<td>44.91</td>
</tr>
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<td>Brada</td>
<td>CN</td>
<td>36.24</td>
<td>39.56</td>
</tr>
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<td>CN</td>
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<td>43.39</td>
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Table C.3. Rail freight rates to Vancouver in $ per tonne, Langbank to Yorkton, CN, 2005 to 2008

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<th>Rail Rate to Vancouver ($/tonne)</th>
<th>Distance to Vancouver (km)</th>
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Table C.5. Rail freight rates to Vancouver in $ per tonne, Moosomin to Yorkton, CP, 2005 to 2008

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<th>Distance to Vancouver (km)</th>
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Rail Freight Rates

The following is a list of the rail freight rates used in the simulation. Note that the data provided for the years 1974 to 1994 represent the freight rate based on the grain being exported out of Thunder Bay. After 1994, the grain was priced in store with a final destination of Vancouver. The different distances have been accounted for in determining the cost per tonne per kilometer. Each rail agent in the simulation has this list and then checks what year it is before determining the freight rate to charge at each location based on their known distance to port. The data shows a large increase in rates between 1994 and 1995, reflecting the removal of the Crow Benefit. After that time, rail rates were relatively stable from 1995 to 2004, at which point they began increasing at a faster rate.

For the years 2005 to 2008, in almost every location within the data series, except for 2007, the rate charge from CP was higher than the rate charge for CN. Although the two lines appear to be almost identical, CP is on average $0.000197/tonne/kilometer more expensive than CN. This may not seem to be a large amount, but when multiplied against a 1,700 kilometer journey and a 9,000 tonne train, the difference adds up to an additional $3,014.10 per train. The average wheat volume of wheat transported out of Saskatchewan per year is just over 13 million metric tonnes.

The base freight rate is the data that was obtained from the Parrish & Heimbecker in Saskatoon on the CN line. The calculated CN rates are distance based. The calculated CP rates are based off of the regressed freight rates; that differential was applied backwards against the known CN freight rates.
Actual freight rates were not used in the simulation. The freight rate for Saskatoon was used as the benchmark freight rate and then adjusted based on the distance by rail to Vancouver. The Alberta Agriculture data was used to determine the average price spread between CN and CP freight rates as historical freight rate information for each elevator location was not available at the time the model was run. Historical freight rates for all grains and elevator locations in western Canada are now accessible online (Rosaasen et al, 2011).
Table C.6. Freight rates used in simulation in $ per tonne, 1977 to 2006

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<tr>
<th>Year</th>
<th>Base Freight Rate $ / tonne</th>
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<th>CP Rail Rate in $/t/km</th>
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<td>0.0034</td>
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<tr>
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<td>0.0032</td>
<td>0.0034</td>
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### Table D.1. Wheat prices and production, 1977 to 2006

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<th>Average Durum Price ($ / T)</th>
<th>Winter Wheat (T)</th>
<th>Total Spring Wheat (T)</th>
<th>Subtotal Winter + Spring (T)</th>
<th>Average RSW Price ($ / T)</th>
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(Canadian Wheat Board, 2010)
Table D.2. Adjusted wheat prices, 1977 to 2006

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(Canadian Wheat Board, 2010)
Table D.3. Saskatchewan Wheat Production in Tonnes, CAR 1A to 3BN, 1977 to 2006

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(Statistics Canada, 2007)
Table D.4. Saskatchewan Wheat Production in Tonnes, CAR 3BS to 7A, 1977 to 2006

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(Statistics Canada, 2007)
Table D.5. Saskatchewan Wheat Production in Tonnes, CAR 7B to 9B, 1977 to 2006

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<th>7B</th>
<th>8A</th>
<th>8B</th>
<th>9A</th>
<th>9B</th>
<th>Total</th>
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</tbody>
</table>

(Statistics Canada, 2007)
APPENDIX E

NetLogo© Source Code (version 4.1.2)

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;GRAIN SUPPLY CHAIN;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

extensions [ gis ]

globals [ 

    run-number
    year

    ;; farmer globals
    port-price
    total-farmer-inventory
    total-potential-farmer-del-to-el
    total-farmer-del-to-elev
    total-farmer-del-to-elev2
    avg-farmer-price
    avg-farmer-price2
    total-farmer-revenue
    total-prod-volume
    total-farmer-check-inventory1
    total-farmer-check-inventory2
    lucky-farmers

    total-farmer1a-revenue
    total-farmer1b-revenue
    total-farmer2a-revenue
    total-farmer2b-revenue
    total-farmer3an-revenue
    total-farmer3as-revenue
    total-farmer3bn-revenue
    total-farmer3bs-revenue
    total-farmer4a-revenue
    total-farmer4b-revenue
    total-farmer5a-revenue
    total-farmer5b-revenue
    total-farmer6a-revenue
    total-farmer6b-revenue
    total-farmer7a-revenue
]
total-farmer7b-revenue
total-farmer8a-revenue
total-farmer8b-revenue
total-farmer9a-revenue
total-farmer9b-revenue

;; elevator globals

all-elevators
elevators-with-room
poss-large-elevators
poss-medium-elevators
poss-small-elevators
min-elevator-price
elevator-basis2
delivery-made
large-ele-capacity
medium-ele-capacity
small-ele-capacity
total-elevator-delivery
total-elevator-delivery2
total-elevator-space
large-elevators
medium-elevators
small-elevators
ave-small-ele-%cap
ave-medium-ele-%cap
ave-large-ele-%cap

;; railAgent globals

all-railAgents
large-train
medium-train
small-train

;; gis variables

world-envelope
gis-width
gis-height
factor

cn-dataset
cpr-dataset
all-car-dataset
car1A-dataset
car1B-dataset
car2A-dataset
car2B-dataset
car3AN-dataset
car3AS-dataset
car3BN-dataset
car3BS-dataset
car4A-dataset
car4B-dataset
car5A-dataset
car5B-dataset
car6A-dataset
car6B-dataset
car7A-dataset
car7B-dataset
car8A-dataset
car8B-dataset
car9A-dataset
car9B-dataset

viterra-dataset
pioneer-dataset
cargill-dataset
p&h-dataset
therest-dataset

;; census agricultural region (CAR) variables

car1a
car1b
car2a
car2b
car3an
car3as
car3bn
car3bs
car4a
car4b
car5a
car5b
car6a
car6b
car7a
car7b
car8a
car8b
car9a
car9b

farmers1a
farmers1b
farmers2a
farmers2b
farmers3an
farmers3as
farmers3bn
farmers3bs
farmers4a
farmers4b
farmers5a
farmers5b
farmers6a
farmers6b
farmers7a
farmers7b
farmers8a
farmers8b
farmers9a
farmers9b

wheat-prod1a-list
wheat-prod1b-list
wheat-prod2a-list
wheat-prod2b-list
wheat-prod3a-list
wheat-prod3b-list
wheat-prod3c-list
wheat-prod3d-list
wheat-prod3e-list
wheat-prod4a-list
wheat-prod4b-list
wheat-prod5a-list
wheat-prod5b-list
wheat-prod6a-list
wheat-prod6b-list
wheat-prod7a-list
wheat-prod7b-list
wheat-prod8a-list
wheat-prod8b-list
wheat-prod9a-list
wheat-prod9b-list

;; wheat price list
wheat-price-list

;; freight rate lists
cn-freighrate-list
cp-freighrate-list

;; tariff rate lists
cargill-tariff-rate-list
viterra-tariff-rate-list
pioneer-tariff-rate-list
p&h-tariff-rate-list
therest-tariff-rate-list

]

breed [farmers farmer]
farmers-own [  
some-property  
grain-inventory
}
truck-distance
truck-distance2
truck-rate
truck-rate2
farmer-truck-cost
farmer-delivery-to-elevator
farmer-delivery-to-elevator2
potential-farmer-del-to-el
potential-farmer-del-to-ele2
farmer-price
farmer-price2
farmer-revenue
best-company
farmer-check-inventory1
farmer-check-inventory2
prod-volume
farmer-inventory

breed [elevatorCGs elevatorCG]
elevatorCGs-own [ ]
elevator-delivery
elevator-delivery2
physical-elevator-capacity
elevator-capacity
elevator-handling-fees
elevator-inventory
elevator-price
elevator-price2
elevator-delivery-to-rail
elevator-delivery-to-rail2
best-railAgent
elevator-revenueCG
elevator-costCG
elevator-incomeCG
rail-capacity
shortage
percent-capacity
check-inventory1
check-inventory2
elevator-space
elevator-storage-cost
elevator-basis
initial-capacity
railway
dist-to-vc
station
short-one-train

breed [elevatorTRs elevatorTR]
elevatorTRs-own [ ]
elevator-delivery
elevator-delivery2
physical-elevator-capacity
elevator-capacity
elevator-handling-fees
elevator-inventory
elevator-price
elevator-price2
elevator-delivery-to-rail
elevator-delivery-to-rail2
best-railAgent
elevator-revenueTR
elevator-costTR
elevator-incomeTR
rail-capacity
shortage
percent-capacity
check-inventory1
check-inventory2
elevator-space
elevator-storage-cost
elevator-basis
initial-capacity
railway
dist-to-vc
station
short-one-train
]

breed [elevatorPHs elevatorPH]
elevatorPHs-own [
elevator-delivery
  elevator-delivery2
  physical-elevator-capacity
elevator-capacity
elevator-handling-fees
elevator-inventory
elevator-price
elevator-price2
elevator-delivery-to-rail
elevator-delivery-to-rail2
best-railAgent
elevator-revenuePH
elevator-costPH
elevator-incomePH
rail-capacity
shortage
percent-capacity
check-inventory1
check-inventory2
elevator-space
elevator-storage-cost
elevator-basis
initial-capacity
railway
dist-to-vc
station
short-one-train
]
]}
breed [elevatorPNs elevatorPN] elevatorPNs-own [ 
elevator-delivery

elevator-delivery2

physical-elevator-capacity


elevator-capacity

elevator-handling-fees

elevator-inventory

elevator-price

elevator-price2

elevator-delivery-to-rail

elevator-delivery-to-rail2

best-railAgent

elevator-revenuePN

elevator-costPN

elevator-incomePN

rail-capacity

shortage

percent-capacity

check-inventory1

check-inventory2

elevator-space

elevator-storage-cost

elevator-basis

initial-capacity

railway

dist-to-vc

station

short-one-train

]
breed [elevatorVIs elevatorVI] elevatorVIs-own [ 
elevator-delivery

elevator-delivery2

physical-elevator-capacity


elevator-capacity

elevator-handling-fees

elevator-inventory

elevator-price

elevator-price2

elevator-delivery-to-rail

elevator-delivery-to-rail2

best-railAgent

elevator-revenueVI

elevator-costVI

elevator-incomeVI

rail-capacity

shortage

percent-capacity

check-inventory1

check-inventory2

elevator-space
elevator-storage-cost
elevator-basis
initial-capacity
railway
dist-to-vc
station
short-one-train
]

breed [railAgentCNs railAgentCN]
railAgentCNs-own [  
  rail-delivery  
rail-quantity  
railAgent-revenueCN  
railAgent-costCN  
railAgent-incomeCN  
rail-rate  
large-num-trains  
med-num-trains  
small-num-trains  
delivery-size  
dist-to-vc  
slack-train
]

breed [railAgentCPRs railAgentCPR]
railAgentCPRs-own [  
  rail-delivery  
rail-quantity  
railAgent-revenueCPR  
railAgent-costCPR  
railAgent-incomeCPR  
rail-rate  
large-num-trains  
med-num-trains  
small-num-trains  
delivery-size  
dist-to-vc  
slack-train
]

breed [portAgents portAgent]
portAgents-own [  
elevatorTR-ship-portion  
elevatorPH-ship-portion  
elevatorPN-ship-portion  
elevatorVI-ship-portion  
elevatorCG-ship-portion  
number-of-ships  
monthly-ship-tonnage  
port-deliveryTR  
port-deliveryPH  
port-deliveryPN  
port-deliveryVI  
port-deliveryCG
]
elevatorTR-demurr-check
elevatorPH-demurr-check
elevatorPN-demurr-check
elevatorVI-demurr-check
elevatorCG-demurr-check
elevatorTR-demurrage
elevatorPH-demurrage
elevatorPN-demurrage
elevatorVI-demurrage
elevatorCG-demurrage
total-vessel-demurrage
]

breed [demAgents demAgent]
demAgents-own [ ]
total-inland-demurrage
elevatorVI-inland-demurrage
elevatorCG-inland-demurrage
elevatorPH-inland-demurrage
elevatorPN-inland-demurrage
elevatorTR-inland-demurrage
]

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to initialization-phase
  set run-number 1
  setup
  delete-files
end

to setup
  clear-turtles
  clear-patches
  clear-drawing
  clear-all-plots
  clear-output
  reset-ticks

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  set cargill-dataset gis:load-dataset "C:\Users\Russell\Documents\Grad School\Thesis\Running Model\Input\Elevator Shapefiles\SK_Cargill.shp"
  set p&h-dataset gis:load-dataset "C:\Users\Russell\Documents\Grad School\Thesis\Running Model\Input\Elevator Shapefiles\SK_P&H.shp"
set therest-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\Elevator Shapefiles\\SK_TheRest.shp"

set cn-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\Rail Shapefiles\\SKrlCN+.shp"
set cpr-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\Rail Shapefiles\\SKrlCPR.shp"

set all-car-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CARBoundaries_Intersect.shp"
set car1A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR1A.shp"
set car1B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR1B.shp"
set car2A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR2A.shp"
set car2B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR2B.shp"
set car3AN-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR3AN.shp"
set car3AS-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR3AS.shp"
set car3BN-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR3BN.shp"
set car3BS-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR3BS.shp"
set car4A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR4A.shp"
set car4B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR4B.shp"
set car5A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR5A.shp"
set car5B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR5B.shp"
set car6A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR6A.shp"
set car6B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR6B.shp"
set car7A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR7A.shp"
set car7B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR7B.shp"
set car8A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR8A.shp"
set car8B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR8B.shp"
set car9A-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR9A.shp"
set car9B-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Input\\CAR Boundaries\\CAR9B.shp"

gis:set-world-envelope (gis:envelope-of all-car-dataset)
set gis-width 630.2
set gis-height 631

set factor max list (gis-width / world-width) (gis-height / world-height)

import-data
create-landscape
create-farmer-agents
create-port-&-dem-agents
set-all-agentsets
create-plot

set year 0

end
to import-data
  set-current-directory "C:\Users\Russell\Documents\Grad School\Thesis\Running Model\Input"
  file-open "Wheat Prices 1977-2006.txt"
  set wheat-price-list file-read
  file-close

  file-open "CN Freight Rates 1977-2006.txt"
  set cn-freightrate-list file-read
  file-close

  file-open "CP Freight Rates 1977-2006.txt"
  set cp-freightrate-list file-read
  file-close

  file-open "Cargill Tariff Rates 1977-2006.txt"
  set cargill-tariff-rate-list file-read
  file-close

  file-open "Viterra Tariff Rates 1977-2006.txt"
  set viterra-tariff-rate-list file-read
  file-close

  file-open "Pioneer Tariff Rates 1977-2006.txt"
  set pioneer-tariff-rate-list file-read
  file-close

  file-open "P&H Tariff Rates 1977-2006.txt"
  set p&h-tariff-rate-list file-read
  file-close

  file-open "TheRest Tariff Rates 1977-2006.txt"
  set therest-tariff-rate-list file-read
  file-close
file-open "Wheat Production CAR1 1977-2006.txt"
set wheat-prod1a-list file-read
file-close

file-open "Wheat Production CAR2 1977-2006.txt"
set wheat-prod1b-list file-read
file-close

file-open "Wheat Production CAR3 1977-2006.txt"
set wheat-prod2a-list file-read
file-close

file-open "Wheat Production CAR4 1977-2006.txt"
set wheat-prod2b-list file-read
file-close

file-open "Wheat Production CAR5 1977-2006.txt"
set wheat-prod3an-list file-read
file-close

file-open "Wheat Production CAR6 1977-2006.txt"
set wheat-prod3as-list file-read
file-close

file-open "Wheat Production CAR7 1977-2006.txt"
set wheat-prod3bn-list file-read
file-close

file-open "Wheat Production CAR8 1977-2006.txt"
set wheat-prod3bs-list file-read
file-close

file-open "Wheat Production CAR9 1977-2006.txt"
set wheat-prod4a-list file-read
file-close

file-open "Wheat Production CAR10 1977-2006.txt"
set wheat-prod4b-list file-read
file-close

file-open "Wheat Production CAR11 1977-2006.txt"
set wheat-prod5a-list file-read
file-close

file-open "Wheat Production CAR12 1977-2006.txt"
set wheat-prod5b-list file-read
file-close

file-open "Wheat Production CAR13 1977-2006.txt"
set wheat-prod6a-list file-read
file-close

file-open "Wheat Production CAR14 1977-2006.txt"
set wheat-prod6b-list file-read
file-close

file-open "Wheat Production CAR15 1977-2006.txt"
set wheat-prod7a-list file-read
file-close

file-open "Wheat Production CAR16 1977-2006.txt"
set wheat-prod7b-list file-read
file-close

file-open "Wheat Production CAR17 1977-2006.txt"
set wheat-prod8a-list file-read
file-close

file-open "Wheat Production CAR18 1977-2006.txt"
set wheat-prod8b-list file-read
file-close

file-open "Wheat Production CAR19 1977-2006.txt"
set wheat-prod9a-list file-read
file-close

file-open "Wheat Production CAR20 1977-2006.txt"
set wheat-prod9b-list file-read
file-close

end

to create-landscape

  setup-car-boundary
  setup-cn-rail
  setup-cpr-rail
  set-train-sizes
  setup-elevators
  set-farmer-numbers

end

to setup-car-boundary

  ask patches [set pcolor white]

  gis:set-drawing-color 95
  gis:draw car1A-dataset 1
  gis:draw car1B-dataset 1
  gis:draw car2A-dataset 1
  gis:draw car2B-dataset 1
  gis:draw car3AN-dataset 1
  gis:draw car3AS-dataset 1
  gis:draw car3BN-dataset 1
  gis:draw car3BS-dataset 1
  gis:draw car4A-dataset 1
  gis:draw car4B-dataset 1
gis:draw car5A-dataset 1
gis:draw car5B-dataset 1
gis:draw car6A-dataset 1
gis:draw car6B-dataset 1
gis:draw car7A-dataset 1
gis:draw car7B-dataset 1
gis:draw car8A-dataset 1
gis:draw car8B-dataset 1
gis:draw car9A-dataset 1
gis:draw car9B-dataset 1
end

to setup-cn-rail
    gis:set-drawing-color 35
    gis:draw cn-dataset 1
end

to setup-cpr-rail
    gis:set-drawing-color 15
    gis:draw cpr-dataset 1
end

to set-train-sizes
    set large-train 10000
    set medium-train 5000
    set small-train 2500
    set large-ele-capacity 39000
    set medium-ele-capacity 14000
    set small-ele-capacity 4000
end

to setup-elevators
    create-viterra-elevators
    create-pioneer-elevators
    create-cargill-elevators
    create-p&h-elevators
    create-therest-elevators
end

to create-viterra-elevators
foreach gis:feature-list-of viterra-dataset [
ask patches gis:intersecting ? [  
sprout-elevatorVIs 1 [    
  set shape "elevatorempty"    
  set color 95    
  set initial-capacity gis:property-value ? "CAPACITY"    
  set railway gis:property-value ? "RAILWAY"    
  set dist-to-vc gis:property-value ? "DIST_TO_VC"    
  set station gis:property-value ? "STATION" ]]]

ask elevatorVIs [  
  if initial-capacity < 7000    
[  
    set size 8    
    set rail-capacity small-train    
    set physical-elevator-capacity small-ele-capacity]  
        
  if initial-capacity >= 7000 and initial-capacity < 25000    
[  
    set size 12    
    set rail-capacity medium-train    
    set physical-elevator-capacity medium-ele-capacity]  
        
  if initial-capacity >= 25000    
[  
    set size 15    
    set rail-capacity large-train    
    set physical-elevator-capacity large-ele-capacity]  
        
if railway = "CN" [  
  hatch-railAgentCNs 1 [    
    set shape "railroadew"    
    set color 35    
    set size 8    
    set delivery-size [rail-capacity] of myself    
    set dist-to-vc [dist-to-vc] of myself    
    create-link-with myself]]

if railway = "OTHER" [  
  hatch-railAgentCNs 1 [    
    set shape "railroadew"    
    set color 35    
    set size 8    
    set delivery-size [rail-capacity] of myself    
    set dist-to-vc [dist-to-vc] of myself    
    create-link-with myself]]

if railway = "CP" [  
  hatch-railAgentCPRs 1 [    
    set shape "railroadns"    
    set color 15    
    set size 8    
    set delivery-size [rail-capacity] of myself    
    set dist-to-vc [dist-to-vc] of myself    
    create-link-with myself]]

set best-railAgent one-of link-neighbors
to create-pioneer-elevators

foreach gis:feature-list-of pioneer-dataset [

    ask patches gis:intersecting ? [

        sprout-elevatorPNs 1 [
            set initial-capacity 0
            set shape "elevatorempty"
            set color 25
            set initial-capacity gis:property-value ? "CAPACITY"
            set railway gis:property-value ? "RAILWAY"
            set dist-to-vc gis:property-value ? "DIST_TO_VC"
            set station gis:property-value ? "STATION" ]]

    ask elevatorPNs [

        if initial-capacity < 7000
            [ set size 8
              set rail-capacity small-train
              set physical-elevator-capacity small-ele-capacity]

        if initial-capacity >= 7000 and initial-capacity < 25000
            [ set size 12
              set rail-capacity medium-train
              set physical-elevator-capacity medium-ele-capacity]

        if initial-capacity >= 25000
            [ set size 15
              set rail-capacity large-train
              set physical-elevator-capacity large-ele-capacity]

        if railway = "CN"
            [ hatch-railAgentCNs 1 [
                set shape "railroadew"
                set color 35
                set size 8
                set delivery-size [rail-capacity] of myself
                set dist-to-vc [dist-to-vc] of myself
                create-link-with myself]]

        if railway = "OTHER"
            [ hatch-railAgentCNs 1 [
                set shape "railroadew"
                set color 35
                set size 8
                set delivery-size [rail-capacity] of myself
                set dist-to-vc [dist-to-vc] of myself
                create-link-with myself]]
if railway = "CP" [  
hatch-railAgentCPRs 1 [  
   set shape "railroadns"  
   set color 15  
   set size 8  
   set delivery-size [rail-capacity] of myself  
   set dist-to-vc [dist-to-vc] of myself  
   create-link-with myself]]

   set best-railAgent one-of link-neighbors

] end

to create-cargill-elevators

foreach gis:feature-list-of cargill-dataset [  
   ask patches gis:intersecting ? [  
      sprout-elevatorCGs 1 [  
         set initial-capacity 0  
         set shape "elevatorempty"  
         set color 65  
         set initial-capacity gis:property-value ? "CAPACITY"  
         set railway gis:property-value ? "RAILWAY"  
         set dist-to-vc gis:property-value ? "DIST_TO_VC"  
         set station gis:property-value ? "STATION" ]]]

   ask elevatorCGs [  
      if initial-capacity < 7000  
         [ set size 8  
            set rail-capacity small-train  
            set physical-elevator-capacity small-ele-capacity]  
      if initial-capacity >= 7000 and initial-capacity < 25000  
         [ set size 12  
            set rail-capacity medium-train  
            set physical-elevator-capacity medium-ele-capacity]  
      if initial-capacity >= 25000  
         [ set size 15  
            set rail-capacity large-train  
            set physical-elevator-capacity large-ele-capacity]  

   if railway = "CN" [  
      hatch-railAgentCNs 1 [  
         set shape "railroadew"  
         set color 35  
         set size 8  
         set delivery-size [rail-capacity] of myself

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set dist-to-vc [dist-to-vc] of myself
create-link-with myself]]

if railway = "OTHER" [hatch-railAgentCNs 1 [
    set shape "railroadew"
    set color 35
    set size 8
    set delivery-size [rail-capacity] of myself
    set dist-to-vc [dist-to-vc] of myself
    create-link-with myself]]

if railway = "CP" [hatch-railAgentCPRs 1 [
    set shape "railroadns"
    set color 15
    set size 8
    set delivery-size [rail-capacity] of myself
    set dist-to-vc [dist-to-vc] of myself
    create-link-with myself]]

set best-railAgent one-of link-neighbors
]
end
to create-p&h-elevators

foreach gis:feature-list-of p&h-dataset [
    ask patches gis:intersecting ? [
        sprout-elevatorPHs 1 [
            set initial-capacity 0
            set shape "elevatorempty"
            set color 45
            set initial-capacity gis:property-value ? "CAPACITY"
            set railway gis:property-value ? "RAILWAY"
            set dist-to-vc gis:property-value ? "DIST_TO_VC"
            set station gis:property-value ? "STATION" ]]

    ask elevatorPHs [if initial-capacity < 7000
    [ set size 8
        set rail-capacity small-train
        set physical-elevator-capacity small-ele-capacity]

    if initial-capacity >= 7000 and initial-capacity < 25000 [ set size 12
        set rail-capacity medium-train
        set physical-elevator-capacity medium-ele-capacity]

    if initial-capacity >= 25000 [ set size 15

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set rail-capacity large-train
set physical-elevator-capacity large-ele-capacity]

if railway = "CN" [  
hatch-railAgentCNs 1 [  
set shape "railroadew"  
set color 35  
set size 8  
set delivery-size [rail-capacity] of myself  
set dist-to-vc [dist-to-vc] of myself  
create-link-with myself]]

if railway = "OTHER" [  
hatch-railAgentCNs 1 [  
set shape "railroadew"  
set color 35  
set size 8  
set delivery-size [rail-capacity] of myself  
set dist-to-vc [dist-to-vc] of myself  
create-link-with myself]]

if railway = "CP" [  
hatch-railAgentCPRs 1 [  
set shape "railroadns"  
set color 15  
set size 8  
set delivery-size [rail-capacity] of myself  
set dist-to-vc [dist-to-vc] of myself  
create-link-with myself]]

set best-railAgent one-of link-neighbors
}

end
to create-therest-elevators

foreach gis:feature-list-of therest-dataset [  
ask patches gis:intersecting ? [  
  sprout-elevatorTRs 1 [  
set initial-capacity 0  
set shape "elevatorempty"  
set color 125  
set initial-capacity gis:property-value ? "CAPACITY"  
set railway gis:property-value ? "RAILWAY"  
set dist-to-vc gis:property-value ? "DIST_TO_VC"  
set station gis:property-value ? "STATION" ]]]

ask elevatorTRs [
if initial-capacity < 7000
  [ set size 8
    set rail-capacity small-train
    set physical-elevator-capacity small-ele-capacity]

if initial-capacity >= 7000 and initial-capacity < 25000
  [ set size 12
    set rail-capacity medium-train
    set physical-elevator-capacity medium-ele-capacity]

if initial-capacity >= 25000
  [ set size 15
    set rail-capacity large-train
    set physical-elevator-capacity large-ele-capacity]

if railway = "CN"
  [ hatch-railAgentCNs 1
    set shape "railroadew"
    set color 35
    set size 8
    set delivery-size [rail-capacity] of myself
    set dist-to-vc [dist-to-vc] of myself
    create-link-with myself]]

if railway = "OTHER"
  [ hatch-railAgentCNs 1
    set shape "railroadew"
    set color 35
    set size 8
    set delivery-size [rail-capacity] of myself
    set dist-to-vc [dist-to-vc] of myself
    create-link-with myself]]

if railway = "CP"
  [ hatch-railAgentCPRs 1
    set shape "railroadns"
    set color 15
    set size 8
    set delivery-size [rail-capacity] of myself
    set dist-to-vc [dist-to-vc] of myself
    create-link-with myself]]

  set best-railAgent one-of link-neighbors

] end

to set-farmer-numbers
  set car1a 1017
  set car1b 770
  set car2a 906

end
set car2b 1587
set car3an 644
set car3as 1208
set car3bn 1422
set car3bs 717
set car4a 313
set car4b 696
set car5a 1978
set car5b 2077
set car6a 2102
set car6b 1584
set car7a 1403
set car7b 1212
set car8a 1377
set car8b 1685
set car9a 1766
set car9b 958

end

to create-farmer-agents
  create-farmers-in-CAR1A
  create-farmers-in-CAR1B
  create-farmers-in-CAR2A
  create-farmers-in-CAR2B
  create-farmers-in-CAR3AN
  create-farmers-in-CAR3AS
  create-farmers-in-CAR3BN
  create-farmers-in-CAR3BS
  create-farmers-in-CAR4A
  create-farmers-in-CAR4B
  create-farmers-in-CAR5A
  create-farmers-in-CAR5B
  create-farmers-in-CAR6A
  create-farmers-in-CAR6B
  create-farmers-in-CAR7A
  create-farmers-in-CAR7B
  create-farmers-in-CAR8A
  create-farmers-in-CAR8B
  create-farmers-in-CAR9A
  create-farmers-in-CAR9B
end

to create-farmers-in-CAR1A
  ask patch 245 -179 [ 
    sprout-farmers car1a [ 
      set color 118 
      set shape "default"
    ]
  ]
set size 2
set heading random 360
fd random-normal 110 5
set some-property 1
if any? other turtles-here [find-new-spot1A]
ifelse gis:contains? car1A-dataset self
  [setxy pxcor pycor
   set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
  [find-new-spot1A]]
end

to find-new-spot1A

  set heading random 360
  fd random 100
  if any? other turtles-here [find-new-spot1A]
  ifelse gis:contains? car1A-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
   [find-new-spot1A]
end

to create-farmers-in-CAR1B

  ask patch 233 -120 [ sprout-farmers car1b [ set color 118 set shape "default" set size 2.0 set heading random 360 fd random-normal 110 5 set some-property 2 if any? other turtles-here [find-new-spot1B]
  ifelse gis:contains? car1B-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
   [find-new-spot1B]]]
end

to find-new-spot1B

  set heading random 360
  fd random 100
  if any? other turtles-here [find-new-spot1B]
ifelse gis:contains? car1B-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
    [find-new-spot1B]
end

to create-farmers-in-CAR2A

    ask patch 123 -154 [
        sprout-farmers car2a [
            set color 118
            set shape "default"
            set size 2.0
            set heading random 360
            fd random-normal 110 5
            set some-property 3
            if any? other turtles-here [find-new-spot2A]
            ifelse gis:contains? car2A-dataset self
                [setxy pxcor pycor
                 set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
                [find-new-spot2A]]
        end
    end

to find-new-spot2A

    set heading random 360
    fd random 100
    if any? other turtles-here [find-new-spot2A]
    ifelse gis:contains? car2A-dataset self
        [setxy pxcor pycor
         set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
        [find-new-spot2A]
    end

to create-farmers-in-CAR2B

    ask patch 85 -115 [
        sprout-farmers car2b [
            set color 118
            set shape "default"
            set size 2.0
            set heading random 360
            fd random-normal 110 5
            set some-property 4
            if any? other turtles-here [find-new-spot2B]
ifelse gis:contains? car2B-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
    [find-new-spot2B]]
end

to find-new-spot2B
    set heading random 360
    fd random 100
    if any? other turtles-here [find-new-spot2B]
    ifelse gis:contains? car2B-dataset self
        [setxy pxcor pycor
         set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
        [find-new-spot2B]
    end

to create-farmers-in-CAR3AN
    ask patch -47 -117 [
        sprout-farmers car3an [
            set color 118
            set shape "default"
            set size 2.0
            set heading random 360
            fd random-normal 110 5
            set some-property 5
            if any? other turtles-here [find-new-spot3AN]
            ifelse gis:contains? car3AN-dataset self
                [setxy pxcor pycor
                 set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
                [find-new-spot3AN]]
        end
    ]

end

to find-new-spot3AN
    set heading random 360
    fd random 100
    if any? other turtles-here [find-new-spot3AN]
    ifelse gis:contains? car3AN-dataset self
        [setxy pxcor pycor
         set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
        [find-new-spot3AN]
    end
to create-farmers-in-CAR3AS

ask patch 3 -181 [

sprout-farmers car3as [

  set color 118
  set shape "default"
  set size 2.0
  set heading random 360
  fd random-normal 110 5
  set some-property 6
  if any? other turtles-here [find-new-spot3AS]
  ifelse gis:contains? car3AS-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
    [find-new-spot3AS]]
end

to find-new-spot3AS

  set heading random 360
  fd random 100
  if any? other turtles-here [find-new-spot3AS]
  ifelse gis:contains? car3AS-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
    [find-new-spot3AS]
end

to create-farmers-in-CAR3BN

ask patch -147 -85 [

sprout-farmers car3an [

  set color 118
  set shape "default"
  set size 2.0
  set heading random 360
  fd random-normal 110 5
  set some-property 7
  if any? other turtles-here [find-new-spot3BN]
  ifelse gis:contains? car3BN-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
    [find-new-spot3BN]]
end

to find-new-spot3BN
set heading random 360
fd random 100
if any? other turtles-here [find-new-spot3BN]
ifelse gis:contains? car3BN-dataset self
   [setx pxcor pycor
    set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
   [find-new-spot3BN]
end
to create-farmers-in-CAR3BS
   ask patch -143 -173 [
   sprout-farmers car3bs [
      set color 118
      set shape "default"
      set size 2.0
      set heading random 360
      fd random-normal 110 5
      set some-property 8
      if any? other turtles-here [find-new-spot3BS]
      ifelse gis:contains? car3BS-dataset self
         [setx pxcor pycor
          set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
         [find-new-spot3BS]]]
end
to find-new-spot3BS
   set heading random 360
   fd random 100
   if any? other turtles-here [find-new-spot3BS]
   ifelse gis:contains? car3BS-dataset self
      [setx pxcor pycor
       set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
      [find-new-spot3BS]
end
to create-farmers-in-CAR4A
   ask patch -257 -168 [
   sprout-farmers car4a [
      set color 118
      set shape "default"
set size 2.0
set heading random 360
fd random-normal 110 5
set some-property 9
if any? other turtles here [find-new-spot4A]
ifelse gis:contains? car4A-dataset self
   [setxy pycor pycor
    set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
   [find-new-spot4A]]
end

to find-new-spot4A

   set heading random 360
   fd random 100
   if any? other turtles here [find-new-spot4A]
   ifelse gis:contains? car4A-dataset self
      [setxy pycor pycor
       set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
      [find-new-spot4A]
   end
end

to create-farmers-in-CAR4B

   ask patch -259 -90 [
   
   sprout-farmers car4b [
   
   set color 118
   set shape "default"
   set size 2.0
   set heading random 360
   fd random-normal 110 5
   set some-property 10
   if any? other turtles here [find-new-spot4B]
   ifelse gis:contains? car4B-dataset self
      [setxy pycor pycor
       set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
      [find-new-spot4B]]
   end
end

to find-new-spot4B

   set heading random 360
   fd random 100
   if any? other turtles here [find-new-spot4B]
   ifelse gis:contains? car4B-dataset self
      [setxy pycor pycor
       set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
      [find-new-spot4B]]
end
set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] [find-new-spot4B]
end


to create-farmers-in-CAR5A

ask patch 214 -64 [ 
  sprout-farmers car5a [ 
    set color 118 
    set shape "default" 
    set size 2.0 
    set heading random 360 
    fd random-normal 110 5 
    set some-property 11 
    if any? other turtles-here [find-new-spot5A] 
    ifelse gis:contains? car5A-dataset self 
      [setxy pxcor pycor 
        set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
      [find-new-spot5A]]
  end]
end

to find-new-spot5A

set heading random 360 
fd random 100 
if any? other turtles-here [find-new-spot5A] 
ifelse gis:contains? car5A-dataset self 
  [setxy pxcor pycor 
    set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
  [find-new-spot5A]
end

to create-farmers-in-CAR5B

ask patch 190 2 [ 
  sprout-farmers car5b [ 
    set color 118 
    set shape "default" 
    set size 2.0 
    set heading random 360 
    fd random-normal 110 5 
    set some-property 12 
    if any? other turtles-here [find-new-spot5B] 
    ifelse gis:contains? car5B-dataset self
to find-new-spot5B

    set heading random 360
    fd random 100
    if any? other turtles here [find-new-spot5B]
    ifelse gis:contains? car5B-dataset self
        [setxy pxcor pycor
            set grain-inventory random-normal farmer-start-inventory farmer-
            start-inv-stdv]
        [find-new-spot5B]
    end

end
to create-farmers-in-CAR6A

    ask patch 21 -33 [
        sprout-farmers car6a [
            set color 118
            set shape "default"
            set size 2.0
            set heading random 360
            fd random-normal 110 5
            set some-property 13
            if any? other turtles here [find-new-spot6A]
            ifelse gis:contains? car6A-dataset self
                [setxy pxcor pycor
                    set grain-inventory random-normal farmer-start-inventory farmer-
                    start-inv-stdv]
                [find-new-spot6A]
            end
        ]
    ]
end
to find-new-spot6A

    set heading random 360
    fd random 100
    if any? other turtles here [find-new-spot6A]
    ifelse gis:contains? car6A-dataset self
        [setxy pxcor pycor
            set grain-inventory random-normal farmer-start-inventory farmer-
            start-inv-stdv]
        [find-new-spot6A]
    end
to create-farmers-in-CAR6B
ask patch -89 -3 [ 
sprout-farmers car6b [ 
set color 118 
set shape "default" 
set size 2.0 
set heading random 360 
fd random-normal 110 5 
set some-property 14 
if any? other turtles-here [find-new-spot6B] 
ifelse gis:contains? car6B-dataset self 
[setx pxcor pycor 
set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
[find-new-spot6B]] ] 
end

to find-new-spot6B

set heading random 360 
fd random 100 
if any? other turtles-here [find-new-spot6B] 
ifelse gis:contains? car6B-dataset self 
[setx pxcor pycor 
set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
[find-new-spot6B] 
end

to create-farmers-in-CAR7A

ask patch -246 -28 [ 
sprout-farmers car7a [ 
set color 118 
set shape "default" 
set size 2.0 
set heading random 360 
fd random-normal 110 5 
set some-property 15 
if any? other turtles-here [find-new-spot7A] 
ifelse gis:contains? car7A-dataset self 
[setx pxcor pycor 
set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
[find-new-spot7A]]] 
end

to find-new-spot7A
set heading random 360
fd random 100
if any? other turtles-here [find-new-spot7A]
ifelse gis:contains? car7A-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
    [find-new-spot7A]
end

to create-farmers-in-CAR7B

ask patch -249 29 [sprout-farmers car7b [
    set color 118
    set shape "default"
    set size 2.0
    set heading random 360
    fd random-normal 110 5
    set some-property 16
    if any? other turtles-here [find-new-spot7B]
    ifelse gis:contains? car7B-dataset self
        [setxy pxcor pycor
         set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
        [find-new-spot7B]]
end

to find-new-spot7B

set heading random 360
fd random 100
if any? other turtles-here [find-new-spot7B]
ifelse gis:contains? car7B-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
    [find-new-spot7B]
end

to create-farmers-in-CAR8A

ask patch 191 83 [
    sprout-farmers car8a [
    set color 118
    set shape "default"
    set size 2.0
    set heading random 360
    fd random-normal 110 5
set some-property 17
if any? other turtles-here [find-new-spot8A]
ifelse gis:contains? car8A-dataset self
  [setxy pxcor pycor
   set grain-inventory random-normal farmer-start-inventory farmer-
   start-inv-stdv]
  [find-new-spot8A]]
end
to find-new-spot8A
  set heading random 360
  fd random 100
  if any? other turtles-here [find-new-spot8A]
  ifelse gis:contains? car8A-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-
     start-inv-stdv]
    [find-new-spot8A]
  end
to create-farmers-in-CAR8B
  ask patch 26 51 [
    sprout-farmers car8b [
      set color 118
      set shape "default"
      set size 2.0
      set heading random 360
      fd random-normal 110 5
      set some-property 18
      if any? other turtles-here [find-new-spot8B]
      ifelse gis:contains? car8B-dataset self
        [setxy pxcor pycor
         set grain-inventory random-normal farmer-start-inventory farmer-
         start-inv-stdv]
        [find-new-spot8B]]
      end
to find-new-spot8B
  set heading random 360
  fd random 100
  if any? other turtles-here [find-new-spot8B]
  ifelse gis:contains? car8B-dataset self
    [setxy pxcor pycor
     set grain-inventory random-normal farmer-start-inventory farmer-
     start-inv-stdv]
    [find-new-spot8B]
end

to create-farmers-in-CAR9A

    ask patch -73 107 [ 
        sprout-farmers car9a [ 
            set color 118 
            set shape "default" 
            set size 2.0 
            set heading random 360 
            fd random-normal 110 5 
            set some-property 19 
            if any? other turtles-here [find-new-spot9A] 
            ifelse gis:contains? car9A-dataset self 
                [setxy pxcor pycor 
                    set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
                    [find-new-spot9A]]
            end
        end 
    end 

to find-new-spot9A

    set heading random 360 
    fd random 100 
    if any? other turtles-here [find-new-spot9A] 
    ifelse gis:contains? car9A-dataset self 
        [setxy pxcor pycor 
            set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
            [find-new-spot9A]
    end

to create-farmers-in-CAR9B

    ask patch -251 133 [ 
        sprout-farmers car9b [ 
            set color 118 
            set shape "default" 
            set size 2.0 
            set heading random 360 
            fd random-normal 110 5 
            set some-property 20 
            if any? other turtles-here [find-new-spot9B] 
            ifelse gis:contains? car9B-dataset self 
                [setxy pxcor pycor 
                    set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv] 
                    [find-new-spot9B]]
            end
        end 
    end
to find-new-spot9B
  set heading random 360
  fd random 100
  if any? other turtles-here [find-new-spot9B]
  ifelse gis:contains? car9B-dataset self
   [setx pxcor pycor
    set grain-inventory random-normal farmer-start-inventory farmer-start-inv-stdv]
  [find-new-spot9B]
end

to set-all-agentsets
  set all-railAgents (turtle-set railAgentCNs railAgentCPRs)
  set all-elevators (turtle-set elevatorCGs elevatorTRs elevatorPHs elevatorPNs elevatorVIs)
  set large-elevators all-elevators with [physical-elevator-capacity = large-ele-capacity]
  set medium-elevators all-elevators with [physical-elevator-capacity = medium-ele-capacity]
  set small-elevators all-elevators with [physical-elevator-capacity = small-ele-capacity]
  set farmers1a farmers with [some-property = 1]
  set farmers1b farmers with [some-property = 2]
  set farmers2a farmers with [some-property = 3]
  set farmers2b farmers with [some-property = 4]
  set farmers3an farmers with [some-property = 5]
  set farmers3as farmers with [some-property = 6]
  set farmers3bn farmers with [some-property = 7]
  set farmers3bs farmers with [some-property = 8]
  set farmers4a farmers with [some-property = 9]
  set farmers4b farmers with [some-property = 10]
  set farmers5a farmers with [some-property = 11]
  set farmers5b farmers with [some-property = 12]
  set farmers6a farmers with [some-property = 13]
  set farmers6b farmers with [some-property = 14]
  set farmers7a farmers with [some-property = 15]
  set farmers7b farmers with [some-property = 16]
  set farmers8a farmers with [some-property = 17]
  set farmers8b farmers with [some-property = 18]
  set farmers9a farmers with [some-property = 19]
  set farmers9b farmers with [some-property = 20]
end

to create-port-&-dem-agents
  create-portAgents 1
create-demAgents 1
end

to create-plot

    set-current-plot "farmer data"
    set-current-plot-pen "revenue"

    set-current-plot "inland demurrage"
    set-current-plot-pen "elevator dem"

    set-current-plot "vessel demurrage"
    set-current-plot-pen "port dem"

    set-current-plot "farmer inventory"
    set-current-plot-pen "farmer inventory"
end

to delete-files

    set-current-directory "C:\Users\Russell\Documents\Grad School\Thesis\Running Model\Output"

    ;; start procedure that deletes the last run of data
    file-delete "Farmer Output.csv"
    file-delete "ElevatorCG Output.csv"
    file-delete "ElevatorTR Output.csv"
    file-delete "ElevatorPH Output.csv"
    file-delete "ElevatorPN Output.csv"
    file-delete "ElevatorVI Output.csv"
    file-delete "Demurrage Output.csv"
    file-delete "RailAgentCN Output.csv"
    file-delete "RailAgentCPR Output.csv"
    file-delete "Port Output.csv"
    file-delete "Demurrage Agent Output.csv"
end

to go

    clear-variables
run-railAgents
run-elevators
farmer-set-delivery
set-best-elevator
farmers-grow-grain
farmer-make-delivery
elevator-take-delivery
rail-take-delivery
tally-inland-demurrage
deliver-grain-to-port
tick-advance 0.9
calculate-turtle-income
tick-advance 0.1
export-data
update-plot

if ticks < sim-length [go]
set run-number run-number + 1
if run-number <= total-runs [ setup
go]  
if run-number > total-runs [stop]
end

to clear-variables

ask railAgentCNs [ set rail-delivery 0 set railAgent-revenueCN 0 set railAgent-costCN 0 set railAgent-incomeCN 0 set rail-quantity 0 set rail-delivery 0 set slack-train 0 ]

ask railAgentCPRs [ set rail-delivery 0 set railAgent-revenueCPR 0 set railAgent-costCPR 0 set railAgent-incomeCPR 0 set rail-quantity 0 set rail-delivery 0 set slack-train 0 ]

ask elevatorCGs [ set elevator-delivery 0 set elevator-delivery2 0 set elevator-storage-cost 0 set elevator-price 0 set elevator-price2 0 set elevator-basis 0 ]
set elevator-basis2 0
set elevator-delivery-to-rail 0
set elevator-delivery-to-rail2 0
set elevator-revenueCG 0
set elevator-costCG 0
set elevator-incomeCG 0
set shortage 0
set check-inventory1 0
set check-inventory2 0
set elevator-space 0
set short-one-train 0
]

ask elevatorTRs [ set elevator-delivery 0
set elevator-delivery2 0
set elevator-storage-cost 0
set elevator-price 0
set elevator-price2 0
set elevator-basis 0
set elevator-basis2 0
set elevator-delivery-to-rail 0
set elevator-delivery-to-rail2 0
set elevator-revenueTR 0
set elevator-costTR 0
set elevator-incomeTR 0
set shortage 0
set check-inventory1 0
set check-inventory2 0
set elevator-space 0
set short-one-train 0
]

ask elevatorPHs [ set elevator-delivery 0
set elevator-delivery2 0
set elevator-storage-cost 0
set elevator-price 0
set elevator-price2 0
set elevator-basis 0
set elevator-basis2 0
set elevator-delivery-to-rail 0
set elevator-delivery-to-rail2 0
set elevator-revenuePH 0
set elevator-costPH 0
set elevator-incomePH 0
set shortage 0
set check-inventory1 0
set check-inventory2 0
set elevator-space 0
set short-one-train 0
]

ask elevatorPNs [ set elevator-delivery 0

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set elevator-delivery2 0
set elevator-storage-cost 0
set elevator-price 0
set elevator-price2 0
set elevator-basis 0
set elevator-basis2 0
set elevator-delivery-to-rail 0
set elevator-delivery-to-rail2 0
set elevator-revenuePN 0
set elevator-costPN 0
set elevator-incomePN 0
set shortage 0
set check-inventory1 0
set check-inventory2 0
set elevator-space 0
set short-one-train 0
]

ask elevatorVIs [  
set elevator-delivery 0
set elevator-delivery2 0
set elevator-storage-cost 0
set elevator-price 0
set elevator-price2 0
set elevator-basis 0
set elevator-basis2 0
set elevator-delivery-to-rail 0
set elevator-delivery-to-rail2 0
set elevator-revenueVI 0
set elevator-costVI 0
set elevator-incomeVI 0
set shortage 0
set check-inventory1 0
set check-inventory2 0
set elevator-space 0
set short-one-train 0
]

ask farmers [  
set farmer-delivery-to-elevator 0
set farmer-delivery-to-elevator2 0
set potential-farmer-del-to-el 0
set farmer-price 0
set farmer-price2 0
set farmer-revenue 0
set farmer-truck-cost 0
set farmer-cost 0
set best-company nobody
]

ask portAgents [  
set monthly-ship-tonnage 0
set elevatorTR-ship-portion 0
set elevatorPH-ship-portion 0
set elevatorPN-ship-portion 0
]
set elevatorVI-ship-portion 0
set elevatorCG-ship-portion 0
set port-deliveryTR 0
set port-deliveryPH 0
set port-deliveryPN 0
set port-deliveryVI 0
set port-deliveryCG 0
set elevatorTR-demurr-check 0
set elevatorPH-demurr-check 0
set elevatorPN-demurr-check 0
set elevatorVI-demurr-check 0
set elevatorCG-demurr-check 0
set elevatorTR-demurrage 0
set elevatorPH-demurrage 0
set elevatorPN-demurrage 0
set elevatorVI-demurrage 0
set elevatorCG-demurrage 0
set total-vessel-demurrage 0
]

ask demAgents [ set total-inland-demurrage 0 ]
]

set elevators-with-room nobody
set poss-large-elevators nobody
set poss-medium-elevators nobody
set poss-small-elevators nobody

set total-potential-farmer-del-to-el 0
set total-farmer-del-to-elev 0
set total-farmer-del-to-elev2 0
set avg-farmer-price 0
set avg-farmer-price2 0
set total-farmer-revenue 0
set total-prod-volume 0
set total-elevator-delivery 0
set total-elevator-delivery2 0
set total-elevator-space 0
set total-farmer-check-inventory1 0
set total-farmer-check-inventory2 0

set total-farmer1a-revenue 0
set total-farmer1b-revenue 0
set total-farmer2a-revenue 0
set total-farmer2b-revenue 0
set total-farmer3an-revenue 0
set total-farmer3as-revenue 0
set total-farmer3bn-revenue 0
set total-farmer3bs-revenue 0
set total-farmer4a-revenue 0
set total-farmer4b-revenue 0
set total-farmer5a-revenue 0
set total-farmer5b-revenue 0
set total-farmer6a-revenue 0
set total-farmer6b-revenue 0
set total-farmer7a-revenue 0
set total-farmer7b-revenue 0
set total-farmer8a-revenue 0
set total-farmer8b-revenue 0
set total-farmer9a-revenue 0
set total-farmer9b-revenue 0

to run-railAgents

    ask railAgentCPRs [ 
        set rail-rate (item year cp-freightrate-list * dist-to-vc)]

    ask railAgentCNs [ 
        set rail-rate (item year cn-freightrate-list * dist-to-vc)]

    ask all-railAgents [ 
        set large-num-trains round (random-normal 0.725 0.092) + round (random-normal 0.7 0.1)

        set med-num-trains round (random-normal 1 0.2)

        set small-num-trains random 2 
    ]

    ask large-elevators [ 
        if percent-capacity < 15 [ 
            ask best-railAgent [ 
                set slack-train -1]]]

    ask medium-elevators [ 
        if percent-capacity < 25 [ 
            ask best-railAgent [ 
                set slack-train -1]]]

    ask small-elevators [ 
        if percent-capacity < 50 [ 
            ask best-railAgent [ 
                if small-num-trains > 0 
                    [set slack-train -1]]]]

    ask all-railAgents [ 
        if [rail-capacity] of one-of link-neighbors = small-train [ 
            if (small-num-trains + slack-train) >= 0 [ 
                set rail-quantity delivery-size * (small-num-trains + slack-train)]]

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if [rail-capacity] of one-of link-neighbors = medium-train [ 
  if (med-num-trains + slack-train) >= 0 [ 
    set rail-quantity delivery-size * (med-num-trains + slack-train)]
]
if [rail-capacity] of one-of link-neighbors = large-train [ 
  if (large-num-trains + slack-train) >= 0 [ 
    set rail-quantity delivery-size * (large-num-trains + slack-train)]
]
end

to run-elevators
  ask elevatorVIs [ 
    set elevator-handling-fees (item year viterra-tariff-rate-list)]
  ask elevatorCGs [ 
    set elevator-handling-fees (item year cargill-tariff-rate-list)]
  ask elevatorPNs [ 
    set elevator-handling-fees (item year pioneer-tariff-rate-list)]
  ask elevatorPHs [ 
    set elevator-handling-fees (item year p&h-tariff-rate-list)]
  ask elevatorTRs [ 
    set elevator-handling-fees (item year therest-tariff-rate-list)]
  ask all-elevators [ 
    if percent-capacity < 5 [ 
      set elevator-storage-cost elevator-handling-fees * -2]
    if percent-capacity >= 5 and percent-capacity < 10 [ 
      set elevator-storage-cost elevator-handling-fees * -1.3]
    if percent-capacity >= 10 and percent-capacity < 15 [ 
      set elevator-storage-cost elevator-handling-fees * -0.6]
    if percent-capacity >= 15 and percent-capacity < 20 [ 
      set elevator-storage-cost elevator-handling-fees * 0]
    if percent-capacity >= 20 and percent-capacity < 25 [ 
      set elevator-storage-cost elevator-handling-fees * 0.4]
    if percent-capacity >= 25 and percent-capacity < 30 [ 
      set elevator-storage-cost elevator-handling-fees * 0.7]
    if percent-capacity >= 30 and percent-capacity < 35 [ 
      set elevator-storage-cost elevator-handling-fees * 0.9]
if percent-capacity >= 35 and percent-capacity < 40
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 40 and percent-capacity < 45
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 45 and percent-capacity < 50
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 50 and percent-capacity < 55
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 55 and percent-capacity < 60
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 60 and percent-capacity < 65
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 65 and percent-capacity < 70
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 70 and percent-capacity < 75
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 75 and percent-capacity < 80
    [ set elevator-storage-cost elevator-handling-fees * 1]

if percent-capacity >= 80 and percent-capacity < 85
    [ set elevator-storage-cost elevator-handling-fees * 1.05]

if percent-capacity >= 85 and percent-capacity < 90
    [ set elevator-storage-cost elevator-handling-fees * 1.1]

if percent-capacity >= 90 and percent-capacity < 95
    [ set elevator-storage-cost elevator-handling-fees * 1.15]

if percent-capacity >= 95 and percent-capacity < 100
    [ set elevator-storage-cost elevator-handling-fees * 1.2]

if percent-capacity >= 100
    [ set elevator-storage-cost elevator-handling-fees * 1.25]

set elevator-basis elevator-storage-cost + elevator-handling-fees

set port-price item year wheat-price-list

set elevator-price (port-price - [rail-rate] of best-railAgent - elevator-basis)
]

ask large-elevators [

    if [rail-quantity] of best-railAgent = 0
[ set elevator-capacity large-ele-capacity ]

if [rail-quantity] of best-railAgent = 10000
    [ set elevator-capacity large-ele-capacity * 1.256410256 ]

if [rail-quantity] of best-railAgent = 20000
    [ set elevator-capacity large-ele-capacity * 1.512820513 ]
]

ask medium-elevators [
    if [rail-quantity] of best-railAgent = 0
        [ set elevator-capacity medium-ele-capacity ]
    if [rail-quantity] of best-railAgent = 5000
        [ set elevator-capacity medium-ele-capacity * 1.357142857 ]
    if [rail-quantity] of best-railAgent = 10000
        [ set elevator-capacity medium-ele-capacity * 1.714285714 ]
]

ask small-elevators [
    if [rail-quantity] of best-railAgent = 0
        [ set elevator-capacity small-ele-capacity ]
    if [rail-quantity] of best-railAgent = 2500
        [ set elevator-capacity small-ele-capacity * 1.625 ]
]

end

to farmer-set-delivery

    if remainder ticks 12 = 10 [ask farmers [set potential-farmer-del-to-el oct * grain-inventory]]
        if remainder ticks 12 = 11 [ask farmers [set potential-farmer-del-to-el nov * grain-inventory]]
            if remainder ticks 12 = 0 [ask farmers [set potential-farmer-del-to-el dec * grain-inventory]]
                if remainder ticks 12 = 1 [ask farmers [set potential-farmer-del-to-el jan * grain-inventory]]
                    if remainder ticks 12 = 2 [ask farmers [set potential-farmer-del-to-el feb * grain-inventory]]
                        if remainder ticks 12 = 3 [ask farmers [set potential-farmer-del-to-el mar * grain-inventory]]
                            if remainder ticks 12 = 4 [ask farmers [set potential-farmer-del-to-el apr * grain-inventory]]
                                if else grain-inventory < high-stock
[set potential-farmer-del-to-el apr * grain-inventory]
[set potential-farmer-del-to-el high-stock-adj * apr * grain-inventory]]

if remainder ticks 12 = 5 [ask farmers [
ifelse grain-inventory < high-stock
[set potential-farmer-del-to-el may * grain-inventory]
[set potential-farmer-del-to-el high-stock-adj * may * grain-inventory]]]

if remainder ticks 12 = 6 [ask farmers [
ifelse grain-inventory < high-stock
[set potential-farmer-del-to-el jun * grain-inventory]
[set potential-farmer-del-to-el high-stock-adj * jun * grain-inventory]]]

if remainder ticks 12 = 7 [ask farmers [
ifelse grain-inventory < high-stock
[set potential-farmer-del-to-el jul * grain-inventory]
[set potential-farmer-del-to-el high-stock-adj * jul * grain-inventory]]]

if remainder ticks 12 = 8 [ask farmers [
ifelse grain-inventory < high-stock
[set potential-farmer-del-to-el aug * grain-inventory]
[set potential-farmer-del-to-el high-stock-adj * aug * grain-inventory]]]

if remainder ticks 12 = 9 [ask farmers [
ifelse grain-inventory < high-stock
[set potential-farmer-del-to-el sep * grain-inventory]
[set potential-farmer-del-to-el high-stock-adj * sep * grain-inventory]]]

end

to set-best-elevator

set elevators-with-room all-elevators with [percent-capacity < 50]

set poss-large-elevators elevators-with-room with [physical-elevator-capacity = large-ele-capacity]
set poss-medium-elevators elevators-with-room with [physical-elevator-capacity = medium-ele-capacity]
set poss-small-elevators elevators-with-room with [physical-elevator-capacity = small-ele-capacity]

ask n-of always-large farmers [
    set best-company min-one-of poss-large-elevators [distance myself]]

ask n-of always-medium farmers [
    set best-company min-one-of poss-medium-elevators [distance myself]]

ask n-of always-small farmers [
    set best-company min-one-of poss-small-elevators [distance myself]]

ask farmers [if best-company = nobody [set best-company max-one-of elevators-with-room [
    elevator-price - (0.975 * ((abs([xicor] of myself - xcor) + abs([ycor] of myself - ycor)) * factor) ^ -0.4494))]]

end

to farmers-grow-grain

set year int((ticks - 1) / 12)
if remainder ticks 12 = 8 [harvest-crop]

end

to harvest-crop

ask farmers1a [set prod-volume item year wheat-prod1a-list
set prod-volume (prod-volume / car1a)]

ask farmers1b [set prod-volume item year wheat-prod1b-list
set prod-volume (prod-volume / car1b)]

ask farmers2a [set prod-volume item year wheat-prod2a-list
set prod-volume (prod-volume / car2a)]

ask farmers2b [set prod-volume item year wheat-prod2b-list
set prod-volume (prod-volume / car2b)]

ask farmers3an [set prod-volume item year wheat-prod3an-list
set prod-volume (prod-volume / car3an)]

ask farmers3as [set prod-volume item year wheat-prod3as-list
set prod-volume (prod-volume / car3as)]
ask farmers3bn [set prod-volume item year wheat-prod3bn-list set prod-volume (prod-volume / car3bn)]
ask farmers3bs [set prod-volume item year wheat-prod3bs-list set prod-volume (prod-volume / car3bs)]
ask farmers4a [set prod-volume item year wheat-prod4a-list set prod-volume (prod-volume / car4a)]
ask farmers4b [set prod-volume item year wheat-prod4b-list set prod-volume (prod-volume / car4b)]
ask farmers5a [set prod-volume item year wheat-prod5a-list set prod-volume (prod-volume / car5a)]
ask farmers5b [set prod-volume item year wheat-prod5b-list set prod-volume (prod-volume / car5b)]
ask farmers6a [set prod-volume item year wheat-prod6a-list set prod-volume (prod-volume / car6a)]
ask farmers6b [set prod-volume item year wheat-prod6b-list set prod-volume (prod-volume / car6b)]
ask farmers7a [set prod-volume item year wheat-prod7a-list set prod-volume (prod-volume / car7a)]
ask farmers7b [set prod-volume item year wheat-prod7b-list set prod-volume (prod-volume / car7b)]
ask farmers8a [set prod-volume item year wheat-prod8a-list set prod-volume (prod-volume / car8a)]
ask farmers8b [set prod-volume item year wheat-prod8b-list set prod-volume (prod-volume / car8b)]
ask farmers9a [set prod-volume item year wheat-prod9a-list set prod-volume (prod-volume / car9a)]
ask farmers9b [set prod-volume item year wheat-prod9b-list set prod-volume (prod-volume / car9b)]

ask farmers [ set grain-inventory grain-inventory + prod-volume ;;]
]
end

to farmer-make-delivery

ask farmers [ set farmer-check-inventory1 grain-inventory
if best-company != nobody [
    ask best-company [
        set delivery-made 0
        set elevator-space (elevator-capacity - elevator-inventory)
            if elevator-delivery + [potential-farmer-del-to-el] of myself <= 
            elevator-space [
                set elevator-delivery elevator-delivery + [potential-farmer-del-to-el] of myself
                set delivery-made 1]
    ]

    if delivery-made = 1 [
        set truck-distance (abs([xcor] of best-company - xcor) +
        abs([ycor] of best-company - ycor)) * factor
            set truck-rate (0.975 * (truck-distance ^ (-0.4494)))
            set farmer-price ([elevator-price] of best-company - (0.975 *
            (truck-distance ^ (-0.4494))))
            set farmer-delivery-to-elevator potential-farmer-del-to-el
            set grain-inventory (grain-inventory - farmer-delivery-to-
            elevator)
                set farmer-check-inventory2 grain-inventory
                set color [color] of best-company ]
]
]
end
to elevator-take-delivery
    ask all-elevators [
        set elevator-inventory (elevator-inventory + elevator-delivery)
        set check-inventory1 elevator-inventory
            ifelse elevator-inventory > [rail-quantity] of best-railAgent
                [set elevator-delivery-to-rail [rail-quantity] of best-railAgent
                set elevator-inventory elevator-inventory - elevator-delivery-to-rail]
                [top-up-procedure]]
end
to top-up-procedure
    set elevator-basis2 elevator-storage-cost
    set elevator-price2 (port-price - [rail-rate] of best-railAgent -
    elevator-basis2)
if physical-elevator-capacity = small-ele-capacity [
    set lucky-farmers n-of luckyS farmers in-radius (small-catchment-area * factor)]

if physical-elevator-capacity = medium-ele-capacity [
    set lucky-farmers n-of luckyM farmers in-radius (med-catchment-area * factor)]

if physical-elevator-capacity = large-ele-capacity [
    set lucky-farmers n-of luckyL farmers in-radius (large-catchment-area * factor)]

ask lucky-farmers [
    set potential-farmer-del-to-ele2 (grain-inventory * 0.1) ]

ask lucky-farmers [
    ask myself [
        set delivery-made 0
        set elevator-space (elevator-capacity - elevator-inventory)
        if elevator-delivery2 + [potential-farmer-del-to-ele2] of myself <= elevator-space [
            set elevator-delivery2 elevator-delivery2 + [potential-farmer-del-to-ele2] of myself
            set delivery-made 1]]

    if delivery-made = 1 [
        set truck-distance2 (abs([xcor] of myself - xcor) + abs([ycor] of myself - ycor)) * factor
        set truck-rate2 (0.975 * (truck-distance2 ^ (-0.4494)))
        set farmer-price2 ([elevator-price2] of myself - truck-rate2)
        set farmer-delivery-to-elevator2 potential-farmer-del-to-ele2
        set grain-inventory grain-inventory - farmer-delivery-to-elevator2
        set color [color] of myself]]

set elevator-delivery2 sum [farmer-delivery-to-elevator2] of lucky-farmers
set elevator-inventory elevator-inventory + elevator-delivery2
set check-inventory2 elevator-inventory
ifelse elevator-inventory > [rail-quantity] of best-railAgent [set elevator-delivery-to-rail2] [
    set elevator-delivery-to-rail2 elevator-inventory - elevator-delivery-to-rail2
    set shortage [rail-quantity] of best-railAgent - elevator-delivery-to-rail2
]
end
to rail-take-delivery
ask all-elevators [
  ask best-railAgent [
]

ask large-elevators [
  set percent-capacity (elevator-inventory / large-ele-capacity) * 100]

ask medium-elevators [
  set percent-capacity (elevator-inventory / medium-ele-capacity) * 100]

ask small-elevators [
  set percent-capacity (elevator-inventory / small-ele-capacity) * 100]
end

to tally-inland-demurrage

ask demAgents [
  set total-inland-demurrage (sum [shortage] of all-elevators)
  set elevatorVI-inland-demurrage (sum [shortage] of elevatorVIs)
  set elevatorCG-inland-demurrage (sum [shortage] of elevatorCGs)
  set elevatorPH-inland-demurrage (sum [shortage] of elevatorPHs)
  set elevatorPN-inland-demurrage (sum [shortage] of elevatorPNs)
  set elevatorTR-inland-demurrage (sum [shortage] of elevatorTRs)
]

ask large-elevators [
  if elevator-basis >= 0 and percent-capacity >= 75 and [rail-quantity] of best-railAgent = 0 [set short-one-train large-train]]

ask medium-elevators [
  if elevator-basis >= 0 and percent-capacity >= 75 and [rail-quantity] of best-railAgent = 0 [set short-one-train medium-train]]

ask small-elevators [
  if elevator-basis >= 0 and percent-capacity >= 85 and [rail-quantity] of best-railAgent = 0 [set short-one-train small-train]]
end

to deliver-grain-to-port

ask portAgents [
set port-deliveryPN (sum [elevator-delivery-to-rail] of elevatorPNs + sum [elevator-delivery-to-rail2] of elevatorPNs)
set port-deliveryVI (sum [elevator-delivery-to-rail] of elevatorVIs + sum [elevator-delivery-to-rail2] of elevatorVIs)

set number-of-ships round (port-deliveryCG + port-deliveryTR + port-deliveryPH + port-deliveryPN + port-deliveryVI) / ship-DWT + random 2

set monthly-ship-tonnage number-of-ships * ship-DWT
get approx 25% of a ship's capacity
set elevatorPH-ship-portion monthly-ship-tonnage * 0.09 ;; P&H elevators get approx 9% of a ship's capacity
set elevatorPN-ship-portion monthly-ship-tonnage * 0.17 ;; Pioneer elevators get approx 17% of a ship's capacity
set elevatorVI-ship-portion monthly-ship-tonnage * 0.38 ;; Viterra elevators get approx 38% of a ship's capacity
set elevatorCG-ship-portion monthly-ship-tonnage * 0.11 ;; Cargill elevators get approx 11% of a ship's capacity

set elevatorCG-demurr-check port-deliveryCG - elevatorCG-ship-portion
if elevatorCG-demurr-check < 0 [ set elevatorCG-demurrage (elevatorCG-ship-portion - port-deliveryCG)]

set elevatorTR-demurr-check port-deliveryTR - elevatorTR-ship-portion
if elevatorTR-demurr-check < 0 [ set elevatorTR-demurrage (elevatorTR-ship-portion - port-deliveryTR)]

set elevatorPH-demurr-check port-deliveryPH - elevatorPH-ship-portion
if elevatorPH-demurr-check < 0 [ set elevatorPH-demurrage (elevatorPH-ship-portion - port-deliveryPH)]

set elevatorPN-demurr-check port-deliveryPN - elevatorPN-ship-portion
if elevatorPN-demurr-check < 0 [ set elevatorPN-demurrage (elevatorPN-ship-portion - port-deliveryPN)]

set elevatorVI-demurr-check port-deliveryVI - elevatorVI-ship-portion
if elevatorVI-demurr-check < 0 [ set elevatorVI-demurrage (elevatorVI-ship-portion - port-deliveryVI)]

set total-vessel-demurrage (elevatorTR-demurrage + elevatorPH-demurrage + elevatorPN-demurrage + elevatorVI-demurrage + elevatorCG-demurrage)
]

end
to calculate-turtle-income

ask farmers [
    set farmer-truck-cost (truck-distance * truck-rate) + (truck-distance2 * truck-rate)
    set farmer-revenue (farmer-price * farmer-delivery-to-elevator) + (farmer-price2 * farmer-delivery-to-elevator2)
]

ask elevatorCGs [
    set elevator-revenueCG (elevator-basis * elevator-delivery) + (elevator-basis2 * elevator-delivery2)
    set elevator-incomeCG elevator-revenueCG - elevator-costCG
]

ask elevatorTRs [
    set elevator-revenueTR (elevator-basis * elevator-delivery) + (elevator-basis2 * elevator-delivery2)
    set elevator-incomeTR elevator-revenueTR - elevator-costTR
]

ask elevatorPHs [
    set elevator-revenuePH (elevator-basis * elevator-delivery) + (elevator-basis2 * elevator-delivery2)
    set elevator-incomePH elevator-revenuePH - elevator-costPH
]

ask elevatorPNs [
    set elevator-revenuePN (elevator-basis * elevator-delivery) + (elevator-basis2 * elevator-delivery2)
    set elevator-incomePN elevator-revenuePN - elevator-costPN
]

ask elevatorVIs [
    set elevator-revenueVI (elevator-basis * elevator-delivery) + (elevator-basis2 * elevator-delivery2)
    set elevator-costVI (elevator-delivery-to-rail * [rail-rate] of best-railAgent)
(elevator-delivery-to-rail2 \* [rail-rate] of best-railAgent)
  set elevator-incomeVI elevator-revenueVI - elevator-costVI
]

ask railAgentCNs [
  set railAgent-revenueCN rail-rate * rail-delivery
]

ask railAgentCPRs [
  set railAgent-revenueCPR rail-rate * rail-delivery
]
end

to update-plot

  set-current-plot "farmer data"
  set-current-plot- pen "revenue"
    plot mean [farmer-revenue] of farmers

  set-current-plot "inland demurrage"
  set-current-plot- pen "elevator dem"
    plot sum [total-inland-demurrage] of demAgents

  set-current-plot "vessel demurrage"
  set-current-plot- pen "port dem"
    plot sum [total-vessel-demurrage] of portAgents

  set-current-plot "farmer inventory"
  set-current-plot- pen "farmer inventory"
    plot total-farmer-inventory
end

to export-data

  set-current-directory "C:\\Users\\Russell\\Documents\\Grad School\\Thesis\\Running Model\\Output"

  if run-number = 1 and ticks = 1 [create-files]

  set total-potential-farmer-del-to-el sum [potential-farmer-del-to-el] of farmers
  set total-farmer-del-to-elev sum [farmer-delivery-to-elevator] of farmers
  set avg-farmer-price mean [farmer-price] of farmers
  set avg-farmer-price2 mean [farmer-price2] of farmers
set total-farmer-revenue sum [farmer-revenue] of farmers

set total-farmer1a-revenue sum [farmer-revenue] of farmers1a
set total-farmer1b-revenue sum [farmer-revenue] of farmers1b
set total-farmer2a-revenue sum [farmer-revenue] of farmers2a
set total-farmer2b-revenue sum [farmer-revenue] of farmers2b
set total-farmer3an-revenue sum [farmer-revenue] of farmers3an
set total-farmer3as-revenue sum [farmer-revenue] of farmers3as
set total-farmer3bn-revenue sum [farmer-revenue] of farmers3bn
set total-farmer3bs-revenue sum [farmer-revenue] of farmers3bs
set total-farmer4a-revenue sum [farmer-revenue] of farmers4a
set total-farmer4b-revenue sum [farmer-revenue] of farmers4b
set total-farmer5a-revenue sum [farmer-revenue] of farmers5a
set total-farmer5b-revenue sum [farmer-revenue] of farmers5b
set total-farmer6a-revenue sum [farmer-revenue] of farmers6a
set total-farmer6b-revenue sum [farmer-revenue] of farmers6b
set total-farmer7a-revenue sum [farmer-revenue] of farmers7a
set total-farmer7b-revenue sum [farmer-revenue] of farmers7b
set total-farmer8a-revenue sum [farmer-revenue] of farmers8a
set total-farmer8b-revenue sum [farmer-revenue] of farmers8b
set total-farmer9a-revenue sum [farmer-revenue] of farmers9a
set total-farmer9b-revenue sum [farmer-revenue] of farmers9b

set total-farmer-check-inventory1 sum [farmer-check-inventory1] of farmers
set total-farmer-check-inventory2 sum [farmer-check-inventory2] of farmers
set total-farmer-del-to-elev total-elevator-delivery2
set total-farmer-inventory (total-farmer-check-inventory1 - total-farmer-del-to-elev)
end

to create-files

let spacer "\,"

file-open "Farmer Output.csv"
file-print (list spacer "run-number" spacer
  "tick" spacer
  "ch-inv1" spacer
  "ch-inv2" spacer
  "farmer-inventory" spacer
  "farmer-del-to-elev" spacer
  "farmer-del-to-elev2" spacer
  "potential-farmer-del-to-el" spacer
  "avg-farmer-price" spacer
  "avg-farmer-price2" spacer
  "truck-rate" spacer
  "truck-distance" spacer
)
"truck-rate2" spacer
"total-farmer-revenue" spacer
"farmer1a-revenue" spacer
"farmer1b" spacer
"farmer2a" spacer
"farmer2b" spacer
"farmer3an" spacer
"farmer3as" spacer
"farmer3bn" spacer
"farmer3bs" spacer
"farmer4a" spacer
"farmer4b" spacer
"farmer5a" spacer
"farmer5b" spacer
"farmer6a" spacer
"farmer6b" spacer
"farmer7a" spacer
"farmer7b" spacer
"farmer8a" spacer
"farmer8b" spacer
"farmer9a" spacer
"farmer9b" spacer)

file-close

file-open "ElevatorCG Output.csv"
file-print (list spacer "run-number" spacer
 "who" spacer
 "station" spacer
 "tick" spacer
 "short" spacer
 "basis" spacer
 "delivery" spacer
 "delivery2" spacer
 "check-inv1" spacer
 "check-inv2" spacer
 "inventory" spacer
 "working-ele-capcity" spacer
 "physical-ele-capcity" spacer
 "percent-cap" spacer
 "rail-quantity" spacer
 "del-to-rail" spacer
 "del1-to-rail2" spacer
 "shortage" spacer
 "best-railAgent" spacer
 "revenue" spacer
 "cost" spacer
 "income" spacer
 "e-price" spacer
 "e-price2" spacer )

file-close

file-open "ElevatorTR Output.csv"
file-print (list spacer "run-number" spacer
  "who" spacer
  "station" spacer
  "tick" spacer
  "short" spacer
  "basis" spacer
  "delivery" spacer
  "delivery2" spacer
  "check-inv1" spacer
  "check-inv2" spacer
  "inventory" spacer
  "working-ele-capacity" spacer
  "physical-ele-capicty" spacer
  "percent-cap" spacer
  "rail-quantity" spacer
  "del-to-rail" spacer
  "del-to-rail2" spacer
  "shortage" spacer
  "best-railAgent" spacer
  "revenue" spacer
  "cost" spacer
  "income" spacer
  "e-price" spacer
  "e-price2" spacer )

file-close

file-open "ElevatorPH Output.csv"
file-print (list spacer "run-number" spacer
  "who" spacer
  "station" spacer
  "tick" spacer
  "short" spacer
  "basis" spacer
  "delivery" spacer
  "delivery2" spacer
  "check-inv1" spacer
  "check-inv2" spacer
  "inventory" spacer
  "working-ele-capacity" spacer
  "physical-ele-capicty" spacer
  "percent-cap" spacer
  "rail-quantity" spacer
  "del-to-rail" spacer
  "del-to-rail2" spacer
  "shortage" spacer
  "best-railAgent" spacer
  "revenue" spacer
  "cost" spacer
  "income" spacer
  "e-price" spacer
  "e-price2" spacer )

file-close
file-open "ElevatorPN Output.csv"
file-print (list spacer "run-number" spacer
   "who" spacer
   "station" spacer
   "tick" spacer
   "short" spacer
   "basis" spacer
   "delivery" spacer
   "delivery2" spacer
   "check-inv1" spacer
   "check-inv2" spacer
   "inventory" spacer
   "working-ele-capacity" spacer
   "physical-ele-capcity" spacer
   "percent-cap" spacer
   "rail-quantity" spacer
   "del-to-rail" spacer
   "del-to-rail2" spacer
   "shortage" spacer
   "best-railAgent" spacer
   "revenue" spacer
   "cost" spacer
   "income" spacer
   "e-price" spacer
   "e-price2" spacer )
file-close

file-open "ElevatorVI Output.csv"
file-print (list spacer "run-number" spacer
   "who" spacer
   "station" spacer
   "tick" spacer
   "short" spacer
   "basis" spacer
   "delivery" spacer
   "delivery2" spacer
   "check-inv1" spacer
   "check-inv2" spacer
   "inventory" spacer
   "working-ele-capacity" spacer
   "physical-ele-capcity" spacer
   "percent-cap" spacer
   "rail-quantity" spacer
   "del-to-rail" spacer
   "del-to-rail2" spacer
   "shortage" spacer
   "best-railAgent" spacer
   "revenue" spacer
   "cost" spacer
   "income" spacer
   "e-price" spacer
   "e-price2" spacer )
file-close
file-open "Demurrage Output.csv"
file-print (list spacer "run-number" spacer
  "breed" spacer
  "station" spacer
  "tick" spacer
  "short" spacer
  "inventory" spacer
  "working-ele-capacity" spacer
  "physical-ele-capcity" spacer
  "percent-cap" spacer )
file-close

file-open "RailAgentCN Output.csv"
file-print (list spacer "run-number" spacer
  "who" spacer
  "tick" spacer
  "rail-rate" spacer
  "rail-delivery" spacer
  "rail-quantity" spacer
  "railAgent-revenueA" spacer )
file-close

file-open "RailAgentCPR Output.csv"
file-print (list spacer "run-number" spacer
  "who" spacer
  "tick" spacer
  "rail-rate" spacer
  "rail-delivery" spacer
  "rail-quantity" spacer
  "railAgent-revenueB" spacer )
file-close

file-open "Port Output.csv"
file-print (list spacer "run-number" spacer "tick" spacer "monthly-ship-tonnage"
  spacer "elevatorTR-ship-portion" spacer "port-deliveryTR"
  spacer "elevatorTR-demurr-ck" spacer "elevatorTR-demurrage"
  spacer "elevatorPH-ship-portion" spacer "port-deliveryPH"
  spacer "elevatorPH-demurr-ck" spacer "elevatorPH-demurrage"
  spacer "elevatorCG-ship-portion" spacer "port-deliveryCG"
  spacer "elevatorCG-demurr-ck" spacer "elevatorCG-demurrage"
  spacer "elevatorPN-ship-portion" spacer "port-deliveryPN"
  spacer "elevatorPN-demurr-ck" spacer "elevatorPN-demurrage"
  spacer "elevatorVI-ship-portion" spacer "port-deliveryVI"
  spacer "elevatorVI-demurr-ck" spacer "elevatorVI-demurrage" spacer )
file-close

file-open "Demurrage Agent Output.csv"
file-print (list spacer "run-number" spacer
  "tick" spacer
  "total-inland-demurrage" spacer

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"elevatorVI-inland-demurrage" spacer
"elevatorCG-inland-demurrage" spacer
"elevatorPN-inland-demurrage" spacer
"elevatorPH-inland-demurrage" spacer
"elevatorTR-inland-demurrage" spacer
)
file-close
end
to export-farmer
let spacer ","

file-open "Farmer Output.csv"
ask farmer 1000 [file-print (list spacer run-number spacer
ticks spacer
total-farmer-check-inventory1 spacer
total-farmer-check-inventory2 spacer
total-farmer-inventory spacer
total-farmer-del-to-elev spacer
total-farmer-del-to-elev2 spacer
total-potential-farmer-del-to-el spacer
avg-farmer-price spacer
avg-farmer-price2 spacer
[truck-rate] of self spacer
[truck-distance] of self spacer
[truck-rate2] of self spacer
total-farmer-revenue spacer
total-farmer1a-revenue spacer
total-farmer1b-revenue spacer
total-farmer2a-revenue spacer
total-farmer2b-revenue spacer
total-farmer3an-revenue spacer
total-farmer3as-revenue spacer
total-farmer3bn-revenue spacer
total-farmer3bs-revenue spacer
total-farmer4a-revenue spacer
total-farmer4b-revenue spacer
total-farmer5a-revenue spacer
total-farmer5b-revenue spacer
total-farmer6a-revenue spacer
total-farmer6b-revenue spacer
total-farmer7a-revenue spacer
total-farmer7b-revenue spacer
total-farmer8a-revenue spacer
total-farmer8b-revenue spacer
total-farmer9a-revenue spacer
total-farmer9b-revenue spacer)
]
file-close
end
to export-elevator
let spacer ","

file-open "ElevatorCG Output.csv"

ask elevatorCGs [file-print (list spacer run-number spacer 
who spacer station spacer ticks spacer 
short-one-train spacer elevator-basis spacer elevator-delivery spacer elevator-delivery2 spacer check-inventory1 spacer check-inventory2 spacer elevator-inventory spacer elevator-capacity spacer 
physical-elevator-capacity spacer percent-capacity spacer [rail-quantity] of best-railAgent spacer 
elevator-delivery-to-rail spacer elevator-delivery-to-rail2 spacer shortage spacer 
best-railAgent spacer elevator-revenueCG spacer elevator-costCG spacer elevator-incomeCG spacer elevator-price spacer elevator-price2 spacer )]

file-close

file-open "ElevatorTR Output.csv"

ask elevatorTRs [file-print (list spacer run-number spacer 
who spacer station spacer ticks spacer 
short-one-train spacer elevator-basis spacer elevator-delivery spacer elevator-delivery2 spacer check-inventory1 spacer check-inventory2 spacer elevator-inventory spacer elevator-capacity spacer 
physical-elevator-capacity spacer percent-capacity spacer [rail-quantity] of best-railAgent spacer 
elevator-delivery-to-rail spacer elevator-delivery-to-rail2 spacer shortage spacer 
shortage spacer]
best-railAgent spacer
elevator-revenueTR spacer
elevator-costTR spacer
elevator-incomeTR spacer
elevator-price spacer
elevator-price2 spacer }

file-close

file-open "ElevatorPH Output.csv"

ask elevatorPHs [file-print (list spacer run-number spacer
 who spacer
 station spacer
 ticks spacer
 short-one-train spacer
elevator-basis spacer
elevator-delivery spacer
elevator-delivery2 spacer
check-inventory1 spacer
check-inventory2 spacer
elevator-inventory spacer
elevator-capacity spacer
physical-elevator-capacity spacer
percent-capacity spacer
[rail-quantity] of best-railAgent spacer
elevator-delivery-to-rail spacer
elevator-delivery-to-rail2 spacer
shortage spacer
 best-railAgent spacer
elevator-revenuePH spacer
elevator-costPH spacer
elevator-incomePH spacer
elevator-price spacer
elevator-price2 spacer )]

file-close

file-open "ElevatorPN Output.csv"

ask elevatorPNs [file-print (list spacer run-number spacer
 who spacer
 station spacer
 ticks spacer
 short-one-train spacer
elevator-basis spacer
elevator-delivery spacer
elevator-delivery2 spacer
check-inventory1 spacer
check-inventory2 spacer
elevator-inventory spacer
elevator-capacity spacer
physical-elevator-capacity spacer
percent-capacity spacer
[rail-quantity] of best-railAgent spacer
elevator-delivery-to-rail spacer
elevator-delivery-to-rail2 spacer
shortage spacer
 best-railAgent spacer
elevator-revenuePH spacer
elevator-costPH spacer
elevator-incomePH spacer
elevator-price spacer
elevator-price2 spacer )]
shortage spacer
best-railAgent spacer
elevator-revenuePN spacer
elevator-costPN spacer
elevator-incomePN spacer
elevator-price spacer
elevator-price2 spacer ]

file-close

file-open "ElevatorVI Output.csv"

ask elevatorVIs [file-print (list spacer run-number spacer
   who spacer
   station spacer
ticks spacer
short-one-train spacer
elevator-basis spacer
elevator-delivery spacer
elevator-delivery2 spacer
check-inventory1 spacer
check-inventory2 spacer
elevator-inventory spacer
elevator-capacity spacer
physical-elevator-capacity spacer
percent-capacity spacer
[rail-quantity] of best-railAgent spacer
elevator-delivery-to-rail spacer
elevator-delivery-to-rail2 spacer
shortage spacer
best-railAgent spacer
elevator-revenueVI spacer
elevator-costVI spacer
elevator-incomeVI spacer
elevator-price spacer
elevator-price2 spacer )]

file-close

file-open "Demurrage Output.csv"

ask all-elevators [if short-one-train > 0
   [file-print (list spacer run-number spacer
      breed spacer
      station spacer
ticks spacer
short-one-train spacer
elevator-inventory spacer
elevator-capacity spacer
physical-elevator-capacity spacer
percent-capacity spacer )]]

file-close

end
to export-railAgent

let spacer ","

file-open "RailAgentCN Output.csv"
ask railAgentCNs [  
  if rail-quantity != 0  
  [file-print (list spacer run-number spacer  
    who spacer  
    ticks spacer  
    rail-rate spacer  
    rail-delivery spacer  
    rail-quantity spacer  
    railAgent-revenueCN spacer )]]

file-close

file-open "RailAgentCPR Output.csv"
ask railAgentCPRs [  
  if rail-quantity != 0  
  [file-print (list spacer run-number spacer  
    who spacer  
    ticks spacer  
    rail-rate spacer  
    rail-delivery spacer  
    rail-quantity spacer  
    railAgent-revenueCPR spacer )]]

file-close
end

to export-observingInfo

let spacer ","

file-open "Port Output.csv"
ask portAgents [file-print (list spacer run-number spacer ticks spacer monthly-ship-  
  tonnage  
  elevatorTR-demurr-check spacer elevatorTR-ship-portion spacer port-deliveryTR spacer  
  elevatorTR-demurrage spacer  
  elevatorPH-demurr-check spacer elevatorPH-ship-portion spacer port-deliveryPH spacer  
  elevatorPH-demurrage spacer  
  elevatorCG-demurr-check spacer elevatorCG-ship-portion spacer port-deliveryCG spacer  
  elevatorCG-demurrage spacer  
  elevatorPN-demurr-check spacer elevatorPN-ship-portion spacer port-deliveryPN spacer  
  elevatorPN-demurrage spacer  
  elevatorVI-demurr-check spacer elevatorVI-ship-portion spacer port-deliveryVI spacer  
  elevatorVI-demurrage spacer )]

file-close
file-open "Demurrage Agent Output.csv"

ask demAgents [file-print (list spacer run-number spacer
ticks spacer
total-inland-demurrage spacer
elevatorVI-inland-demurrage spacer
elevatorCG-inland-demurrage spacer
elevatorPN-inland-demurrage spacer
elevatorPH-inland-demurrage spacer
elevatorTR-inland-demurrage spacer )]

file-close

demAgents
end