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

A Thesis
Submitted to the College of Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of
Master of Science

In the
Department of Bioresource Policy, Business & Economics
University of Saskatchewan
by
Russell J. Lawrence

PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department of the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition will be given to me and the University of Saskatchewan in any scholarly use that may be made of any material in this thesis.

Requests for permission to copy or to make other use of the material in this thesis in whole or part should be addressed to:

Head of the Department of Bioresource Policy, Business & Economics
University of Saskatchewan
Saskatoon, Saskatchewan S7N 5A8

ABSTRACT

Lawrence, Russell J., M.Sc. University of Saskatchewan, Saskatoon, September 2011. Grains, Trains and Chains: An Agent-Based Model of the Western Canadian Grain Handling and Transportation Supply Chain.
Supervisors: J.F. Nolan, R.A. Schoney, K. Rosaasen.

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%.

ACKNOWLEDGMENTS

It has been a roller coaster ride for me to complete this work, and I need to extend my thanks to a few people that made sure I stayed for the entire journey and did not get discouraged. I firstly need to thank my supervising committee: To James Nolan, who rode right behind me the whole time experiencing all of the highs and lows, while ensuring that an unexpected turn was just another opportunity; to Richard Schoney for providing support and encouragement, and making sure James and I were still buckled in; and to Ken Rosaasen for giving invaluable insight in order to communicate my experience once the ride was over.

To my external examiner Steven Peterson, for his wisdom, a shared fascination of railways, and his state-side perspective to put my research into context.

To my closest friends and family, for providing words of encouragement whether they were needed or not, and for showing great patience.

And finally to my parents, for providing me with the opportunity to pursue a dream. You have supported me without question through my entire university career, and what I have accomplished was only possible because of you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 combinatorical 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).

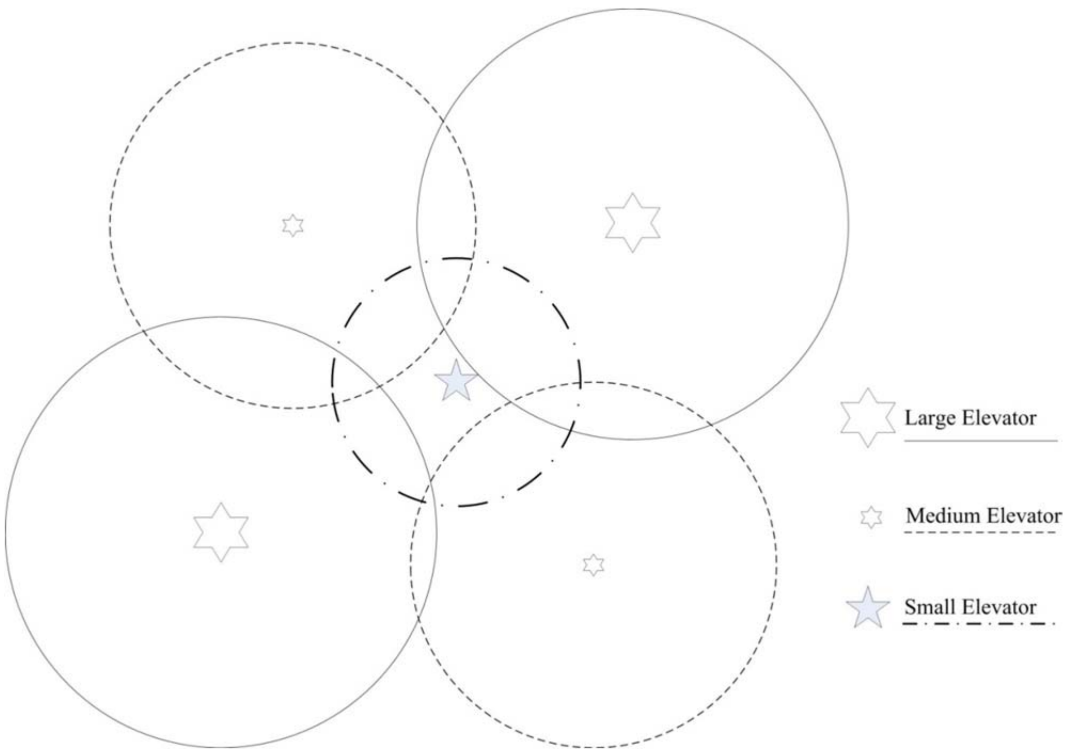


Figure 2.1. Elevator catchment areas

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 and112 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

Railway	Commodity	Origin	Destination	Single Car Rate / Tonne	50 Car Block Rate / Tonne	100 Car Block Rate / Tonne	50 Car Discount / Tonne	100 Car Discount / Tonne
CN	Wheat	Aberdeen, SK	Thunder Bay	$30.10	$26.46	$22.82	$3.64	$7.28
			Vancouver	$32.23	$28.59	$24.95	$3.64	$7.28
Railway	Commodity	Origin	Destination	Single Car Rate / Tonne	56 Car Block Rate / Tonne	112 Car Block Rate / Tonne	56 Car Discount / Tonne	112 Car Discount / Tonne
CP	Wheat	Blackie, AB	Thunder Bay	$39.64	$35.09	$32.36	$4.55	$7.28
			Vancouver	$26.18	$21.63	$18.90	$4.55	$7.28

(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.

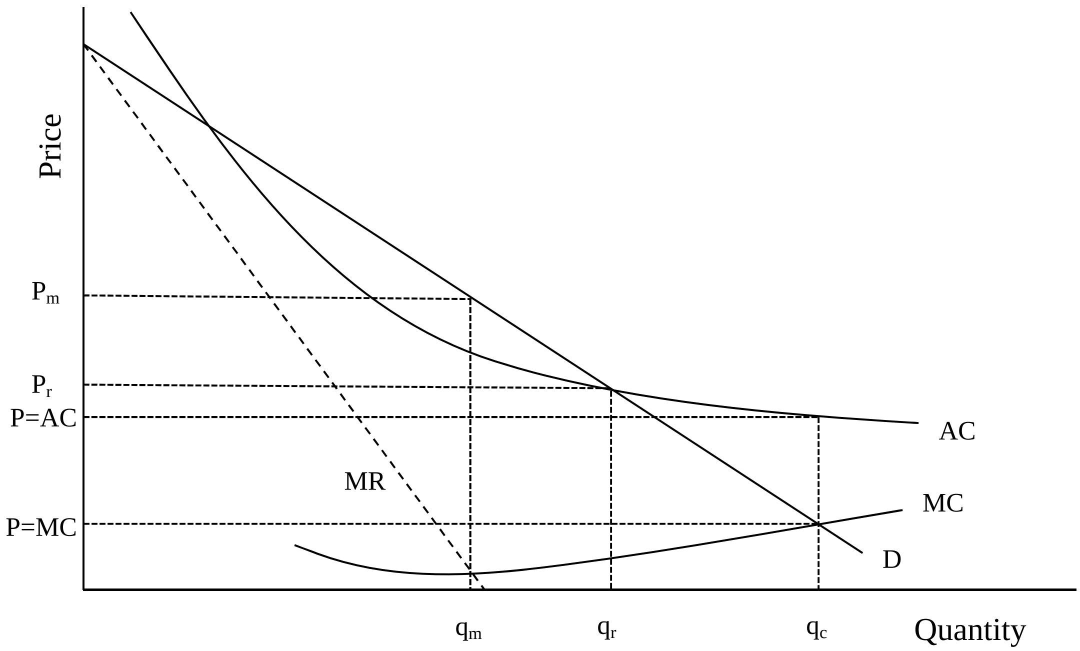


Figure 2.2. Natural monopoly

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 is 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:

= { (A / B) + [(C – D) * $0.022] } * E * 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.

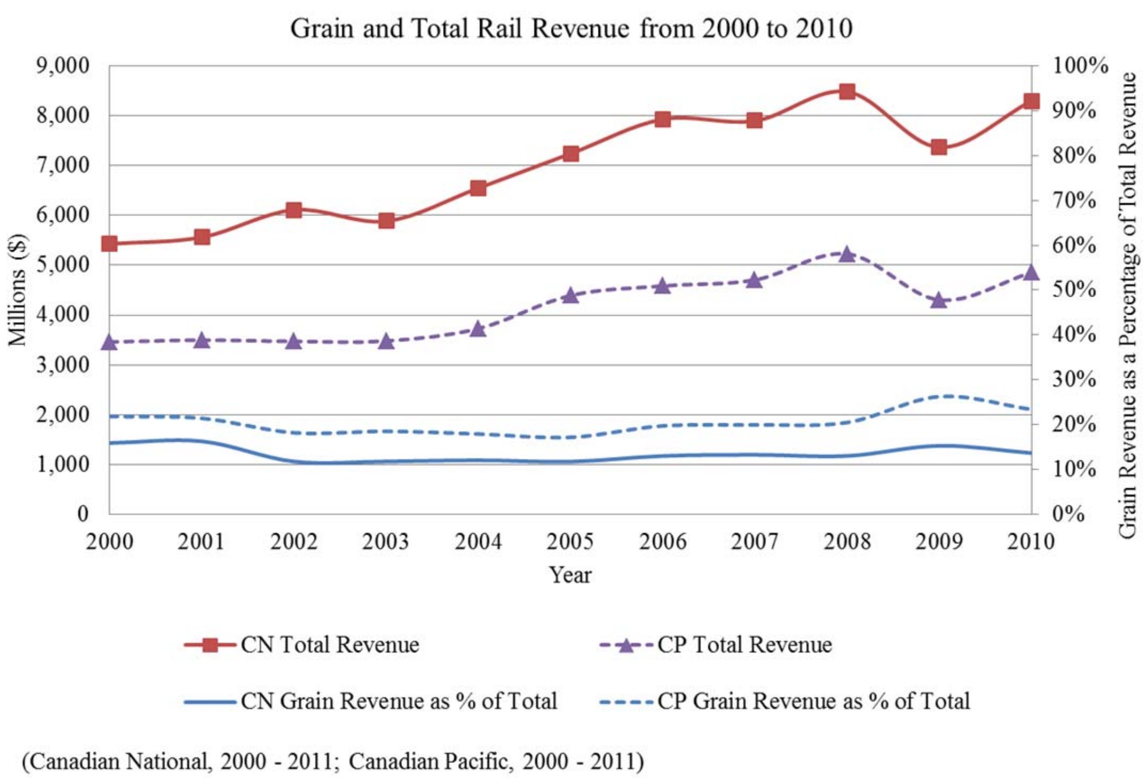


Figure 2.3. Grain and total rail revenue from 2000 to 2010

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[2]. 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

Location	Car Spot	Location	Car Spot	Location	Car Spot
Alameda	3	Indian Head	3	Redvers	5
Antler	5	Kelvington	9	Regina	16
Bateman	12	Kerrobert	4	Rose Valley	6
Biggar	2	Lipton	2	Rosetown	2
Bredenbury	2	Lloydminster	4	Saskatoon	2
Carievale	3	Lloydminster	5	Southey	3
Carnduff	4	Maple Creek	2	Spalding	6
Chaplin	5	Markinch	2	Swift Current	8
Cupar	3	Marsden	4	Tisdale	3
Dafoe	2	Midale	5	Tompkins	2
Duval	7	Milestone	3	Tugaske	15
Estevan	3	Moosomin	3	Unity	4
Eyebrow	11	Mossbank	5	Viscount	11
Foam Lake	2	Nipawin	10	Wadena	4
Golden Prairie	18	Nipawin	4	Webb	2
Grand Coulee	15	Nokomis	6	Wilcox	3
Grenfell	5	Orcadia	7	Wynyard	3
Gull Lake	1	Pense	2	Wynyard	2
Herschel	8	Quappelle	10	Yorkton	15

(Canadian Pacific, 2011)

Table 2.3. CN producer car loading locations in Saskatchewan as of 2011

Location	Car Spot	Location	Car Spot	Location	Car Spot	Location	Car Spot
Aberdeen	1	Elrose	1	Lucky Lake	34	Richlea	2
Aylsham	6	Eston	4	Macrorie	7	Ridgedale	4
Aylsham	2	Eston	34	Madison	8	Rosetown	1
Balcarres	4	Glidden	3	Margo	2	Rowatt	2
Beechy	1	Goodeve	2	Margo	3	Saskatoon	5
Beechy	34	Hamlin	3	Maymont	2	Semans	5
Birch Hills	9	Hamlin	2	Melfort	4	Unity	2
Booth	3	Hanley	2	Melville	1	Valparaiso	4
Brooksby	1	Hudson Bay	3	Mistatime	6	Waseca	1
Canora	2	Hughton	5	Montmartre	10	Waseca	3
Carlyle	15	Humboldt	5	Moose Jaw	1	Watrous	2
Clemenceau	2	Kamsack	8	North Battleford	3	Willmar	6
Davidson	4	Kelliher	6	Parkman	5	Yarbo	2
Delisle	3	Kinistino	3	Paynton	4	Yarbo	6
Delmas	4	Lake Lenore	1	Pelly	4	Zehner	2
Delmas	2	Landis	4	Prud'homme	4		
Dinsmore	5	Landis	10	Radisson	3		
Dunblane	15	Laporte	34	Regina	3		
Eatonia	3	Lucky Lake	1	Richlea	7		

(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.

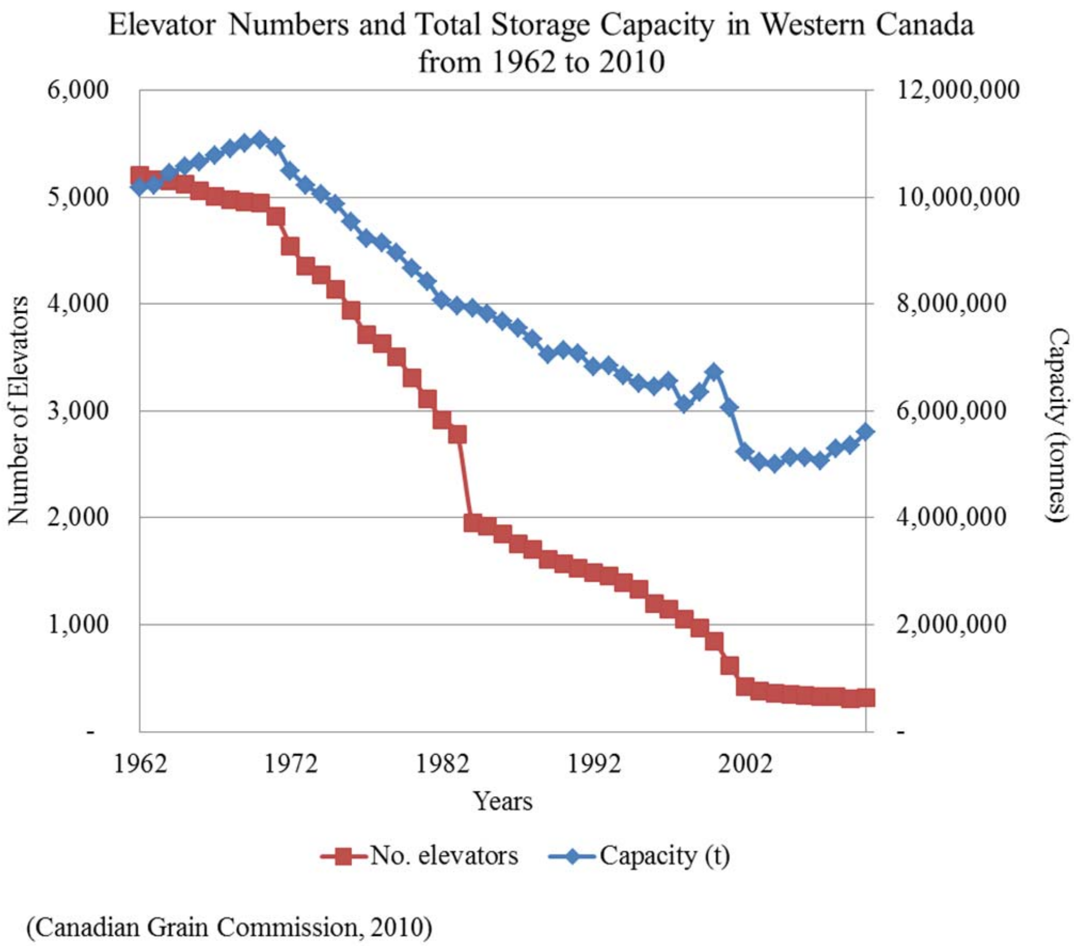


Figure 2.4. Elevator numbers and total storage capacity in western Canada from 1962 to 2010[3]

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

[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.

Chapter 4

THE CANADIAN PRAIRIE GRAIN HANDLING SUPPLY CHAIN MODEL

4.0 Introduction

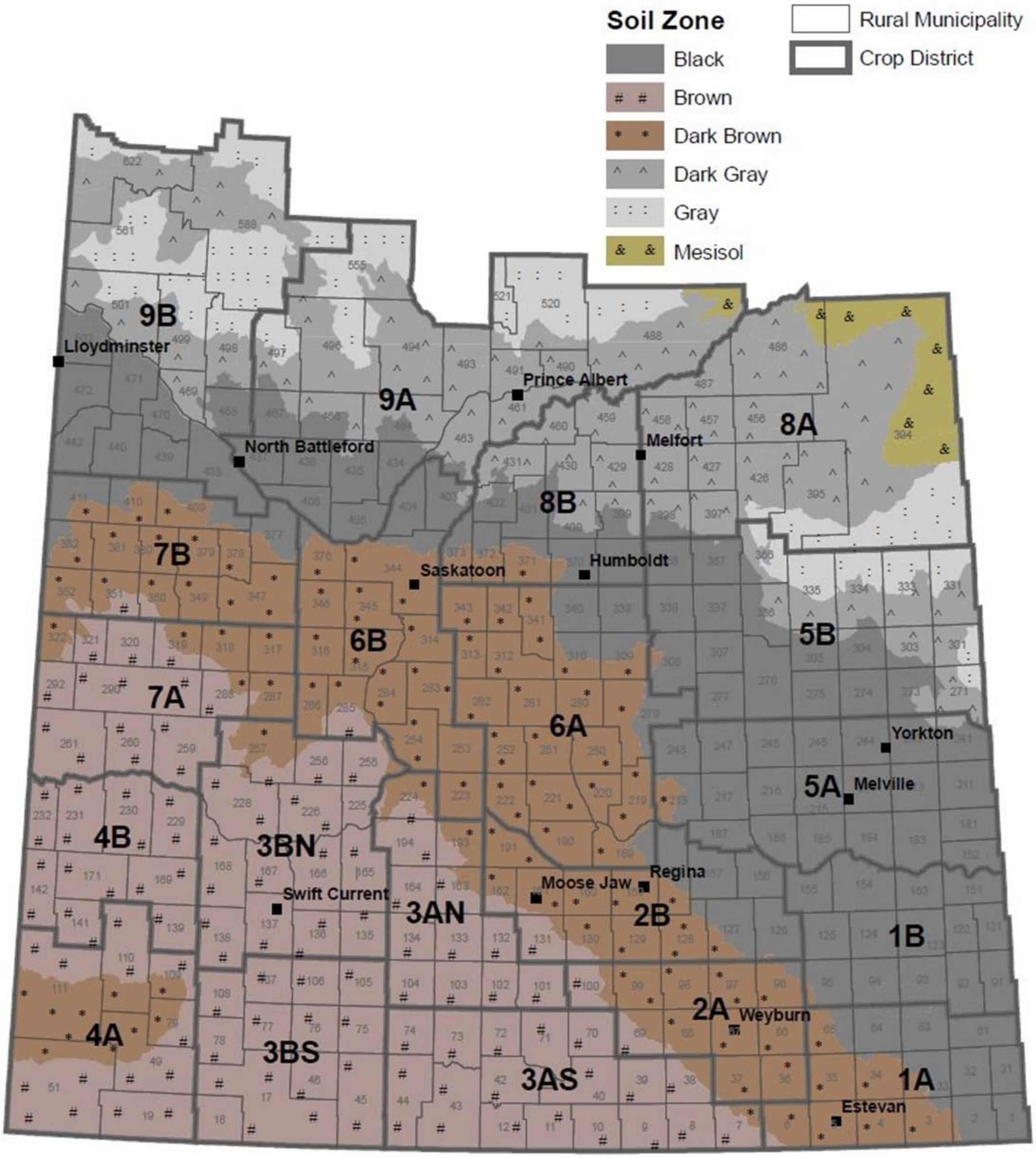
This chapter describes the physical characteristics of the agent based simulation of the grain handling and transportation system in Canada. It begins by outlining the features of the landscape, and defines the agents and the assumptions they operate under.

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

[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.

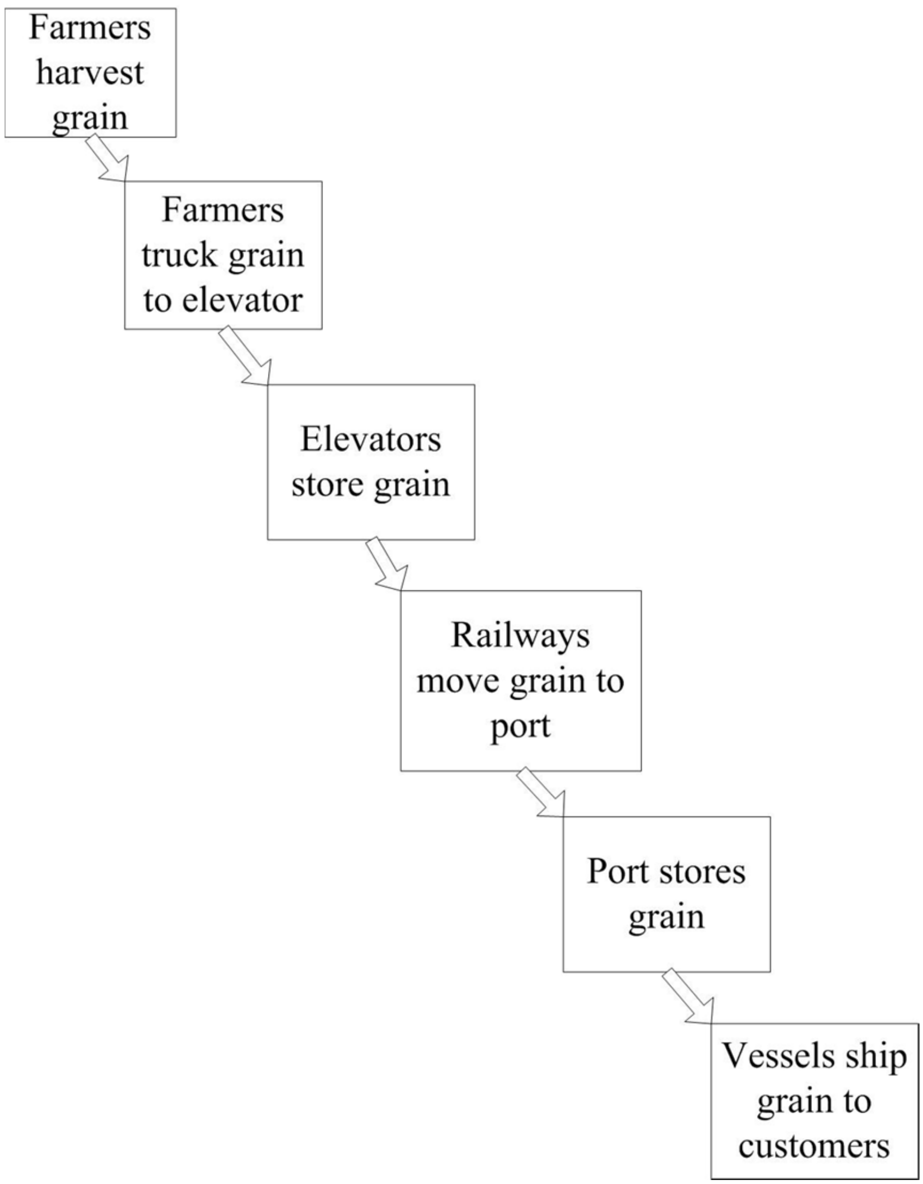


Figure 4.2. A 30,000 foot view of the grain handling supply chain in western Canada

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).

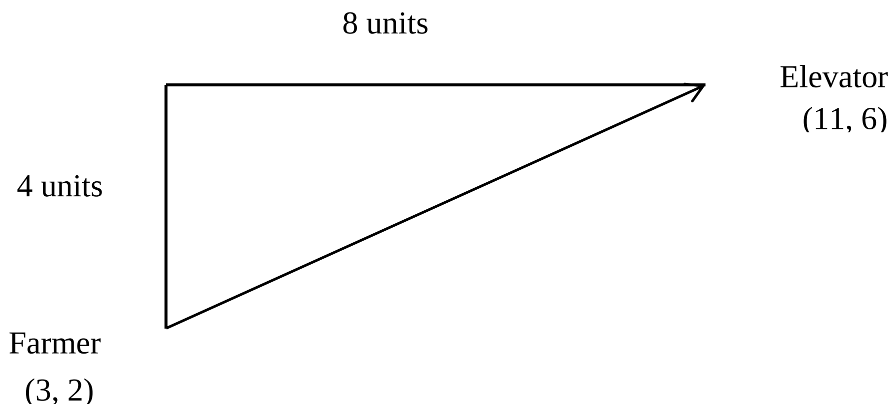
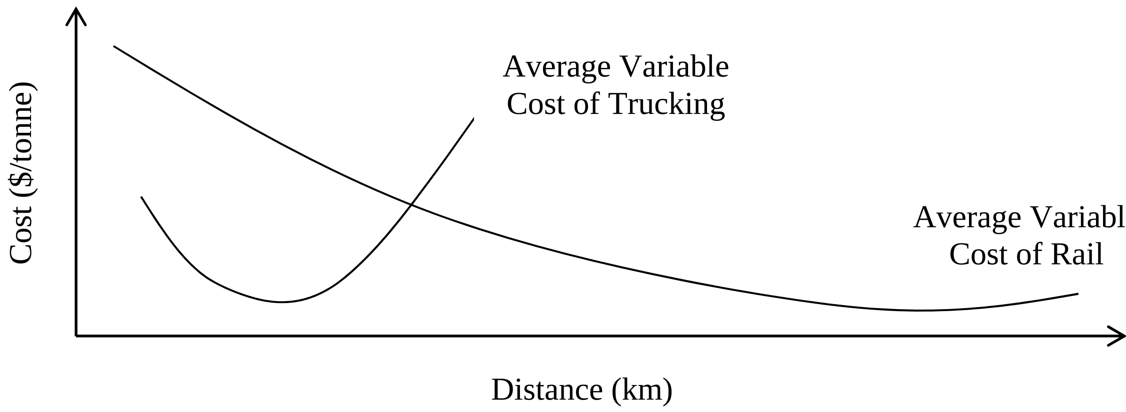


Figure 4.3. Grid distance

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).



(Federal Railroad Administration, 2009)

Figure 4.4. Average variable cost of trucking vs. rail

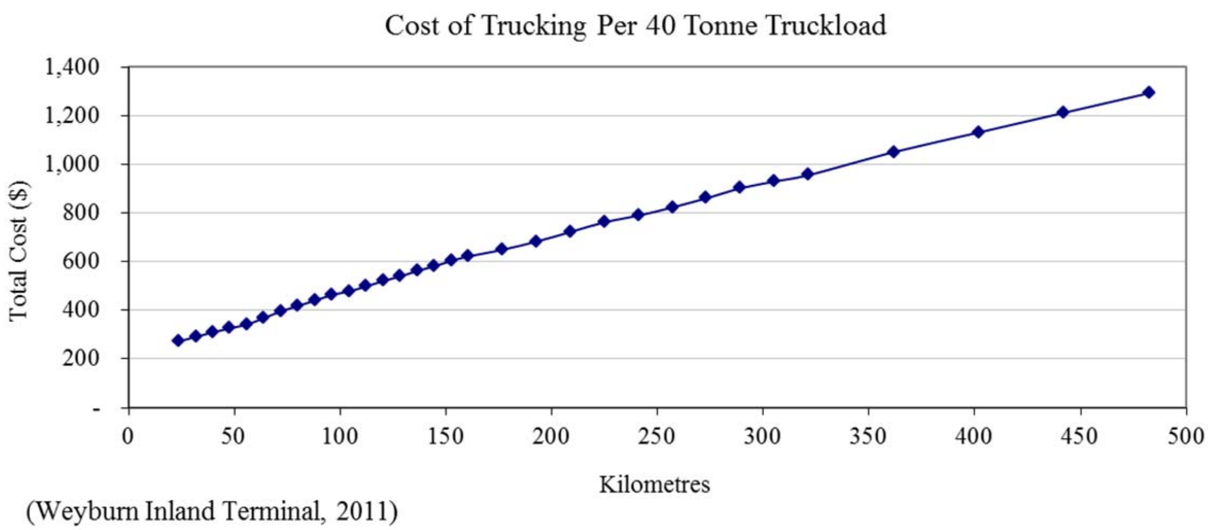


Figure 4.5. Cost of trucking per 40 tonne truckload

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

Primary Elevators in Saskatchewan as of August 2009						
Company	# of Locations		Capacity		Sum of Primary Capacity (tonnes)	%
	Served by CN	Served by CP	Served by CN	Served by CP		
ADM Agri-Industries Company	0	1	0	15,000	15,000	0.52%
Bunge Canada	2	0	57,600	0	57,600	1.98%
Canada Malting Co. Limited	2	0	13,420	0	13,420	0.46%
Cargill Limited	11	2	234,610	44,450	279,060	9.61%
CMI Terminal Joint Venture	0	1	0	27,220	27,220	0.94%
Fill-More Seeds Inc.	1	3	5,100	12,320	17,420	0.60%
Gardiner Dam Terminal Joint Venture	0	1	0	17,000	17,000	0.59%
Great Sandhills Terminal Marketing Centre Ltd.	0	1	0	20,800	20,800	0.72%
Louis Dreyfus Canada Ltd.	2	2	62,680	94,040	156,720	5.39%
Mission Terminal Inc.	0	1	0	3,760	3,760	0.13%
Mobil Grain Ltd.	2	0	8,560	0	8,560	0.29%
North East Terminal Ltd.	0	1	0	35,920	35,920	1.24%
North West Terminal Ltd.	1	0	63,000	0	63,000	2.17%
Parrish & Heimbecker, Limited	7	3	146,920	94,980	241,900	8.33%
Paterson Grain	2	16	14,430	134,250	148,680	5.12%
Prairie Heritage Seeds Inc.	0	1	0	1,290	1,290	0.04%
Prairie West Terminal Ltd.	1	4	12,420	50,750	63,170	2.17%
Richardson Pioneer Limited	19	15	211,340	272,120	483,460	16.64%
RW Organic Ltd.	0	1	0	7,390	7,390	0.25%
South West Terminal Ltd.	0	1	0	52,000	52,000	1.79%
Viterra Inc.	27	25	506,980	579,390	1,086,370	37.39%
Weyburn Inland Terminal Ltd.	0	1	0	105,500	105,500	3.63%
Total	77	80	1,337,060	1,568,180	2,905,240	100.00%
Percentage	49%	51%	46%	54%		

(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

Elevator Capacities by Company within Saskatchewan as of August 2009

Company	# of Locations		% of Capacity		Sum of Primary Capacity (tonnes)	%
	Served by CN	Served by CP	Served by CN	Served by CP		
Cargill	11	2	8.1%	1.5%	279,060	9.6%
Parrish & Heimbecker	7	3	5.1%	3.3%	241,900	8.3%
Richardson Pioneer	19	15	7.3%	9.4%	483,460	16.6%
Viterra	27	25	17.5%	19.9%	1,086,370	37.4%
Remainder	13	35	8.2%	19.9%	814,450	28.0%
Total	77	80	46.0%	54.0%	2,905,240	100.0%

(Canadian Grain Commission, 2009)

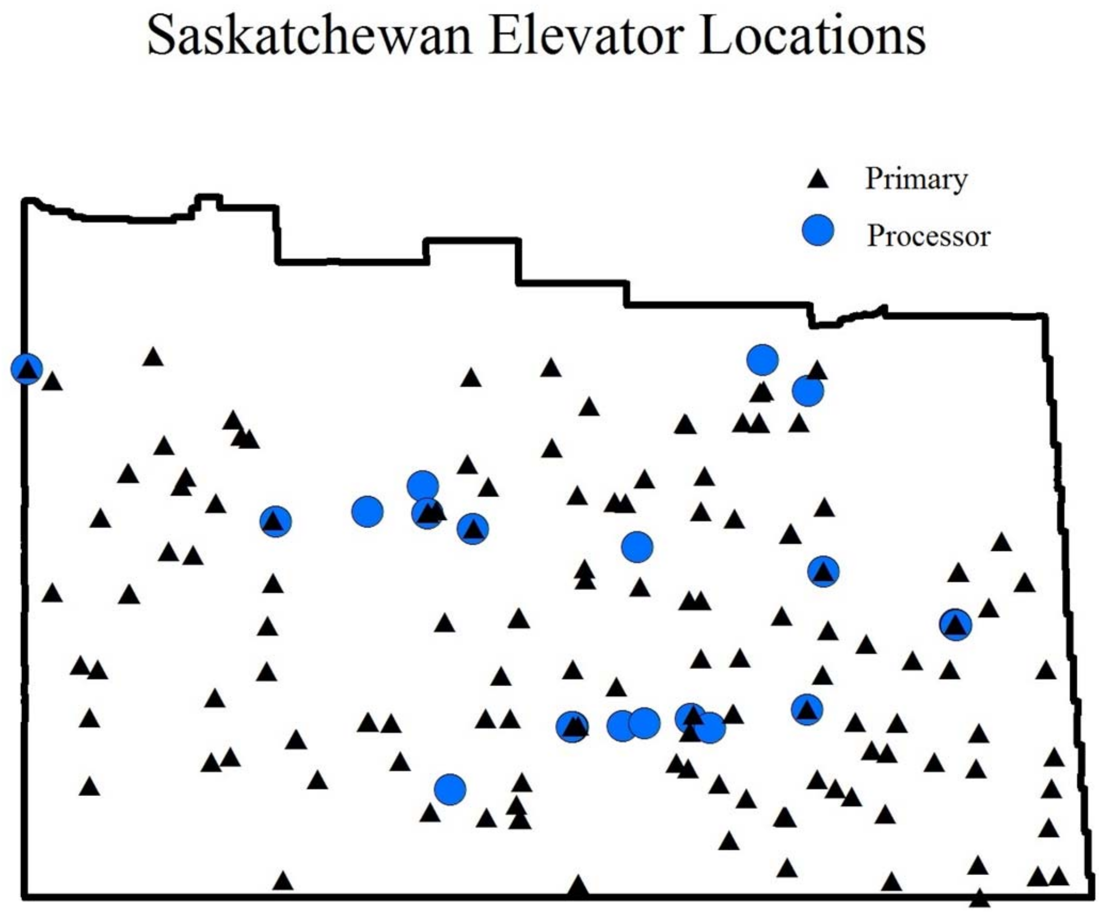


Figure 4.6. Saskatchewan elevator locations as of August 2009

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

Simulated Elevator Capacities in Saskatchewan by Company

Company	# of Locations		% of Capacity		Sum of Primary Capacity (tonnes)	%
	Served by CN	Served by CP	Served by CN	Served by CP		
Cargill	11	2	8.9%	1.8%	312,000	10.7%
Parrish & Heimbecker	7	3	4.7%	4.0%	255,000	8.8%
Richardson Pioneer	19	15	7.4%	9.6%	496,000	17.0%
Viterra	27	25	20.7%	17.2%	1,103,000	37.9%
Remainder	13	35	8.0%	17.7%	747,000	25.6%
Total	77	80	49.7%	50.3%	2,913,000	100.0%

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.

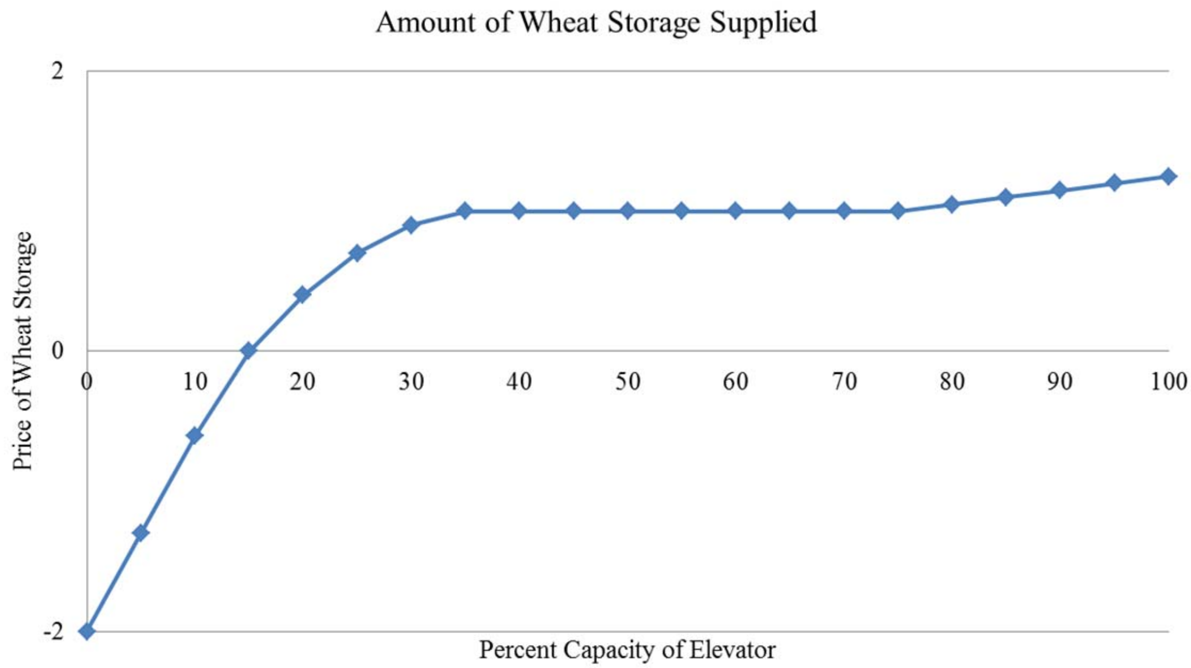
---

[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.



(Paul, 1970)

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).

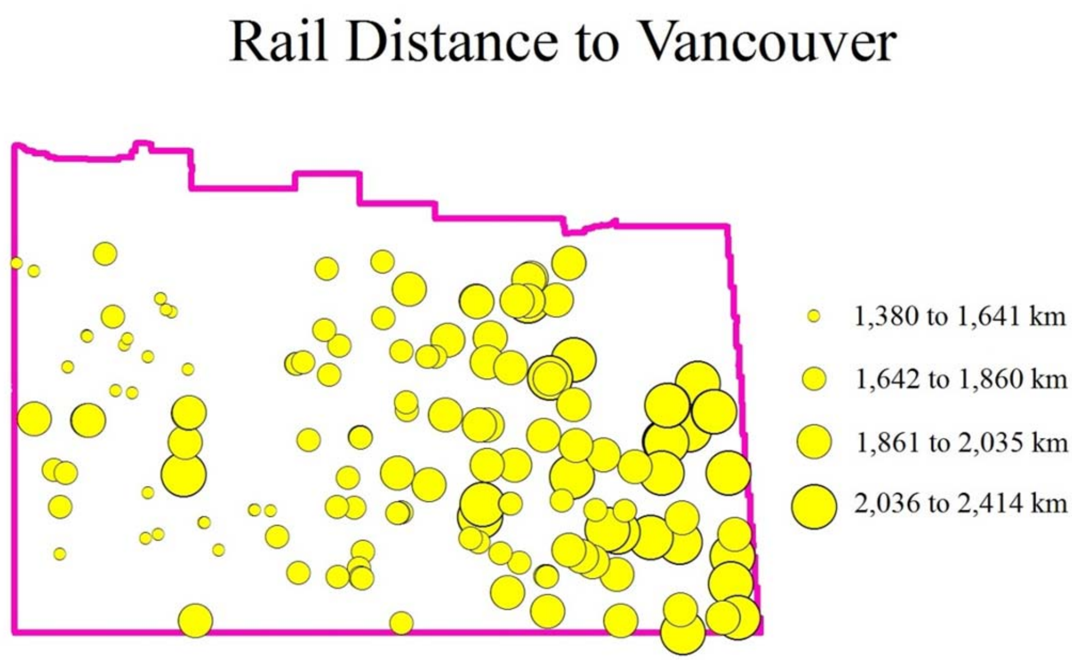
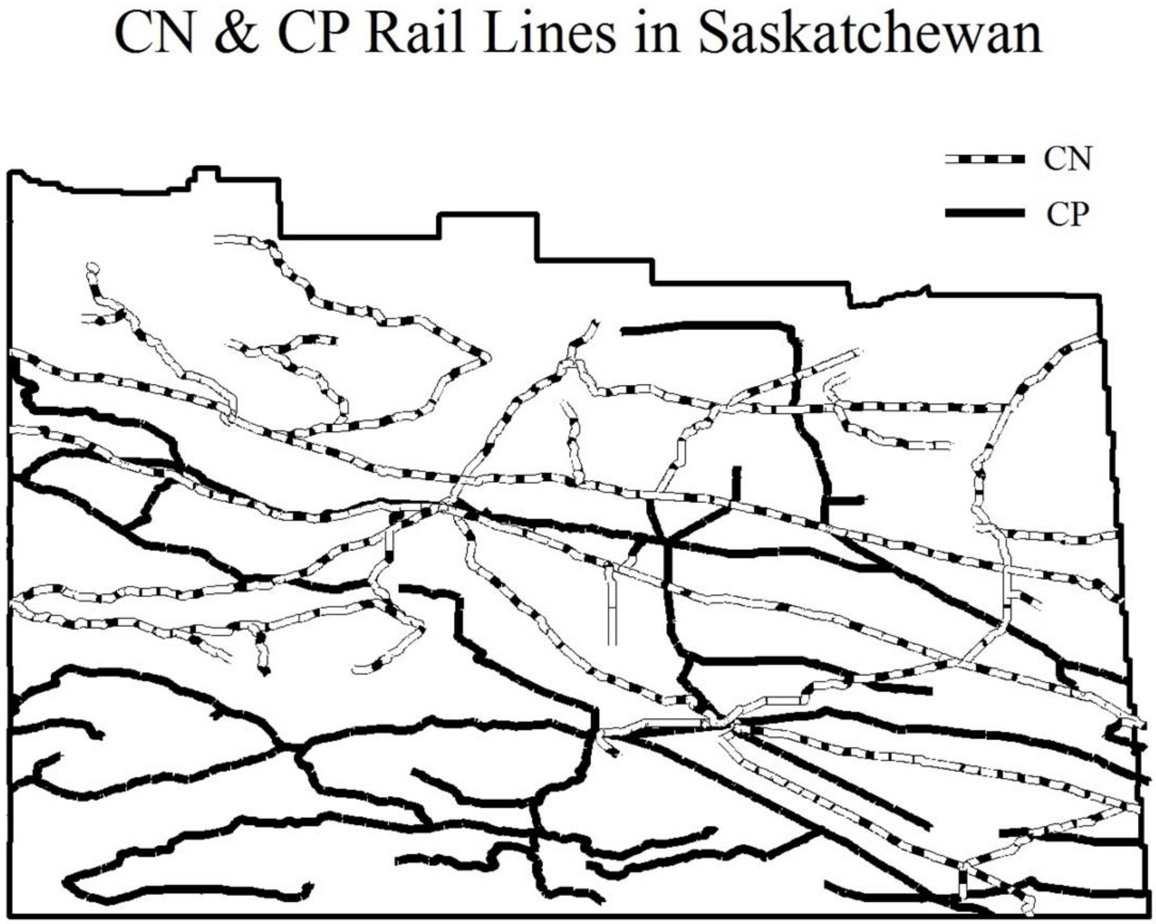


Figure 4.8. Distance to Vancouver in kilometres by rail, Study Area

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.



(DMTI Spatial, 2008)

Figure 4.9. CN and CP rail lines in Saskatchewan

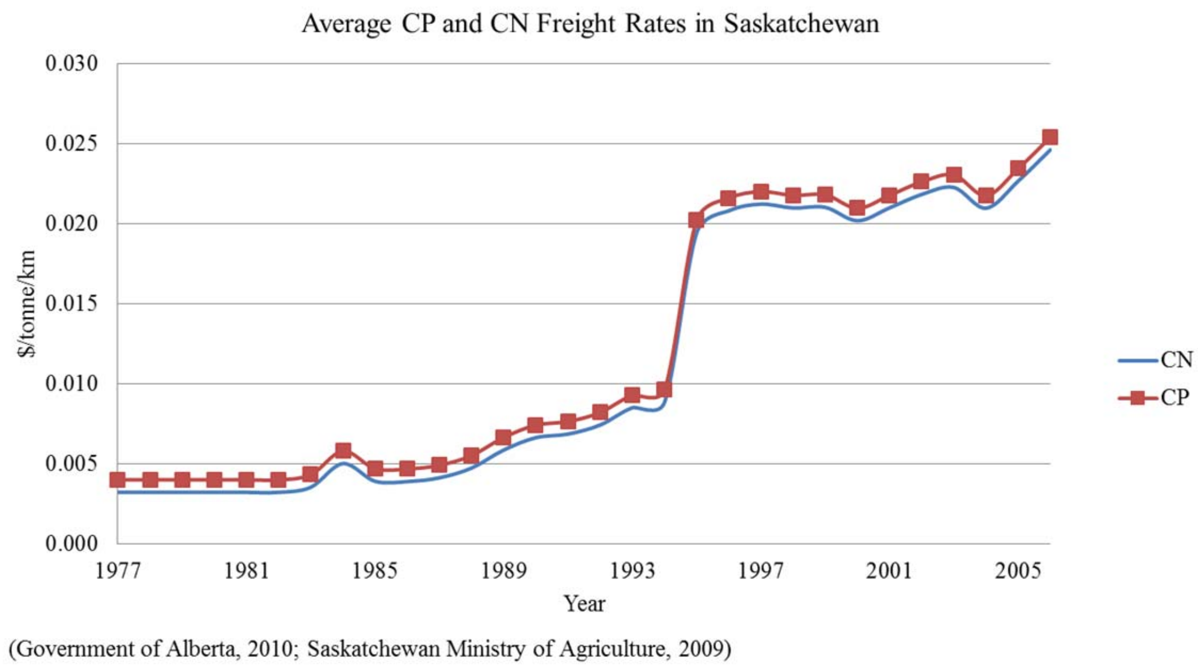


Figure 4.10. Average CN and CP freight rates in Saskatchewan, 1977 to 2006

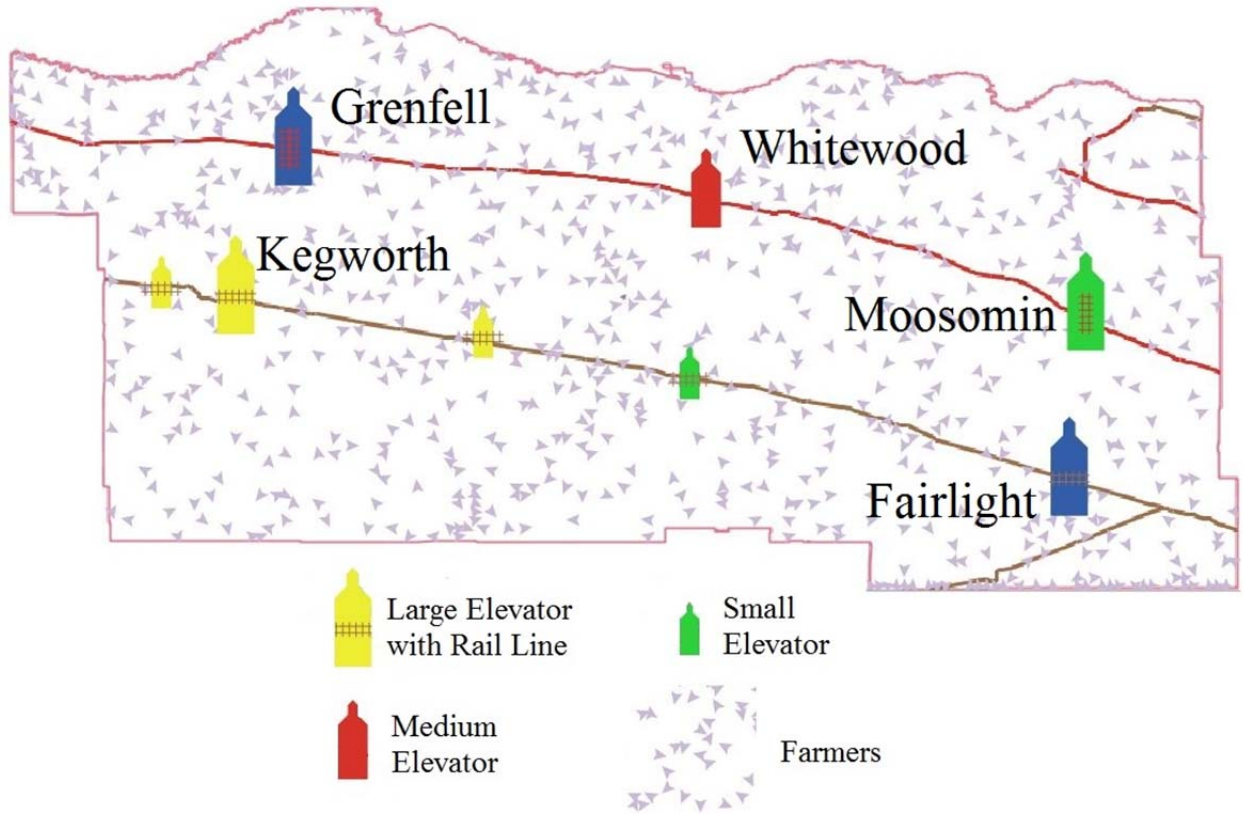


Figure 4.11. Screen shot of CAR 1B after initialization[8]

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

[8]A 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[9]. 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 overdrawing 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

[9] This heuristic was chosen based on the author’s knowledge of the industry as well as knowledge of basic inventory optimization models.

Table 4.4). 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

Elevator Size	Total Capacity (tonnes)	Train Spot Capacity (tonnes)	Spot Capacity as a % of Total Capacity
Large	4,000	2,500	63%
Medium	14,000	5,000	36%
Small	39,000	10,000	26%

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[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.

[10] Carryout stock is the amount of wheat left over once all demand is satisfied.

Table 4.5. Initialization information summary

Initialzation Information Summary

Elevator Size	Number of Elevators	Total Capacity (Tonnes)	Percent Capacity at Initialization	Train Capacity (Tonnes)
Small	49	4,000	0%	2,500
Medium	57	14,000	0%	5,000
Large	51	39,000	0%	10,000
Farmer Starting Inventory	N ~ (300, 50)			

Number of Farmers by CAR

1A	1017	3BS	717	7A	1403
1B	770	4A	313	7B	1212
2A	906	4B	696	8A	1377
2B	1587	5A	1978	8B	1685
3AN	644	5B	2077	9A	1766
3AS	1208	6A	2102	9B	958
3BN	1422	6B	1584		

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

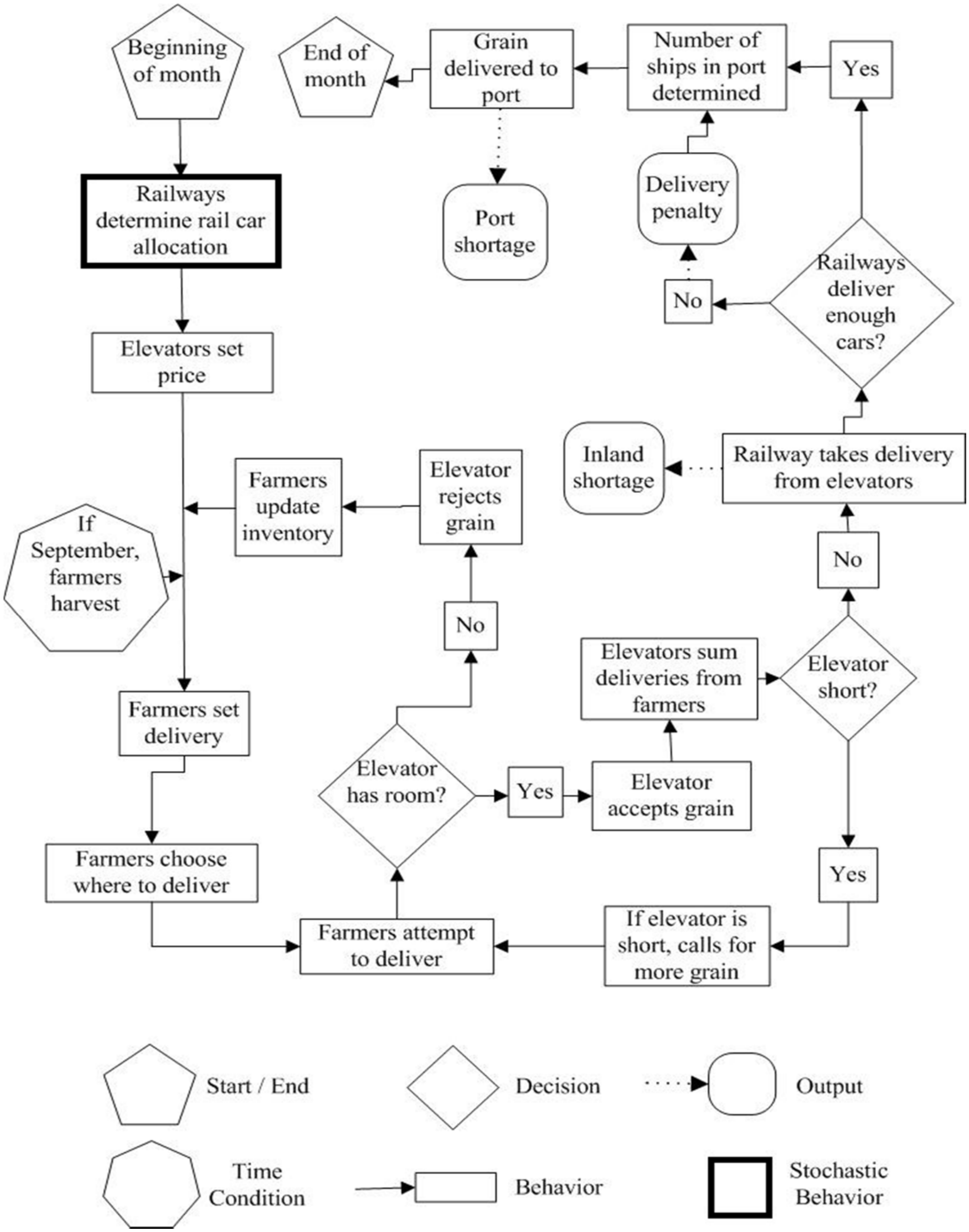


Figure 5.1. Elevator agent overview

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 kilometers.

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 5.1. Number of elevators and average total simulated tonnes of wheat transported per year

Number of Elevators and Average Total Simulated Tonnes of Wheat Transported per Year

Elevator Size	# of Elevators	# of Rail Cars per Train	Average # of Trains per Year	Average Total Tonnes Transported per Year
Small	49	25	6	735,000
Medium	57	50	12	3,420,000
Large	51	100	21	10,710,000
			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].

[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.

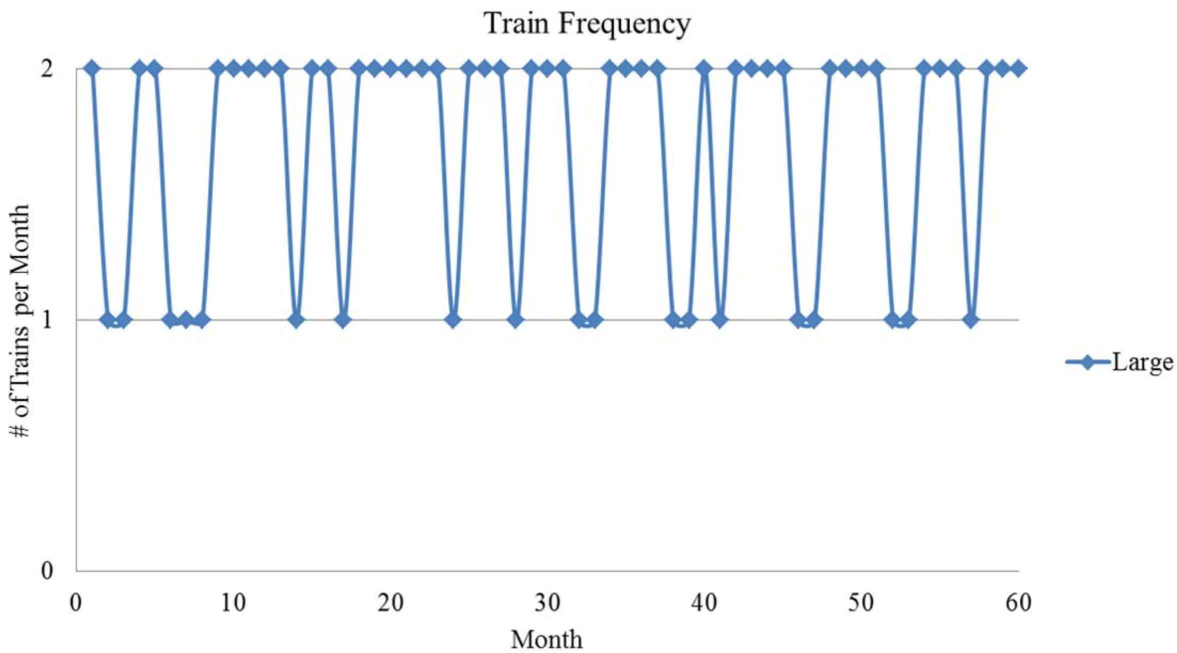


Figure 5.2. Example train allocation to a large capacity elevator

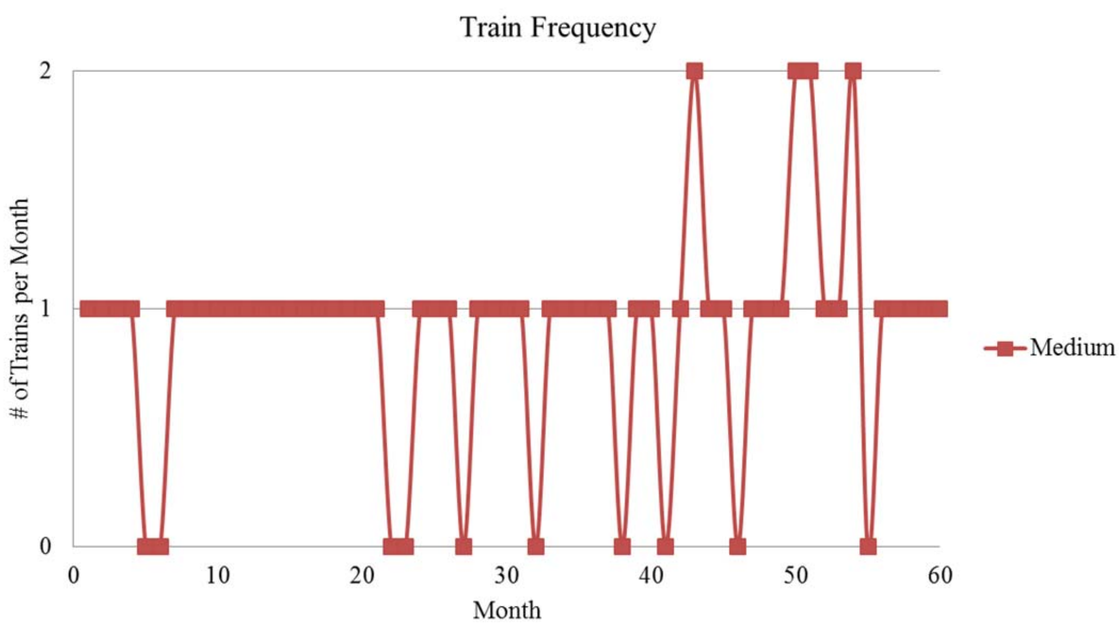


Figure 5.3. Example train allocation to a medium capacity elevator

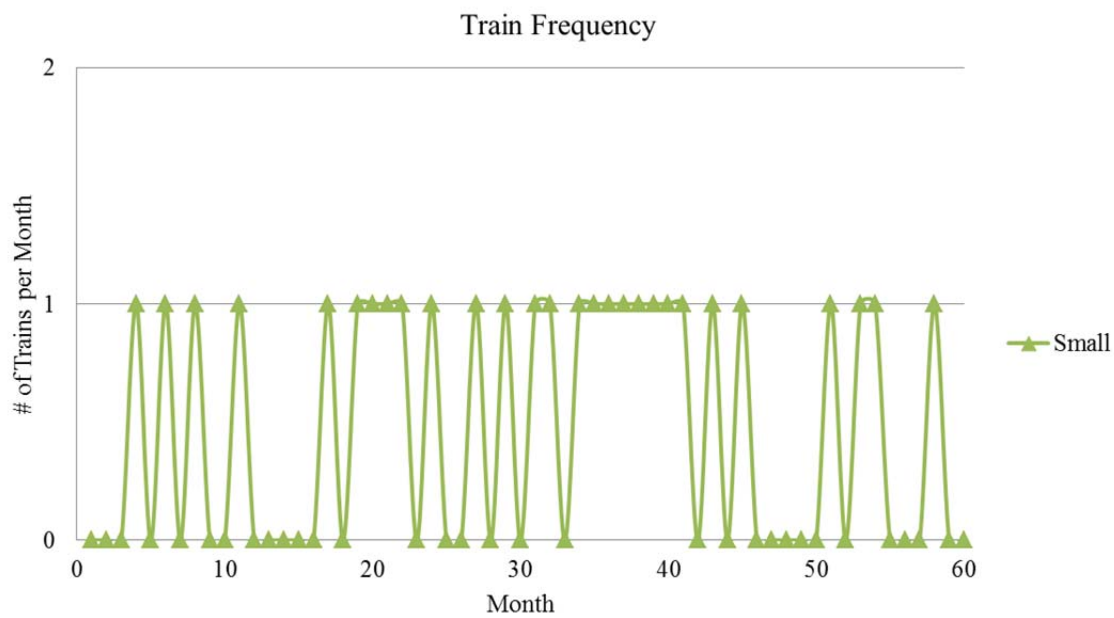


Figure 5.4. Example train allocation to a small capacity elevator

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

Month	Delivery Volume
January	40%
February	40%
March	40%
April	50%
May	50%
June	80%
July	90%
August	100%
September	0%
October	10%
November	20%
December	30%

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

Month	Intended Delivery Volume	Adjusted Delivery Volume if Inventory > 300 tonnes
April	50%	38%
May	50%	38%
June	80%	60%
July	90%	68%
August	100%	75%

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[12]. 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

[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

[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

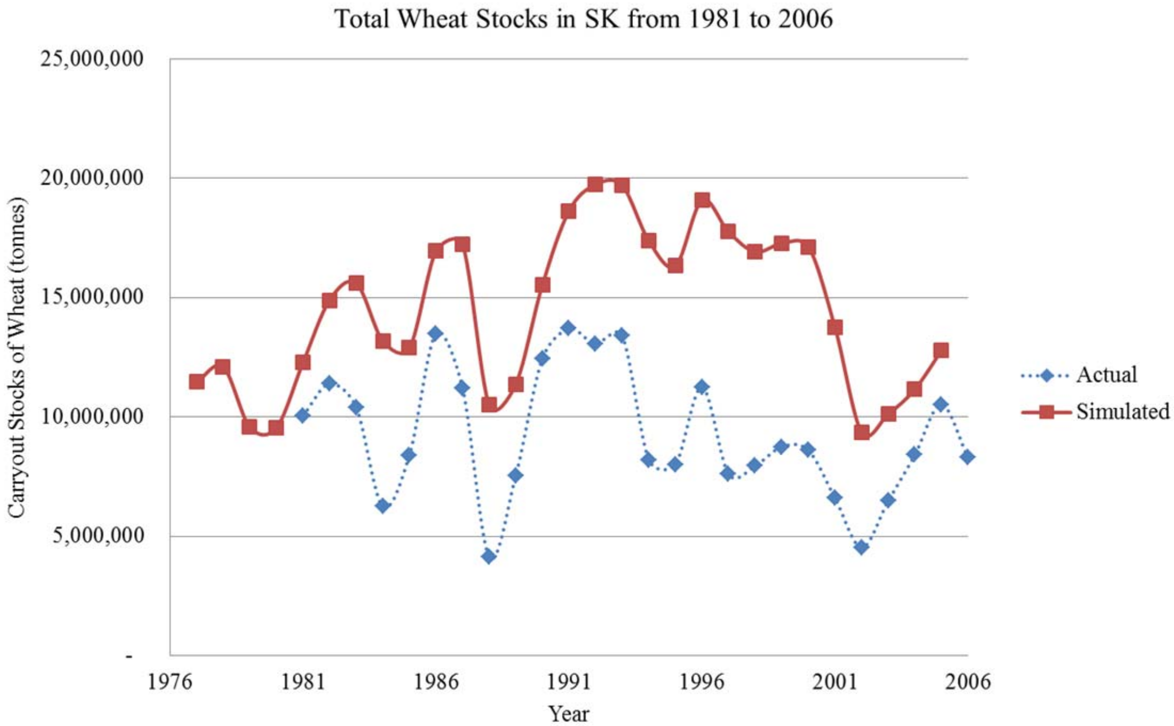
SIMULATION RESULTS AND POLICY IMPLICATIONS – THE ISSUE OF RAIL COMPETITION

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

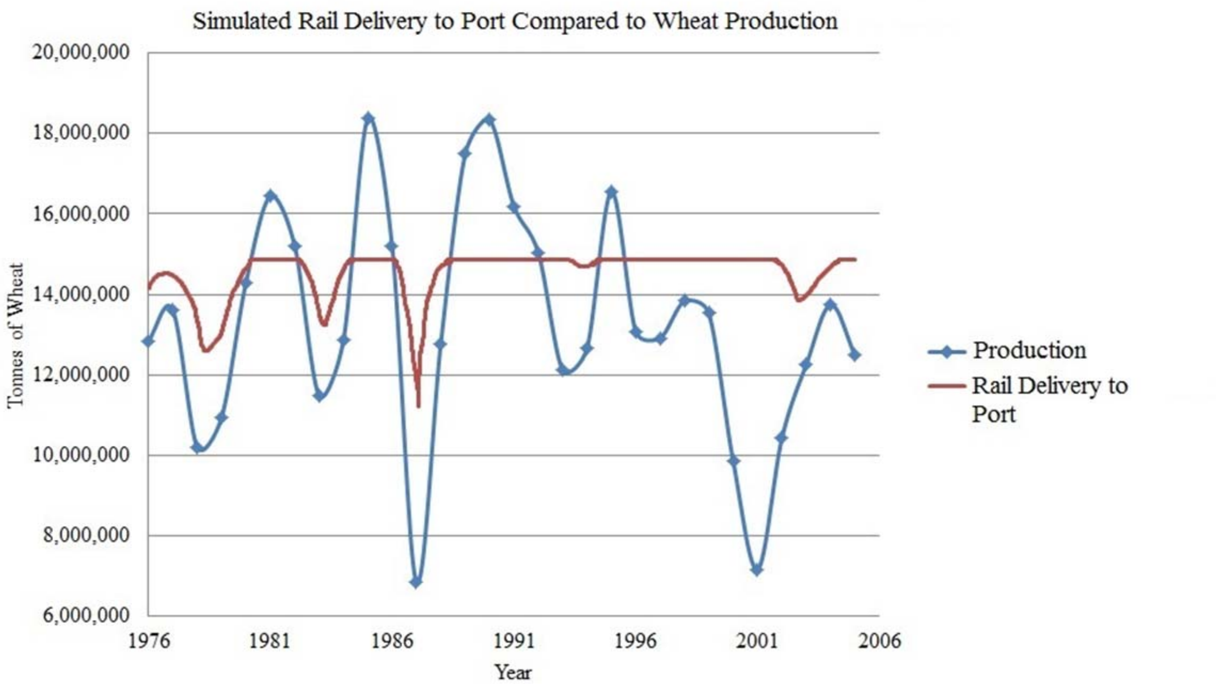


Figure 6.2. Simulated rail delivery to port compared to wheat production

6.2 Delivery Penalty Events[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[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

[14] Also see Section 4.9.

[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.

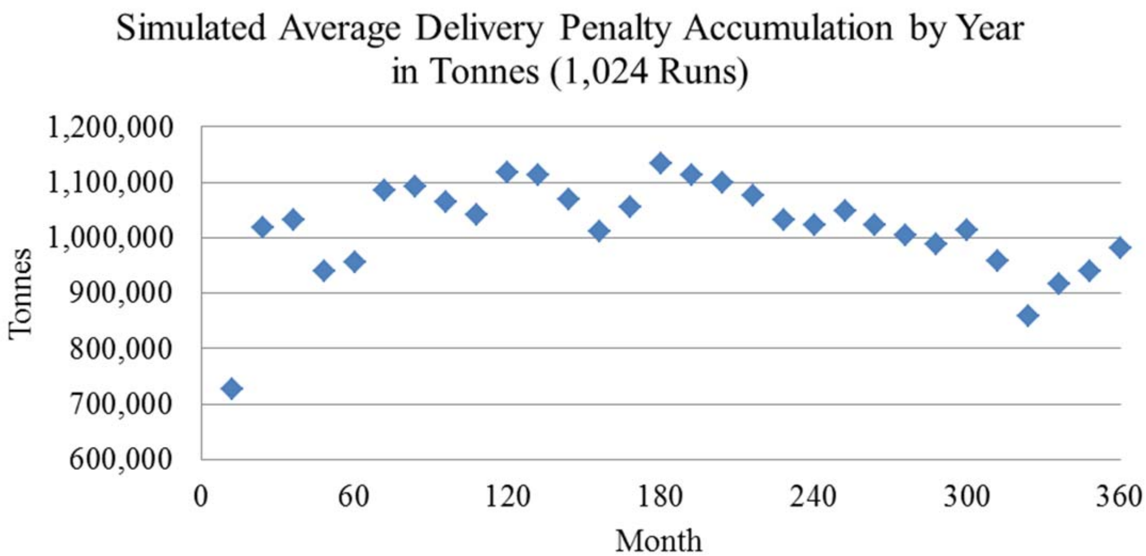


Figure 6.3. Simulated average delivery penalty accumulation by year in tonnes

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[16]. The simulation initialization process means that the average delivery penalty volume is reached by the third year and remains consistent after that time.

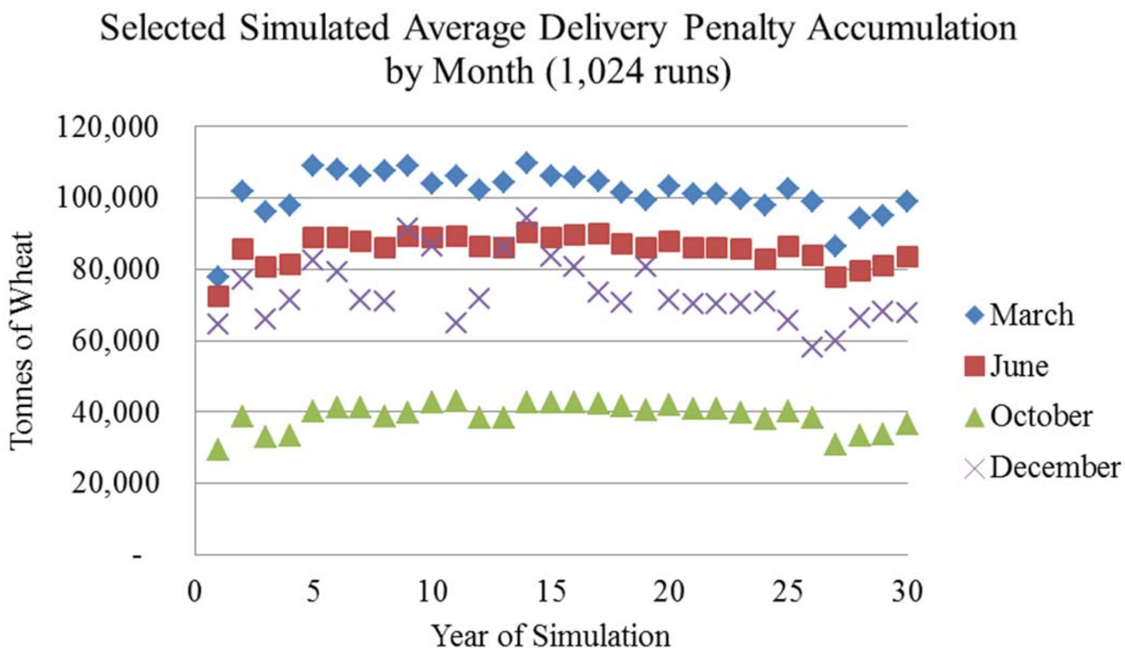


Figure 6.4. Selected simulated average delivery penalty accumulation by month

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.

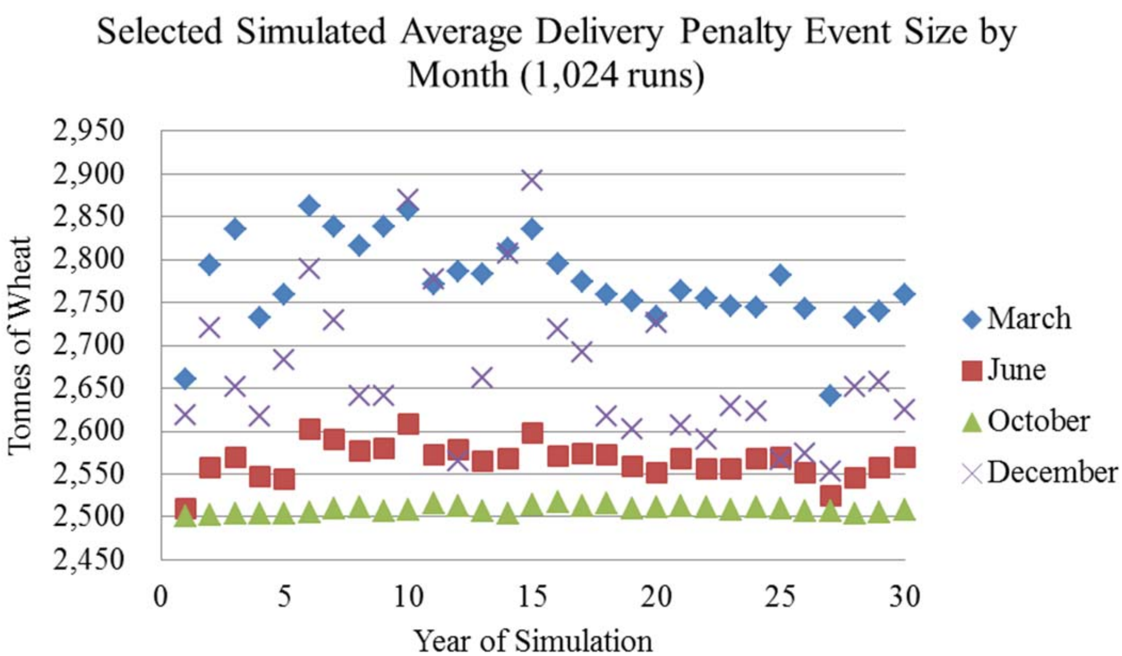


Figure 6.5. Selected simulated average delivery penalty event size by month

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.

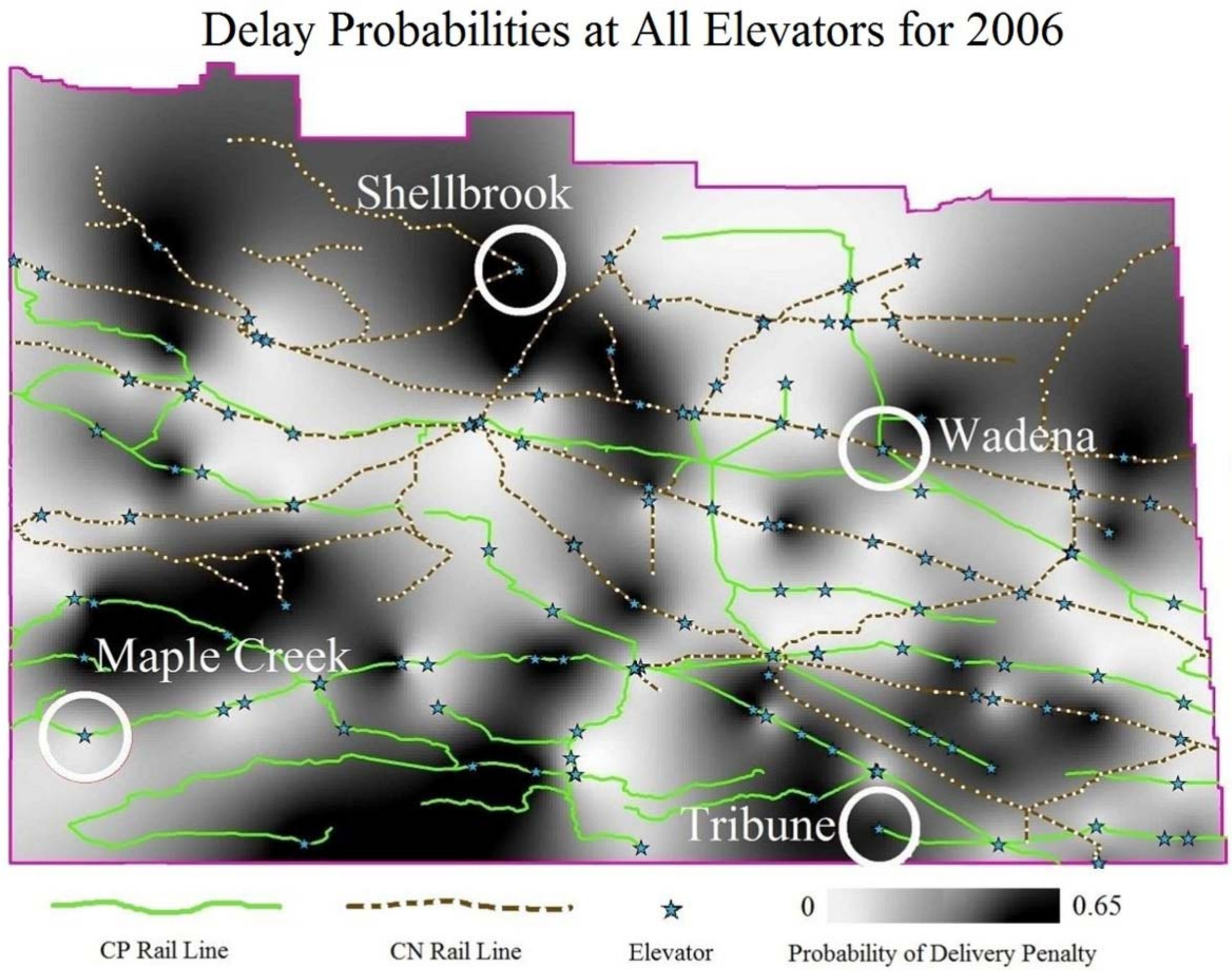


Figure 6.6. Map of delay probabilities, 2006

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.

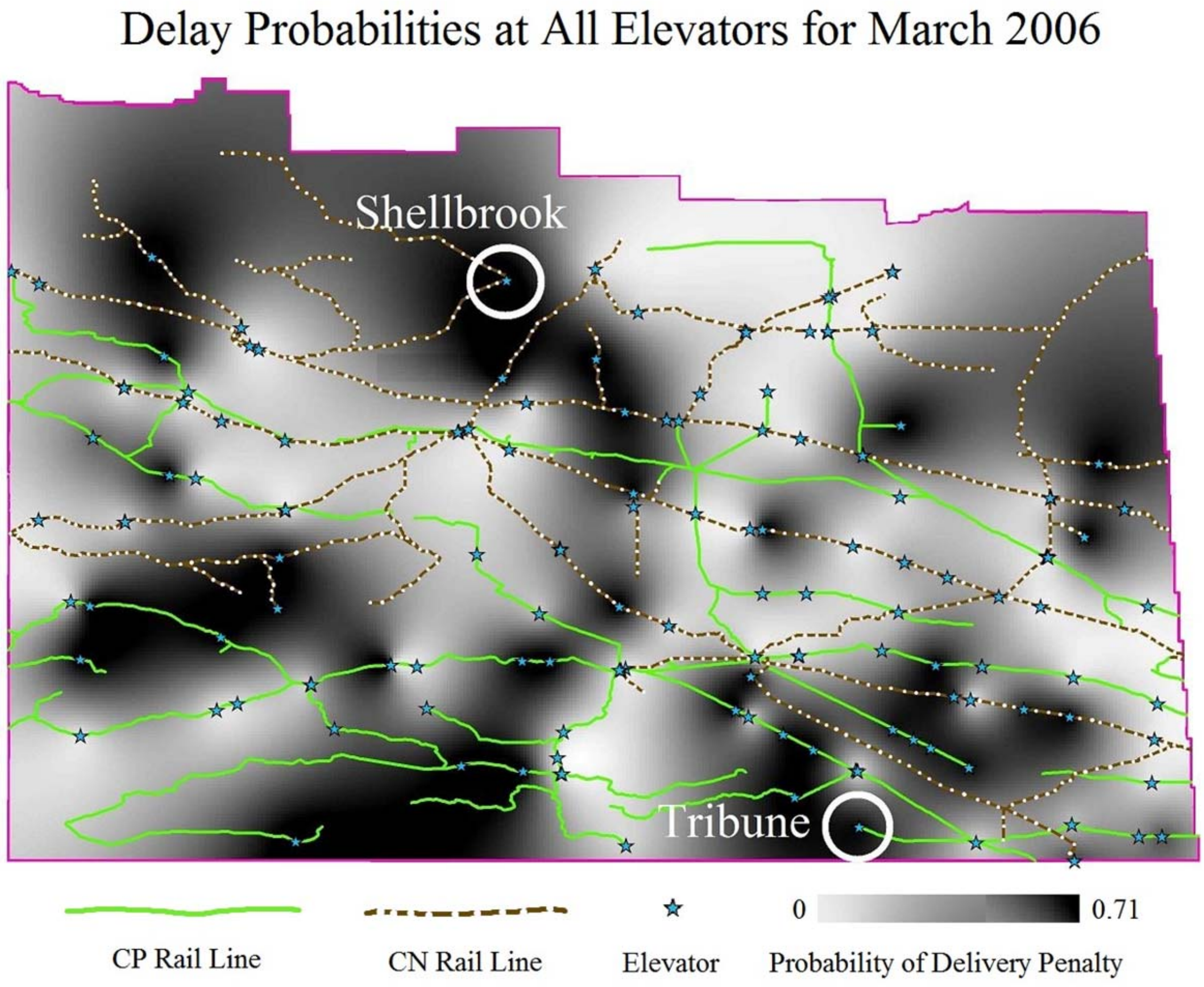


Figure 6.7. Map of delay probabilities for March 2006

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.

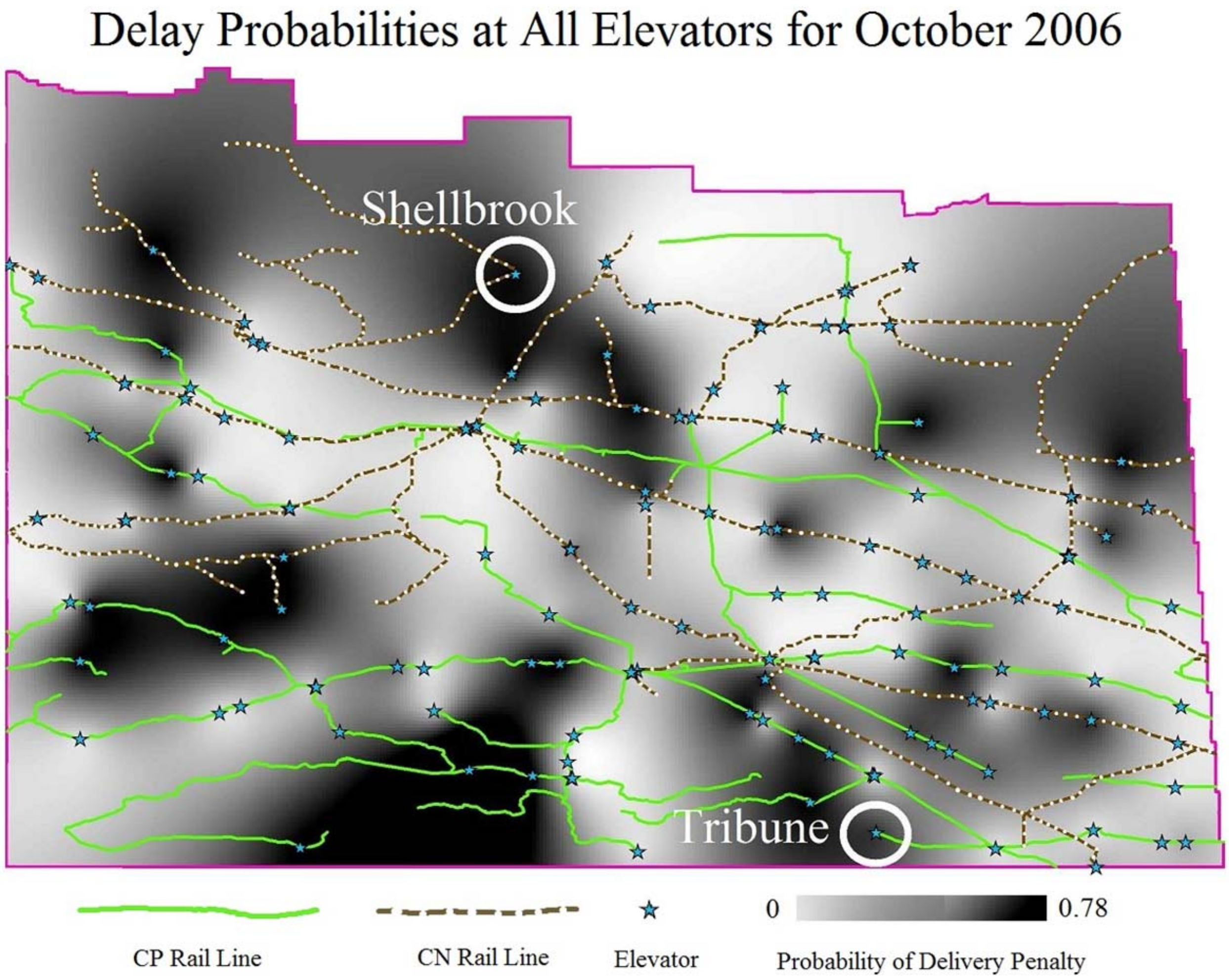


Figure 6.8. Map of delay probabilities for October 2006

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

[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[18] and a distance to port of 1,857 kilometres[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%[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 Cyle Length	14.7
Number of Sets*	16

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

[18] Average freight rate from 2006
[19] Average distance to Vancouver of all elevator locations used in the simulation
[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

REVENUE				
Freight Rate ($ / Tonne)			41.85	
Tonnes			1,017,500	
Total Revenue				42,582,375
EXPENSES				
Fixed Cost				
Locomotive Cost				
Lease Cost / Day ($ / Day)			250	
Number of Sets			16	
Locomotives / Set			2	
Days / Year			365	
			2,920,000	
Labour				
Wages / Month ($)			65,000	
Members / Crew			3	
Number of Sets			16	
			3,120,000	
Variable Cost				
Access				
Locomotive Mass				
	Mass / Locomotive	120		
	Locomotives / Set	2		
	Number of Sets	16		
	Trips / Year	24		
		92,160		
Railcar Mass (Tonnes)			1,221,000	
Dist to Vancouver (km)			1,857	
Tonne-km			2,438,538,120	
			39,016,610	
Total Expenses				45,056,610
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

	Base Case	Break Even	
		Accounting	Economic
Freight Rate ($/T)	$41.85	$44.28	$50.92
Distance to Vancouver (km)	1,857	1,740	1,475
Car Cycle Length	14.7	~ 10	NA

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.

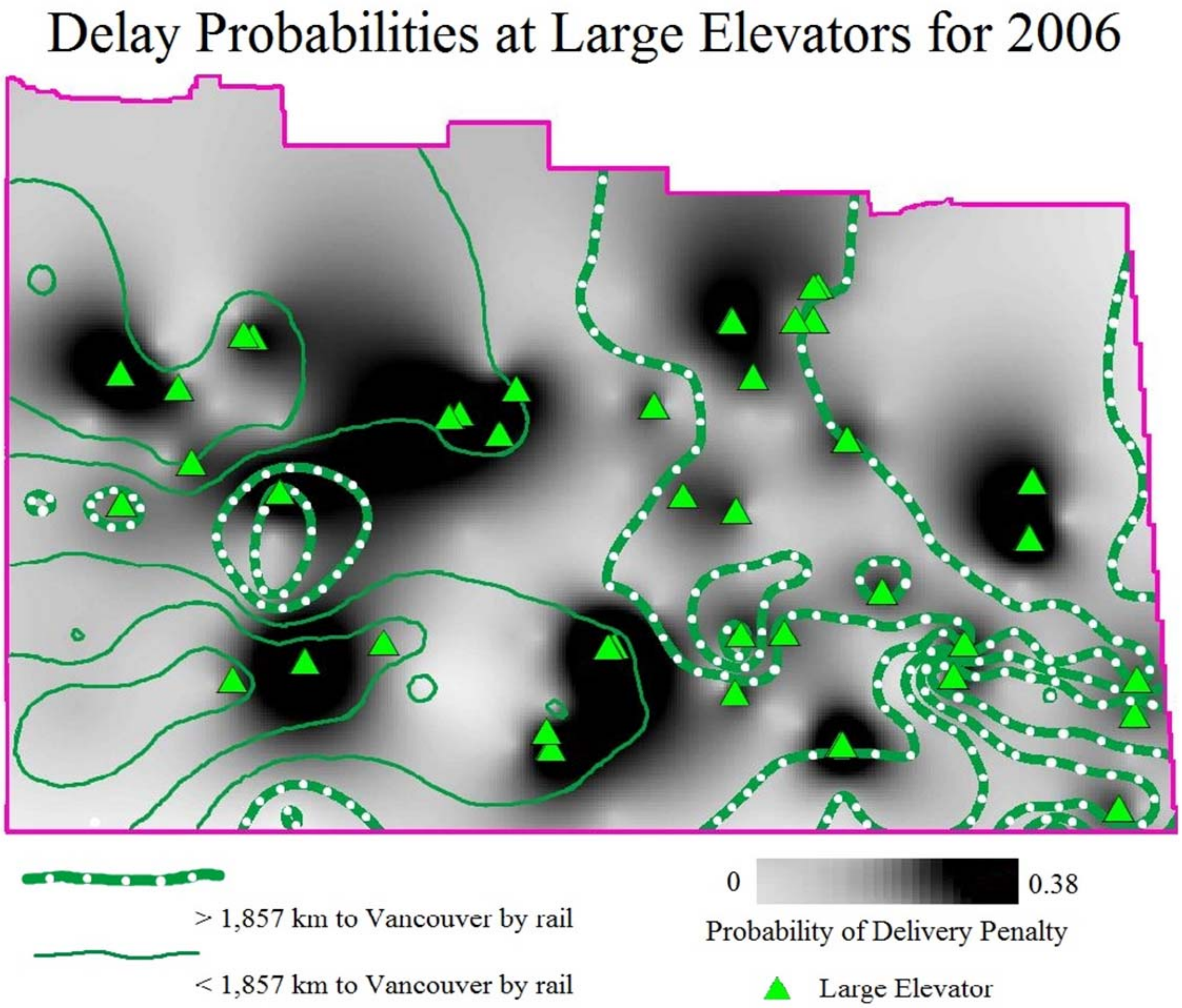


Figure 6.9. Map of delay probabilities at a large elevator in 2006

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

Income Statement for Potential Railway Entrant for 2006
(Only transporting 100 rail car spots)

REVENUE			
Freight Rate ($ / Tonne)		41.85	
Tonnes		80,000	
Total Revenue			3,348,000
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%

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.

REFERENCES

Agriculture Division, Crops Section. (2006). Historical Crop Data 1976 - 2006. Statistics Canada.

Annand, M., & Nolan, J. (2003). Rail Regulation & Competition in Canada: Assessing future policy direction through an analysis of regulatory decisions. *Journal of Transportation Law, Logistics and Policy*, 71(1):65-84.

Armstrong, M., & Doyle, C. (1998). Social obligations and access pricing: Telecommunications and railways in the UK. In D. Gabel, & D. Weiman, *Opening networks to competition: The regulation and pricing of access* (p. Chapter 8). Boston: Kluwer Academic.

Australian Government: Bureau of Transport and Regional Economics. (2003). *Rail Infrastructure Pricing: Principles and Practice. Report 109.* Canberra: Bureau of Transport and Regional Economics.

Babcock, M., Bunch, J., Sanderson, J., & Witt, J. (2003). *Economic impacts of railroad abandonement on rural Kansas communities Report No. KS-03-4.* Kansas: Department of Transportation.

Baldwin, E. (1986). *Understanding and Using Basis - Grains*. Risk and Resilience in Agriculture. NCR Extension Publication No. 217, December 1986. University of Wyoming. Retrieved from the World Wide Web on September 17, 2010 from: http://www.uwagec.org/rnrinag/RnR%20Section%203/RnR%20Understanding%20and%20Using%20Basis%20Grains.pdf

Baldwin, J. (2011). *Royal Commission on Transportation*. Retrieved from World Wide Web on September 16, 2011 from: http://www.thecanadianencyclopedia.com

Ballou, R. (1992). *Business logistics management.* Englewood Cliffs: Prentice Hall.

Berger, T. (2000). Agent-based spatial models applied to agriculture: A simulation tool for technology diffustion, resource use changes and policy analysis. *Agricultural Economics*, 25(213):245-260.

Bitzan, J., VanWechel, T., Benson, D., & Vachal, K. (2003). *The importance of short line railroads to rural and agricultural america.* North Dakota State University, Upper Great Plains Transportation Institute.

Bocker, J., Lind, J., & Zirkler, B. (2001). Using a multi-agent approach to optimize the train coupling and sharing system. *European Journal of Operational Research*, 134:242-252.

Branting, S., Wu, Y., Srikrishnan, R., & Altawheel, M. R. (2007). SHULGI: A geospatial tool for modeling human movement and interaction. In M. North, D. Sallach, & C. Macal (Ed.), *Proceedings of the Agent 2007 Conference on Complex Interaction and Social Emergence.* Argonne, IL: Argonne National Laboratory.

Brennan, T. J. (2000). *The economics of competition policy: Recent developments and cationary notes in antitrust and regulation*. Washington, DC: Resources for the Future.

Brown, D. G., Riolo, R., Robinson, D. T., North, M., & Rand, W. (2005). Spatial process and data models: Towards integration of agent-based models and GIS. *Journal of Geographic Systems*, 7:25-47.

Bunn, D. W., & Oliveira, F. S. (2001). Agent-Based Simulation - An Application to the New Electricity Trading Arrangements of England and Wales. *IEEE Transactions on Evolutionary Computation*, 5(5):193-503.

Campos, J., & Cantos, P. (2000). *Rail Transportation Regulation.* Spain: Economic Development Institute of the World Bank.

Canadian Grain Commission. (1997). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/Primary97-08-01.PDF.

Canadian Grain Commission. (1998). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/Primary98-08-01.PDF.

Canadian Grain Commission. (1999). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/Primary99-08-01.PDF.

Canadian Grain Commission. (2000). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/Primary00-08-01.PDF.

Canadian Grain Commission. (2001). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/primary01-08-01.PDF.

Canadian Grain Commission. (2002). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/Primary02-08-01.pdf.

Canadian Grain Commission. (2003). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/primary03-08-01.pdf.

Canadian Grain Commission. (2004). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/primary04-08-01.pdf.

Canadian Grain Commission. (2005). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/primary05-08-01.pdf.

Canadian Grain Commission. (2006). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/primary06-08-01.pdf.

Canadian Grain Commission. (2007). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/primary07-08-01.pdf.

Canadian Grain Commission. (2008). Primary Elevator Tariffs. *Summary - Licensed Primary Elevator Tariffs*. Retrieved from the World Wide Web on February 12, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/tariff-tarif/pp/primary08-08-01.pdf.

Canadian Grain Commission. (2009). Grain Elevators in Canada: Crop Year 2009-2010. Retrieved from the World Wide Web on February 19, 2011 from: http://www.grainscanada.gc.ca/statistics-statistiques/geic-sgc/2009-08-01.pdf.

Canadian Grain Commission. (2010). Primary Elevators in Western Canada from 1962 to 2010. Retrieved from the World Wide Web on February 19, 2011 from: www.grainscanada.gc.ca.

Canadian National. (2000). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2000-annual-report-en.pdf.

Canadian National. (2001). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2001-annual-report-en.pdf.

Canadian National. (2002). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2002-annual-report-en.pdf.

Canadian National. (2003). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2003-annual-report-en.pdf.

Canadian National. (2004). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2004-annual-report-en.pdf.

Canadian National. (2005). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2005-annual-report-en.pdf.

Canadian National. (2006). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2006-annual-report-en.pdf.

Canadian National. (2007). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2007-annual-report-en.pdf.

Canadian National. (2008). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report-Archive/2008-annual-report-en.pdf.

Canadian National. (2009). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www.cn.ca/documents/Investor-Annual-Report/2009AR_complete.pdf.

Canadian National. (2009). *CN Producer Car Loader Station List.* Retrieved from the World Wide Web on July 5, 2011 from: http://www.cn.ca/en/shipping-guidelines-grain-loader-station-list.htm

Canadian National. (2011). Retrieved March 10, 2011, from Canadian National: http://www.cn.ca/documents/Investor-Financial-Quarterly-2010/Q4-2010-US-GAAP-MDA-en.pdf

Canadian Pacific. (2000). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/eaiy32ipyaqssk6gg36kfr6roh62gbarvw6ww6dlqbbutzfot6bnssilmmpzlw7uczfzzk3ojma2diacbe5hqg7vsxa/cpr-ar-2000.pdf.

Canadian Pacific. (2001). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/enq4ztkejfu6rh2qldu3gvbg6rpryc7efqmt2o53lb27j2vksdnj4xcw46oa6cfe7m7g5cs7uusk57miz4ott3whnxg/cpr-ar-2001.pdf.

Canadian Pacific. (2002). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/e7qwqayev3itwjn5efvtsrq3r4axcedoemtha6prgk7o6hd4mr6vvnrolc4yipxrpnaobi4ff6vk4kkphcdr2jyv65e/cpr-ar-2002.PDF.

Canadian Pacific. (2003). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/ei3mbkvtsvmn4wykyhexct7mllvq76feeeh2sbzyyasxduwswndhkwrh6ymvxpceofkvmxwn75g4vtzxumkwdemwioe/cpr-ar-2003.pdf.

Canadian Pacific. (2004). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/eeg7pjj3ukvdq4m2c3vgjeneayd2eqlm7mzrpbl5bmvld77j3vc7txijng56rpmk3kcaksoliohuadqzhumbtqj2pse/cpr-ar-2004.pdf.

Canadian Pacific. (2005). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/exvjidrm2petwxeacl3cj6zfjlsg6rx6lnr2ma7txdsxspqjxrgarqypxf7cbrnvxixw5voosb4mqwo5ptbqlyfcbjf/cpr-ar-2005.pdf.

Canadian Pacific. (2006). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/ephxzweybodyzr5nmdl6rws33faihup35ychona5th6xwsd72lb4gl3wpzgovsjq2s2iy3xbojvfdkvzylszynuoilb/cpr-ar-2006-cor.pdf.

Canadian Pacific. (2007). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/eauggohocfgt42d4pqp6ir7xrpcyz6tjludhy7raczsxmmlskgxgen5fow5vlgrmkv6bqrcizmfecdoodfqbjshwccd/ar-cp-2007.pdf.

Canadian Pacific. (2008). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/ewar7foricvlmu6xobuqrbgkxjc75mgtxaa7krlsdnmd7c2ceqfytu4auojz5elwze2yunb5owtggqbuzvz7utbthlg/FINAL+ENGLISH+Annual+Report+03+05+09.pdf.

Canadian Pacific. (2009). Annual Report. Retrieived from the World Wide Web on March 15, 2011 from: http://www8.cpr.ca/cms/NR/rdonlyres/e5jcrgyhqfimczhagzkcebtgg2ycrdjq7rtayax4m4v3h3fxw7pz7z5izfgtgxrwru6bhepfm7cz4bau7a2z4ouav3e/ar-cp-2010.pdf.

Canadian Pacific. (2011). *Canadian Pacific announces 2010 results.* Retrieved March 10, 2011, from the World Wide Web from: http://www8.cpr.ca/cms/English/Media/News/General/2010/Q4+2010+results.htm

Canadian Pacific. (2011). *Producer Cars.* Retrieved July 5, 2011 from the World Wide Web from: http://www.cpr.ca/en/customer-centre/shipping-guides/grain/Pages/producer-cars.aspx

Canadian Transportation Agency. (2007). Decision No. 344-R-2007.

Canadian Transportation Agency. (2008). Decision No. 20-R-2008.

Canadian Transportation Agency. (2008). Decision No. 488-R-2008.

Canadian Transportation Agency. (2010). Canadian Transportation Agency dismisses level of service complaint on CN delisting of producer car loading sites. Retrieved from the World Wide Web on July 3, 2011 from: http://www.otc-cta.gc.ca/doc.php?did=2347&lang=eng.

Canadian Transportation Agency. (2011). *Cases in which an appeal is before the Courts*. Retrieved July 5, 2011 from the World Wide Web from: http://www.otc-cta.gc.ca/doc.php?sid=2068&lang=eng

Canadian Transportation Agency. (2011). Level of Service. Retrieved July 5, 2011 from the World Wide Web from: http://www.otc-cta.gc.ca/doc.php?did=1007&lang=eng.

Canadian Wheat Board. (2010). *Farmers: Historical Payments*. Retrieved May 11, 2010 from the World Wide Web from: http://www.cwb.ca/public/en/farmers/payments/historical/

Canadian Wheat Board. (2011). *About us: A snap shot of the CWB*. Retrieved July 3 from the World Wide Web from: http://www.cwb.ca/public/en/about/snapshot/

Carlson, L., & Nolan, J. (2005). Pricing Access to Rail Infrastructure. *Canadian Journal of Administrative Sciences*, 22:45-57.

Clark, E., & Easaw, J. Z. (2007). Optimal access pricing options for natural monopoly networks when costs are sunk and revenues are uncertain. *European Journal of Operational Research*, 178:595-602.

Coase, R. (1946). The marginal cost controversy. *Economica*, 13 (51):169-182.

Coase, R. (1970). The theory of public utility pricing and its application. *The Bell Journal of Economics and Management Science*, 1 (1):113-128.

Cobia, D. W., Wilson, W. W., Gunn, S. P., & Coon, R. C. (1986). *Pricing systems of trainloading country elevator co-operatives, Agricultural Economics Report No. 214.* North Dakota State University, Department of Agricultural Economics, Agricultural Experiment Station and Agricultural Cooperative Service, United States Department of Agriculture, Fargo, ND and Washinton, DC.

Colley West Shipping Ltd. (2011). Brochure. Retrieved September 18, 2011 from the World Wide Web from: http://www.colleywest.bc.ca/ColleyWest-Brochure.pdf

Competition Bureau. (2007). Competition Bureau completes measures to increase competition in grain handling industry. Retrieved February 17, 2011 from the World Wide Web from: http://www.competitionbureau.gc.ca/eic/site/cb-bc.nsf/eng/02368.html.

Conrad, M., & Finkel, A. (2002). *History of the Canadian Peoples: 1867 to the Present.* Toronto: Pearson Education Canada.

Crooks, A., Castle, C., & Batty, M. (2008). Key challenges in agent-based modeling for geo-spatial simulation. *Computers, Environment and Urban Systems*, 32:417-430.

Davidsson, P., Henesey, L., Ramstedt, L., Tornquist, J., & Wernstedt, F. (2005). Agent-based approaches to transport logistics. In F. Klugl, A. Bazzan, & S. Ossowksi, *Applications of agent technology in traffic and transportation.* Basel: Birkhauser Verlag.

Davis, L., & Hill, L. (1974). Spatial price differentials for corn among Illinois country elevators. *American Journal of Agricultural Economics*, 56 (1):135-144.

Davis, P., & Garces, E. (2010). *Quantitative Techniques for Competition and Antitrust Analysis.* Princeton, NJ: Princeton University Press.

Rosaasen, K., Skotheim, J. & Lokken, J. (2011). Freight Rate Manager. Retrieved September 15, 2011 from the World Wide Web from: http://www.freightratemanager.usask.ca

Dia, H. (2002). An agent-based approach to modeling driver route choice behavior under the influence of real time information. *Transportation Research Part C,* 10:331-349.

DMTI Spatial. (2008). *Equinox*. Retrieved September 25, 2010 from CanMap Rail, version 2009.3, from the World Wide Web: http://equinox.uwo.ca/dbtw-wpd/exec/dbtwpub.dll?QF0=AltTitle|Title|Subtitle|SeriesTitle|Filespecifics|PersAuthor|CorpAuthor|Acronym|Nation|Abstract|Codebook|SupplierTitle|Topic|VarName|QuestionPreface|QuestionText|VarNotes|FreqTable|VarUniverse|Varlist|Va

Doan, D., Paddock, B., & Dyer, J. (2003). Grain Transportation Policy and Transformation in Western Canadian Agriculture. Workshop on Agricultural Policy Reform and Adjustment. Imperial College London, Wye.

Drew, J. (2009). The benefits for rail freight customers of vertical separation and open access. *Transport Reviews*, 29 (2):223-237.

Edsforth, J. (2010). Estimated Contributions Earned by Railways from Handling of Statutory Grains and Grain Products 2007/2008 and 2008/2009. Travacon Research Limited. Retrieved August 25, 2011 from the World Wide Web from: http://www.apas.ca/dbdocs//4ca0c72d55829.pdf

Eley, R., Fulton, M., Gray, R., & Perlich, K. (1996). Freight rates and deregulation, Module D-1. *The Economics of Western Grain Transportation and Handling*. Van Vliet Publication Series.

Estey, W. Z. (1998). *Estey 1998.* Retrieved July 14, 2011 from the World Wide Web from: http://www.tc.gc.ca/media/documents/policy/phase_ii_final_report.pdf

ICF International. (2009). *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors.* Retrieved September 7, 2011 from the World Wide Web from: http://www.fra.dot.gov/Downloads/Comparative_Evaluation_Rail_Truck_Fuel_Efficiency.pdf

Informa Economics. (2008). An Open Market for CWB Grain: A study to determine the implications of an open marketplace in western Canadian wheat, durum and barley for farmers. Retrieved September 7, 2011 from the World Wide Web: http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agc6751/$FILE/informafinalreport.pdf

Franklin, S. (1997). Autonomous agents as emodied AI. *Cybernetics and Systems*, 28:499-520.

Freebairn, J. (1998). Access prices for rail infrastructure. *The Economic Record*, 74 (226):286-296.

Fulton, M. (1996). *Trucking premiums and other forms of price discrimination: Module C-2.* Van Vliet Publication Series.

Fulton, M. (2006). *The Canadian Wheat Board in an Open Market: The Impact of Removing the Single Desk Selling Powers.* Adapting to New Environments: Agriculture and Rural Economies in the 21st Century. Knowledge Impact in Society.

Fulton, M., & Gray, R. (1998). The provision of rail service: the impact of competition. *Policy Issues Paper No. 7*. Retrieved from the World Wide Web on May 23, 2010 from the World Wide Web from: http://ageconsearch.umn.edu/bitstream/29164/1/pip07.pdf.

Gambardella, L. M., Rizzoli, A. E., & Funk, P. (2002). Agent-based Planning and Simulation of Combined Rail/Road Transport. *Simulation*, 78(5):293-303.

Garrod, P., & Mikilius, W. (1987). "Captive shippers" and the success of railroads in capturing monopoly rent. *Journal of Law and Economics*, (30)2:423-442.

Gintis, H. (2007). The dynamics of general equilibrium. *Economic Journal*, 117(523):1280-1309.

Goncalves, A., Rodrigues, A., & Correia, L. (2004). Multi-Agent Simulation within Geographic Information Systems. *Proceedings of the 5th Workshop on Agent-Based Simulation.* The Society for Modeling and Simulation International.

Government of Canada. (1897). *The Crow's Nest Pass Agreement.* Retrieved June 15, 2010 from the World Wide Web from: http://www.collectionscanada.gc.ca/canadian-west/052920/05292083_e.html

Government of Canada. (1985). *The Canadian Wheat Board Act*. Retrieved September 9, 2010, from the World Wide Web from: http://laws.justice.gc.ca/PDF/C-24.pdf

Government of Saskatchewan. (2005). *Forages - Relative Cultivar Yields for Perennial Species.* Retrieved July 21, 2011 from the World Wide Web from: http://www.agriculture.gov.sk.ca/Forages-Relative_Cultivar_Yields_Perennials

Gray, R. (1996). *Road damage and maintenance: Module C-3.* Van Vliet Publication Series.

Guatier, A., & Mitra, M. (2008). Regulation of an open access essential facility. *Economica*, 75: 662-682.

Hay, D. (2007). *Rural Population*. Retrieved July 7, 2011 from the World Wide Web from: http://esask.uregina.ca/entry/rural_population.html

Heads, J. (1982). *Report of the Task Force on Rates.* Ottawa: Government of Canada.

Hoover, E. M., & Giarratani, F. (1985). *An Introduction to Regional Economics.* Toronto, ON: Random House of Canada Limited.

Hotelling, H. (1929). Stability in Competition. *The Economic Journal*, 39 (153):41-57.

Hotelling, H. (1938). The general welfare in relation to problems of taxation and of railway and utility rates. *Econometrica,* 6 (3):242-269.

Ivaldi, M., & Vibes, C. (2008). Price Competition in the Intercity Passenger Transport Market: A Simulation Model. *Journal of Transport Economics and Policy*, 42(2):225-254.

Jensen, A., & Stelling, P. (2007). Economic impacts of Swedish railway deregulation: A longitudinal study. *Transportation Research Part E,* 516-534.

Johnson, D., & King, R. (1988). *Optimal pricing and inventory control for a country grain elevator.* St. Paul, Minn: University of Minnesota, Institute of Agriculture, Forestry and Home Economics.

Johnson, J., & Harper, D. (1975). The potential consequences of deregulation of transportation. *Land Economics*, 51(1):58-71.

Katz, M., & Shapiro, C. (1985). Network externalities, competition and compatibility. *American Economic Review*, 75(3):424-440.

Kroeger, A. (1999). *Kroeger 1999.* Retrieved July 17, 2010 from the World Wide Web from: http://www.tc.gc.ca/eng/policy/acg-acgb-grain-1999-menu-783.htm

Kulshreshtha, S., & Devine, D. (1978). Historical perspective and propositions on the Crowsnest Pass Freight Rate Agreement. *Candian Journal of Agricultural Economics*, 26(2):72-83.

Leidtke, G. (2009). Principles of micro-behavior commodity transport modeling. *Transportation Research Part E*, 45:795-809.

MacDonald, J. (1989). Railroad deregulation, innovation, and competition: Effects of the Staggers Act on grain transportation. *Journal of Law & Economics*, 11-11.

MacDonald, J., & Cavalluzzo, L. (1996). Railroad deregulation: Pricing reforms, shipper responses, and the effects on labor. *Industrial and Labor Relations Review*, 50(1):80-91.

Mah, M. (2010). *2004-2009 Western Canadian Rail Rates & CWB Deductions*. Retrieved December 2, 2010 from the World Wide Web from: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ1523

Martin, F. L. (1976). A Study to Determine the Optimum Number of Grain Delivery Points in Saskatchewan with Particular Emphasis on the Consequences for Grain Producers. Thesis, (MSc): University of Saskatchewan.

Mes, M., van der Heijden, M., & van Harten, A. (2007). Comparison of agent-based scheduling to look-ahead heuristics for real-time transportation problems. *European Journal of Operational Research*, 181:59-75.

Miller, J. H., & Page, S. E. (2007). *Complex Adaptive Systems: An Introduction to Computational Models of Social Life.* Princeton, NJ: Princeton University Press.

Morgan, L. (1998). *House Committee on Transportation and Infrastructure, Subcommittee on Railroads.* Retrieved February 15, 2011 from the World Wide Web from: http://stb.dot.gov/testandspeech.nsf/0/a772fad6fa4a642d85256603005ccc37/$FILE/HOUSE513.pdf

Nabaa, M., Bertelle, C., Dutot, A., & Olivier, D. (2009). Exploitation of a displacement survey to detect road network use vulnerability. *The 2009 International Conference on Computational Science and Its Applications.* Suwon, Korea.

Natural Resources Canada. (2011). *Rail Transportation Infrastructure*. Retrieved July 11, 2011 from the World Wide Web from: http://atlas.nrcan.gc.ca/site/english/maps/economic/transportation/pm_r/1

Nilsson, J.-E. (1999). Allocation of track capacity: Experimental evidence on the use of priority auctioning in the railway industry. *International Journal of Industrial Organization*, 17: 1139-1162.

Nolan, J., & Skotheim, J. (2008). Spatial competition and regulatory change in the grain handling and transportation system in western Canada. *Annals of Regional Science*, 42:929-944.

North, M. J., & Macal, C. M. (2007). *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation.* New York: Oxford University Press.

Paranuk, H. V., & Brueckner, S. (2001). Entropy and Self-Organization in Multi-Agent Systems. *Proceedings of the 5th international conference on Autonomous agents*. Montreal.

Park, J. J., Wilson, W. W., & Johnson, D. D. (1999). *Canadian transportation and grain handling: Issues affecting the North American barley sector, Agricultural Economics Report No. 427.* North Dakota State University, Department of Agricultural Economics, Agricultural Experiment Station, Fargo, ND.

Park, J., & Koo, W. (2001). *US/Canada grain handling and transportation systems, agribusiness and applied economics Report No. 451.* North Dakota State University: Department of Agribusiness and Applied Economics.

Parker, A.J. (1974). A simulation of an export commodity distribution system. *Proceedings of the 7th conference on Winter Simulation*, (p. 100 - 110). New York.

Parunak, V., & VanderBok, R. (1998). *Modeling the extended supply network.* Ann Arbor, MI: Industrial Technology Institute.

Paul, A. B. (1970). The pricing of binspace: A contribution to the theory of storage. *American Journal of Agricultural Economics*, 52(1):1-12.

Phillips, P., & Nolan, J. (2007). Strategic options in Canadian transport policy: The interface between trade pressures and domestic policy. *Presentation to the Western Transport Corridor Workshop*. Regina, Canada.

Poletti, S. (2005). Optimal time-of-use access charges. *Journal of Regulatory Economics*, 27(2):203-224.

Port Metro Vancouver. (2011). Interactive Map. Retrieved from the World Wide Web on January 24, 2011 from: http://www.portmetrovancouver.com/en/users/interactiveportmap.aspx.

Preston, J., Whelan, G., & Wardman, M. (1999). An Analysis of the Potential for On-track competition in the British Passenger Rail Industry. *Journal of Transport Economics and Policy*, 33(1):77-94.

Prince Rupert Port Authority. (2011). Prince Rupert Grain Specifications. Retrieved September 17, 2011 from the World Wide Web from: http://www.rupertport.com/prince rupertgrain.htm

Producer Car Shippers of Canada. (2011). The Truth about Trucking Incentives. Retrieved September 9, 2011 from the World Wide Web from: http://www.pcsofcan.ca/ truth_about_trucking_incentives.html

QGI Consulting. (2009). Description of Canada's Rail Based Freight Logistics System. Retrieved November, 15, 2010 from the World Wide Web from: www.qgiconsulting.ca/railway_freight_reports_e.htm.

QGI Consulting. (2010). *Rail Car Order and Car Supply Processes*. Retrieved April 19, 2011 from the World Wide Web from: http://www.qgiconsulting.com/pdf/RailwayCarOrderandCarSupplyProcesses.pdf

Quorum Corporation. (2006). *A Review of the Revenue Cap*. Retrieved October 21, 2011 from the World Wide Web from: http://www.quorumcorp.net/Downloads/Papers/QuorumRevenuecapDiscussionandreview.pdf.

Quorum Corporation. (2006). Producer Netback Summary - 2004-05 Crop Year. Retrieved October 22, 2011 from the World Wide Web from: http://www.quorumcorp.net/Downloads/Papers/ProducerNetbackSummary-CY2004-05.pdf

Quorum Corporation. (2007). *Monitoring the Canadian Grain Handling and Transportation System: Annual Report 2006-2007 Crop Year*. Edmonton, Alberta: Quorum Corporation.

Quorum Corporation. (2010). *Grain Monitoring Program Dashboard Q3 2009-2010 Crop Year*. Retrieved March 10, 2011 from the World Wide Web from: http://quorumcorp.net/

Ronen, D. (1986). Short-Tem Scheduling of Vessels for Shipping Bulk or Semi-Bulk Commodities Originating in a Single Area. *Operations Research*, 34(1):164-173.

Nolan, J. & Rosaasen, K. (2011). July 20. Personal interview.

Saskatchewan Ministry of Agriculture. (2009). Canadian Wheat Board Final Price for Wheat, basis in store Saskatoon. *Statistics(10.03)*. Retrieved October 3, 2010 from the World Wide Web from: http://www.agriculture.gov.sk.ca/Default.aspx?DN=d044a25c-9c11-4927-b275-74668172ee2c.

Saskatchewan Trucking Association. (2008). *Newsletter.* Retrieved July 26, 2011 from the World Wide Web from: http://www.sasktrucking.com/forms/decembernewsletter.pdf

Schoney, R. (2011). January 16. Personal interview.

Sharkey, W. W., & Sibley, D. S. (1993). A Bertrand model of pricing and entry. *Economics Letters*, 41:199-206.

Simmons-Boardman Publishing Corporation. (2008). *Locomotive leasing: what's power worth today?* Retrieved May 7, 2011 from the World Wide Web from: http://findarticles.com/p/articles/mi_m1215/is_6_209/ai_n27944848/pg_3/?tag=mantle_skin;content

Statistics Canada. (2006). *Farms classified by farm type (NAICS classification).* 2006 Census of Agriculture.

Statistics Canada. (2006). Saskatchewan Farm Stocks 1980 to 2006. CANSIM using CHASS.

Statistics Canada. (2007). Historical Crop Data 1976-2006. November 2006 Crop Survey.

Stigler, G. J. (1949). A Theory of Delivered Price Systems. *The American Economic Review*, 39(6):1144-1159.

Storey, G. (2006). Grain Handling and Transportation System. The Encyclopedia of Saskatchewan. Retrieved September 6, 2011 from the World Wide Web from: http://esask.uregina.ca/entry/grain_handling_and_transportation_system.html

Teamsters Canada Rail Conference. (2009). CN over, CPR under grain revenue caps: CTA. Retrieved September 6, 2011 from the World Wide Web: http://www.teamstersrail.ca/TCRC_News_December_31_2009.htm

Tesfatsion, L. (2006). *Agent based computational economics: A constructive approach to economic theory.* Iowa State University, Department of Economics. Retrieved June 24, 2010 from the World Wide Web from: http://www2.econ.iastate.edu/tesfatsi/hbintlt.pdf

Tougas, F. (2006). Shippers vs. Railroads: A Canadian Pespective. *Journal of Transportation Law, Logistics & Policy*, 73(2):220-246.

University of Saskatchewan. (2007). *Census Agricultural Regions, 2006: Boundary Files*. Retrieved September 15, 2010, from University of Saskatchewan Directory: http://datalib.usask.ca/dli/agriculture/agcensus/2006/cars/

van Dam, K. H., Lukszo, Z., Ferreira, L., & Sirikijpanichkul, A. (2007). Planning the location of intermodal freight hubs: an agent based approach. *Proceedings of the 2007 IEEE International Conference on Networking, Sensing and Control* (pp. 187-192). London, UK: IEEE.

Vercammen, J. (1996). The freight rate setting process. *The Economics of Western Grain Transportation and Handling. Module B-2.* Van Vliet Publication Series.

Vercammen, J. (2001). Trucking fuel taxes and economic efficiency in primary grain transportation. *Journal of Agricultural and Resource Economics*, 26(2):523-538.

Vercammen, J., & Fulton, M. (1996). Price competition in the setting of elevator tariffs: Module E-1. In *The Economics of Western Grain Transportation and Handling.* Van Vliet Publication Series.

Vercammen, J., Fulton, M., & Gray, R. (1996). *Where do we go from here? The economics of western grain transportation and handling: Module D-2.* Van Vliet Publication Series.

Waiser, B. (2005). *Saskatchewan: A New History*. Markham: Fifth House.

Western Grains Research Foundation. (2011). Endowment Fund: Railway Revenue Cap Overages. Retrieved September 6, 2011 from the World Wide Web from: http://www.westerngrains.com/index.asp?id=133&gfx=&ts=0

Weyburn Inland Terminal. (2011). *Dial-a-Truck Rates*. Retrieved March 13, 2011, from the World Wide Web from: http://www.wit.ca/index.php/Rates.html

Whitacre, R., & Spaulding, A. (2007). Grain marketing tools: A survery of Illinois grain elevators. *American Agricultural Economics Association Meeting.*

Wikipedia. (2011). *Demurrage*. Retrieved May 2, 2011 from the World Wide Web from: http://en.wikipedia.org/wiki/Demurrage

Wilensky, U. (1999). NetLogo. Center for Connected Learning and Computer-Based Modeling.

Williams, J. L. (2011). *Oil Price History and Analysis*. Retrieved July 26, 2011 from the World Wide Web from: http://www.wtrg.com/prices.htm

Wilson, W., Dahl, B., & Carlson, D. (1998). *Logistical strategies and risks in Canadian grain marketing Report No. 408.* North Dakota State University: Department of Agricultural Economics.

APPENDIX A

Primary and Process Elevators

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

Primary Elevators in Saskatchewan as of August 2009						
Company	License	CN (tonnes)	CP (tonnes)	NONE (tonnes)	Other (tonnes)	Total
ADM Agri-Industries Company	Primary		15,000			15,000
Bioriginal Food & Science Corp.	Processor			3,400		3,400
Bunge Canada	Primary	57,600				57,600
	Processor		18,750			18,750
Can Pro Ingredients Ltd.	Processor				3,420	3,420
Canada Malting Co. Limited	Primary	13,420				13,420
CanMar Grain Products Ltd.	Processor			230		230
Can-Oat Milling, a Division of Viterra Inc.	Processor	9,500				9,500
Cargill Limited	Primary	234,610	44,450			279,060
	Processor	24,000				24,000
CMI Terminal Joint Venture	Primary		27,220			27,220
Fill-More Seeds Inc.	Primary	5,100	12,320			17,420
Gardiner Dam Terminal Joint Venture	Primary		17,000			17,000
Grain Millers Canada Corp.	Processor	7,530				7,530
Great Sandhills Terminal Marketing Centre Ltd.	Primary		20,800			20,800
Husky Oil Limited	Processor		8,500			8,500
LDM Yorkton Trading LP	Processor		39,000			39,000
Louis Dreyfus Canada Ltd.	Primary	62,680	94,040			156,720
Milligan Bio-Tech Inc.	Processor		1,080			1,080
Mission Terminal Inc.	Primary		3,760			3,760
Mobil Grain Ltd.	Primary				8,560	8,560
Mustard Capital Inc.	Processor		1,000			1,000
North East Terminal Ltd.	Primary		35,920			35,920
North West Terminal Ltd.	Primary	63,000				63,000
Parrish & Heimbecker, Limited	Primary	146,920	94,980			241,900
	Processor	1,500				1,500
Paterson Grain	Primary	14,430	134,250			148,680
	Processor		3,990			3,990
Pound-Maker Agventures Ltd.	Processor		4,500			4,500
Prairie Heritage Seeds Inc.	Primary		1,290			1,290
Prairie Malt Limited	Processor	107,380				107,380
Prairie West Terminal Ltd.	Primary	12,420	50,750			63,170
R Young Seeds Inc.	Primary			8,000		8,000
Richardson Nutrition Holdings Limited	Processor		36,770			36,770
Richardson Pioneer Limited	Primary	204,370	272,120	960	6,970	484,420
RW Organic Ltd.	Primary		7,390			7,390
South West Terminal Ltd.	Primary		52,000			52,000
Terra Grain Fuels Inc.	Processor	38,300				38,300
Viterra Inc.	Primary	506,980	579,390			1,086,370
	Processor		15,760			15,760
Weyburn Inland Terminal Ltd.	Primary		105,500	2,400		107,900
Wigmore Farms Ltd.	Primary			10,000		10,000
Total		1,509,740	1,697,530	24,990	18,950	3,251,210

(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.

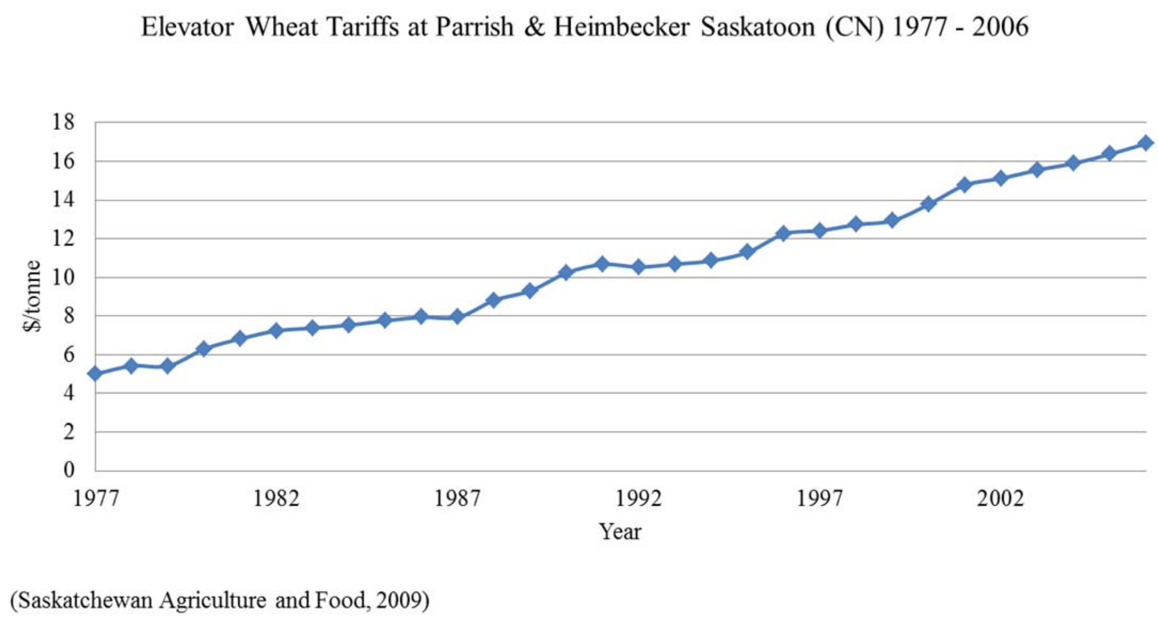


Figure A.1. Elevator wheat tariffs at Parrish & Heimbecker Saskatoon (CN) 1997 to 2006

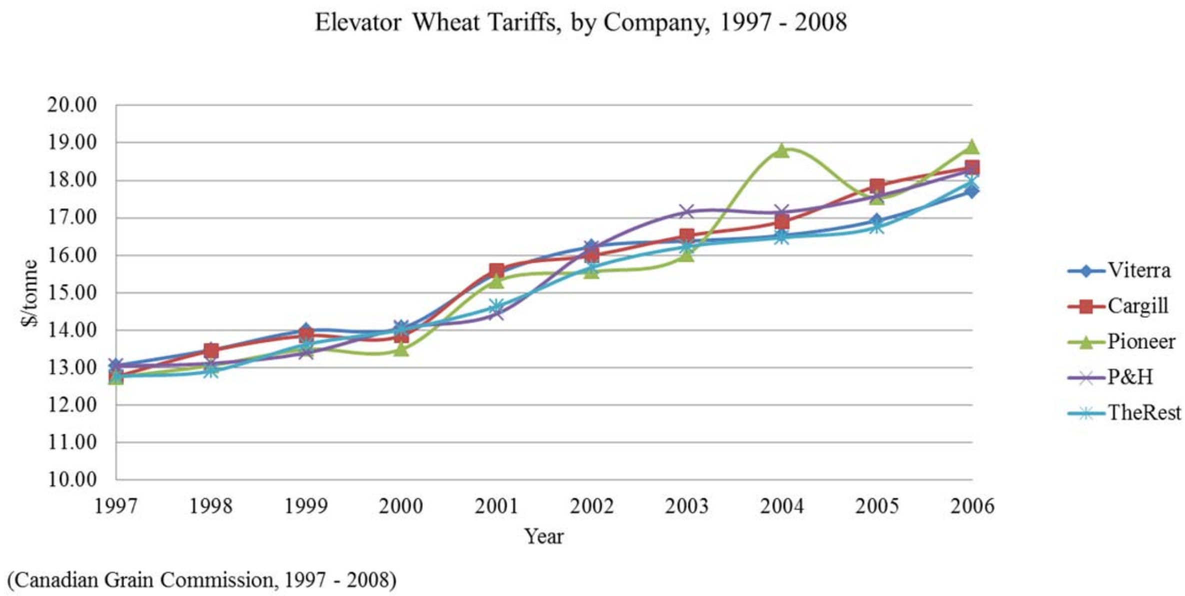


Figure A.2. Elevator wheat tariffs by company, 1997 to 2008

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

Parrish & Heimbecker Wheat Tariff Rates Regressed Against Years					
Multiple R	0.993741118				
R Square	0.987521409				
Adjusted R Square	0.987118874				
Standard Error	0.452295427				
Observations	33				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	-805.0548217	16.47159662	-48.87533615	6.65143E-31	
Year	0.409555481	0.008268779	49.53034354	4.4247E-31	
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	501.8651912	501.8651912	2453.254931	4.4247E-31
Residual	31	6.34170576	0.204571154		
Total	32	508.206897			

Table A.3. Elevator wheat tariffs by company, 1977 to 2006

Year	Viterra	Cargill Ltd	Pioneer Grain	Parrish & Heimbecker	The Rest
			$ / Tonne		
1977	*4.64*	*4.64*	*4.64*	*4.64*	*4.64*
1978	*5.05*	*5.05*	*5.05*	*5.05*	*5.05*
1979	*5.46*	*5.46*	*5.46*	*5.46*	*5.46*
1980	*5.87*	*5.87*	*5.87*	*5.87*	*5.87*
1981	*6.27*	*6.27*	*6.27*	*6.27*	*6.27*
1982	*6.68*	*6.68*	*6.68*	*6.68*	*6.68*
1983	*7.09*	*7.09*	*7.09*	*7.09*	*7.09*
1984	*7.50*	*7.50*	*7.50*	*7.50*	*7.50*
1985	*7.91*	*7.91*	*7.91*	*7.91*	*7.91*
1986	*8.32*	*8.32*	*8.32*	*8.32*	*8.32*
1987	*8.73*	*8.73*	*8.73*	*8.73*	*8.73*
1988	*9.14*	*9.14*	*9.14*	*9.14*	*9.14*
1989	*9.55*	*9.55*	*9.55*	*9.55*	*9.55*
1990	*9.96*	*9.96*	*9.96*	*9.96*	*9.96*
1991	*10.37*	*10.37*	*10.37*	*10.37*	*10.37*
1992	*10.78*	*10.78*	*10.78*	*10.78*	*10.78*
1993	*11.19*	*11.19*	*11.19*	*11.19*	*11.19*
1994	*11.60*	*11.60*	*11.60*	*11.60*	*11.60*
1995	*12.01*	*12.01*	*12.01*	*12.01*	*12.01*
1996	*12.42*	*12.42*	*12.42*	*12.42*	*12.42*
1997	13.06	12.76	12.75	13.05	12.77
1998	13.47	13.45	13.06	13.12	12.91
1999	13.99	13.85	13.49	13.39	13.62
2000	14.06	13.85	13.49	14.06	14.02
2001	15.51	15.60	15.31	14.44	14.64
2002	16.23	15.99	15.56	16.18	15.68
2003	16.38	16.52	16.01	17.15	16.23
2004	16.53	16.90	18.80	17.15	16.47
2005	16.93	17.85	17.53	17.58	16.75
2006	17.71	18.35	18.90	18.28	17.97
	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.

APPENDIX C

Railways

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

	CN		CP	
	Adj. R^2	*$ / tonne / km*	*Adj.* R^2	*$ / tonne / km*
2005	0.975	0.0209	0.981	0.0218
2006	0.975	0.0228	0.981	0.0236
2007	0.975	0.0229	0.976	0.0227
2008	0.975	0.0244	0.981	0.0260

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 C.2. Rail freight rates to Vancouver in $ per tonne, Aberdeen to Landis, CN, 2005 to 2008

Station	Rwy	Rail Rate to Vancouver ($/tonne)				Distance to Vancouver (km)
		2005	2006	2007	2008	
Aberdeen	CN	39.09	42.67	42.91	45.68	1,752
Amazon	CN	39.76	43.39	43.67	46.44	1,815
Balcarres	CN	41.85	45.68	45.92	48.70	2,059
Biggar	CN	36.93	40.31	40.53	43.31	1,613
Birch Hills	CN	40.47	44.17	44.40	47.17	1,985
Booth	CN	41.15	44.91	45.16	47.93	1,871
Brada	CN	36.24	39.56	39.77	42.53	1,607
Bruno	CN	39.76	43.39	43.62	46.39	1,805
Canora	CN	43.92	47.93	48.19	50.96	2,036
Carrot River	CN	43.23	47.19	47.44	50.22	2,011
Clavet	CN	38.32	41.82	42.08	44.84	1,729
Davidson	CN	39.09	42.67	42.90	45.67	1,813
Dixon	CN	40.47	44.17	44.40	47.17	1,829
Elrose	CN	38.68	42.22	42.44	45.21	2,028
Fairlight	CN	43.24	47.20	47.44	50.22	2,412
Glenavon	CN	41.15	44.91	45.16	47.93	2,307
Hague	CN	39.09	42.67	42.90	45.67	1,749
Hamlin	CN	36.24	39.56	39.77	42.53	1,605
Humboldt	CN	40.47	44.17	44.40	47.17	1,836
Ituna	CN	42.53	46.42	46.68	49.44	1,959
Kamsack	CN	44.61	48.68	48.93	51.70	2,076
Kegworth	CN	41.15	44.91	45.16	47.93	2,316
Kindersley	CN	37.96	41.43	41.66	44.42	1,943
Kipling	CN	41.85	45.68	45.92	48.70	2,345
Kyle	CN	38.77	42.31	42.54	45.31	2,066
Lake Lenore	CN	41.14	44.90	45.14	47.92	1,862
Landis	CN	36.24	39.56	39.77	42.53	1,576

Table C.3. Rail freight rates to Vancouver in $ per tonne, Langbank to Yorkton, CN, 2005 to 2008

Station	Rwy	Rail Rate to Vancouver ($/tonne)				Distance to Vancouver (km)
		2005	2006	2007	2008	
Langbank	CN	42.52	46.41	46.67	49.44	2,369
Lloydminster	CN	34.17	37.29	37.50	40.28	1,585
Marengo	CN	37.96	41.43	41.66	44.42	1,891
Marshall	CN	34.17	37.29	37.50	40.28	1,479
Melfort	CN	41.84	45.67	45.91	48.69	1,923
Melville	CN	43.92	47.93	48.19	50.96	2,016
Nicklen	CN	42.53	46.42	46.68	49.44	1,974
Norquay	CN	45.29	49.43	49.70	52.48	2,103
N. Battleford	CN	36.24	39.56	39.77	42.53	1,600
Quill Lake	CN	41.85	45.68	45.92	48.70	1,899
Raymore	CN	41.15	44.91	45.16	47.93	1,879
Regina	CN	39.10	42.68	42.90	45.68	2,150
Rhein	CN	44.61	48.68	48.92	51.70	2,078
Rowatt	CN	40.15	43.82	44.04	46.82	2,176
Saskatoon	CN	38.32	41.82	42.07	44.84	1,700
Shellbrook	CN	39.09	42.67	42.89	45.67	1,761
Tisdale	CN	42.53	46.42	46.67	49.44	1,970
Turtleford	CN	37.62	41.06	41.28	44.06	1,686
Valparaiso	CN	42.53	46.42	46.68	49.44	1,960
Wadena	CN	42.52	46.19	46.43	49.21	2,050
Wakaw	CN	40.47	44.17	44.40	48.28	1,837
Waldron	CN	43.92	47.93	48.19	50.96	2,040
Watrous	CN	39.76	43.39	43.62	46.39	1,803
Watson	CN	41.15	44.91	45.16	47.93	1,919
White Star	CN	40.47	44.17	44.40	47.17	1,855
Yorkton	CN	44.61	48.68	48.93	51.70	2,079

Table C.4. Rail freight rates to Vancouver in $ per tonne, Alameda to Moose Jaw, CP, 2005 to 2008

Station	Rwy	Rail Rate to Vancouver ($/tonne)				Distance to Vancouver (km)
		2005	2006	2007	2008	
Alameda	CP	43.03	46.75	43.60	52.33	1,991
Antelope	CP	34.02	36.96	33.93	40.73	1,473
Assiniboia	CP	38.14	41.44	38.05	45.67	1,710
Balgonie	CP	39.59	43.02	39.52	47.42	1,790
Brass	CP	35.06	38.09	34.98	41.98	1,614
Cabri	CP	35.39	38.45	35.31	42.37	1,566
Carievale	CP	43.70	47.48	43.60	52.33	2,044
Carnduff	CP	43.70	47.48	43.60	52.33	2,031
Congress	CP	38.14	41.44	38.05	45.67	1,725
Coronach	CP	39.59	43.02	39.52	47.42	1,800
Creelman	CP	40.96	44.51	41.55	49.86	1,887
Cupar	CP	40.96	44.51	40.88	49.05	2,026
Dodsland	CP	35.39	38.45	35.31	42.37	1,606
Estevan	CP	41.64	45.24	41.55	49.86	1,936
Eyebrow	CP	38.91	42.27	38.82	46.59	1,767
Fillmore	CP	40.96	44.51	41.55	49.86	1,876
Grenfell	CP	40.96	44.51	41.55	49.86	1,844
Gull Lake	CP	34.02	36.96	33.93	40.73	1,459
Herbert	CP	35.39	38.45	35.32	42.38	1,565
Hodgeville	CP	38.14	41.44	38.05	45.67	1,787
Indian Head	CP	40.29	43.78	40.21	48.25	1,837
Kelvington	CP	45.09	49.00	42.65	51.18	2,094
Lang	CP	39.59	43.02	40.21	48.25	1,797
Langenburg	CP	45.85	49.82	45.75	54.90	2,147
Last Mountain	CP	40.96	44.51	40.88	49.05	2,002
Leader	CP	36.22	39.35	36.14	43.37	1,654
Limerick	CP	37.46	40.70	37.02	44.43	1,690
Luseland	CP	34.99	38.02	34.90	41.88	1,553
Maple Creek	CP	32.64	35.47	32.57	39.09	1,380
Moose Jaw	CP	37.46	40.70	37.37	44.85	1,697

Table C.5. Rail freight rates to Vancouver in $ per tonne, Moosomin to Yorkton, CP, 2005 to 2008

Station	Rwy	Rail Rate to Vancouver ($/tonne)				Distance to Vancouver (km)
		2005	2006	2007	2008	
Moosomin	CP	43.03	46.75	42.93	51.52	1,940
Morse	CP	36.10	39.23	35.32	42.38	1,579
Mortlach	CP	36.76	39.94	35.32	42.38	1,657
Mossbank	CP	38.14	41.44	38.05	45.67	1,760
Naicam	CP	40.95	44.50	40.87	49.04	1,952
Neville	CP	35.39	38.45	35.78	42.93	1,566
Nokomis	CP	40.69	44.21	40.60	48.73	1,913
Osage	CP	40.73	44.25	49.86	49.86	1,863
Parkbeg	CP	36.76	39.94	42.38	42.38	1,642
Plenty	CP	35.96	39.07	42.37	42.37	1,618
Prairie West	CP	35.39	38.45	42.37	42.37	1,518
Prelate	CP	36.22	39.35	43.37	43.37	1,643
Redvers	CP	45.09	49.00	53.99	53.99	2,198
Reed Lake	CP	35.40	38.46	42.38	42.38	1,565
Rockhaven	CP	36.09	39.22	43.23	43.23	1,719
Rosetown	CP	37.79	41.06	45.24	45.24	2,028
Saskatoon	CP	38.52	41.85	46.11	46.11	1,740
Stoughton	CP	41.64	45.24	49.86	49.86	1,913
Swift Current	CP	34.71	37.71	41.55	41.55	1,518
Tisdale	CP	42.75	46.45	51.18	51.18	2,154
Tribune	CP	43.03	46.75	51.52	51.52	2,002
Wadena	CP	42.74	46.43	42.65	51.18	1,935
Weyburn	CP	40.29	43.78	40.21	48.25	1,847
Whitewood	CP	41.64	45.24	41.55	49.86	1,892
Wilcox	CP	38.91	42.27	38.82	46.59	1,766
Wilkie	CP	35.06	38.09	34.98	41.98	1,603
Wolseley	CP	40.96	44.51	40.21	48.25	1,820
Yellow Grass	CP	39.59	43.02	40.21	48.25	1,818
Yorkton	CP	44.84	48.72	44.75	53.69	2,058

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

Year	Base Freight Rate	CN Rail Rate, in $/t/km	CP Rail Rate, in $/t/km
	$ / tonne	$ / tonne / km	
1977	4.85	0.0032	0.0034
1978	4.85	0.0032	0.0034
1979	4.85	0.0032	0.0034
1980	4.85	0.0032	0.0034
1981	4.85	0.0032	0.0034
1982	4.85	0.0032	0.0034
1983	5.33	0.0035	0.0037
1984	7.57	0.0050	0.0052
1985	5.90	0.0039	0.0041
1986	5.87	0.0039	0.0041
1987	6.23	0.0041	0.0043
1988	7.15	0.0047	0.0049
1989	8.86	0.0058	0.0060
1990	10.03	0.0066	0.0068
1991	10.37	0.0068	0.0070
1992	11.23	0.0074	0.0076
1993	12.86	0.0085	0.0087
1994	13.37	0.0088	0.0090
1995	33.01	0.0194	0.0196
1996	35.37	0.0208	0.0210
1997	36.08	0.0212	0.0214
1998	35.67	0.0210	0.0212
1999	35.74	0.0210	0.0212
2000	34.31	0.0202	0.0204
2001	35.68	0.0210	0.0212
2002	37.11	0.0218	0.0220
2003	37.85	0.0223	0.0225
2004	35.65	0.0210	0.0212
2005	38.52	0.0227	0.0221
2006	41.85	0.0246	0.0241

APPENDIX D

Wheat Production and Prices

Table D.1. Wheat prices and production, 1977 to 2006

Year	Durum Wheat (T)	Average Durum Price ($ / T)	Winter Wheat (T)	Total Spring Wheat (T)	Subtotal Winter + Spring (T)	Average RSW Price ($ / T)	Total Wheat (T)
1977	1,088,600	126.49		11,757,100	11,757,100	113.76	11,759,077
1978	2,313,300	147.13		11,294,400	11,294,400	154.15	11,296,378
1979	1,469,600	203.01		8,736,200	8,736,200	187.75	8,738,179
1980	1,687,400	236.81		9,253,300	9,253,300	216.50	9,255,280
1981	2,286,100	194.96	40,800	11,961,200	12,002,000	194.80	11,963,181
1982	2,558,300	182.46	87,100	13,792,800	13,879,900	186.71	13,794,782
1983	2,068,400	199.04	127,900	13,017,200	13,145,100	187.59	13,019,183
1984	1,632,900	193.30	244,900	9,607,100	9,852,000	180.66	9,609,084
1985	1,388,000	170.94	498,000	10,967,900	11,465,900	153.47	10,969,885
1986	2,966,500	145.32	462,700	14,941,300	15,404,000	121.47	14,943,286
1987	3,075,400	156.82	228,600	11,906,800	12,135,400	125.89	11,908,787
1988	1,360,800	201.49	54,400	5,443,100	5,497,500	190.15	5,445,088
1989	3,048,100	155.11	68,000	9,661,500	9,729,500	167.11	9,663,489
1990	3,252,300	128.22	81,600	14,152,100	14,233,700	127.14	14,154,090
1991	3,619,700	131.96	49,000	14,832,500	14,881,500	128.01	14,834,491
1992	2,558,300	152.26	26,100	13,607,800	13,633,900	150.67	13,609,792
1993	2,721,600	222.19	35,400	12,274,200	12,309,600	154.10	12,276,193
1994	3,701,300	258.62	25,900	8,383,700	8,409,600	188.38	8,385,694
1995	3,674,100	276.46	65,300	8,924,100	8,989,400	250.98	8,926,095
1996	3,755,700	240.80	95,300	12,696,000	12,791,300	203.23	12,697,996
1997	3,510,800	270.07	62,600	9,496,800	9,559,400	185.36	9,498,797
1998	4,749,100	192.26	76,200	8,088,300	8,164,500	177.80	8,090,298
1999	3,407,400	195.76	95,300	10,336,800	10,432,100	161.83	10,338,799
2000	4,757,300	227.77	182,300	8,593,000	8,775,300	170.89	8,595,000
2001	2,476,600	249.37	178,300	7,195,900	7,374,200	199.09	7,197,901
2002	2,830,400	255.19	103,400	4,236,100	4,339,500	226.00	4,238,102
2003	3,211,400	216.20	144,200	7,077,400	7,221,600	197.69	7,079,403
2004	3,946,300	185.78	171,500	8,143,400	8,314,900	174.71	8,145,404
2005	4,878,400	161.68	185,100	8,678,800	8,863,900	163.13	8,680,805
2006	3,129,800	210.26	275,700	9,076,800	9,352,500	199.67	9,078,806

(Canadian Wheat Board, 2010)

Table D.2. Adjusted wheat prices, 1977 to 2006

Year	Total Wheat (T)	Durum % of Total Wheat	Spr + Win % of Total Wheat	Check	Price to Use in Model ($ / T)	Farm Product Price Index SK Grains (1997 = 100)	Prices adjusted for inflation ($ / T)
1977	12,845,700	0.08	0.92	1.00	114.84	69.6	79.93
1978	13,607,700	0.17	0.83	1.00	152.95	76	116.24
1979	10,205,800	0.14	0.86	1.00	189.95	95.9	182.16
1980	10,940,700	0.15	0.85	1.00	219.63	119.8	263.12
1981	14,288,100	0.16	0.84	1.00	194.83	123.1	239.83
1982	16,438,200	0.16	0.84	1.00	186.05	111.9	208.19
1983	15,213,500	0.14	0.86	1.00	189.15	108.2	204.66
1984	11,484,900	0.14	0.86	1.00	182.46	111.6	203.63
1985	12,853,900	0.11	0.89	1.00	155.36	101.5	157.69
1986	18,370,500	0.16	0.84	1.00	125.32	79.7	99.88
1987	15,210,800	0.20	0.80	1.00	132.14	70.1	92.63
1988	6,858,300	0.20	0.80	1.00	192.40	90.1	173.35
1989	12,777,600	0.24	0.76	1.00	164.24	104.4	171.47
1990	17,486,000	0.19	0.81	1.00	127.34	85.9	109.39
1991	18,501,200	0.20	0.80	1.00	128.78	71.4	91.95
1992	16,192,200	0.16	0.84	1.00	150.92	74.3	112.13
1993	15,031,200	0.18	0.82	1.00	166.43	77.1	128.31
1994	12,110,900	0.31	0.69	1.00	209.85	89.5	187.81
1995	12,663,500	0.29	0.71	1.00	258.37	119.7	309.27
1996	16,547,000	0.23	0.77	1.00	211.76	119.6	253.27
1997	13,070,200	0.27	0.73	1.00	208.12	100	208.12
1998	12,913,600	0.37	0.63	1.00	183.12	97.8	179.09
1999	13,839,500	0.25	0.75	1.00	170.18	87.6	149.08
2000	13,532,600	0.35	0.65	1.00	190.88	86.1	164.35
2001	9,850,800	0.25	0.75	1.00	211.73	100.1	211.94
2002	7,169,900	0.39	0.61	1.00	237.52	115.3	273.87
2003	10,433,000	0.31	0.69	1.00	203.39	108.4	220.47
2004	12,261,200	0.32	0.68	1.00	178.27	93.3	166.33
2005	13,742,300	0.35	0.65	1.00	162.62	73.7	119.85
2006	12,482,300	0.25	0.75	1.00	202.32	83.9	169.75

(Canadian Wheat Board, 2010)

Table D.3. Saskatchewan Wheat Production in Tonnes, CAR 1A to 3BN, 1977 to 2006

	Wheat Production in Tonnes						
	Census Agricultural Region						
	1A	1B	2A	2B	3AN	3AS	3BN
1977	525,900	531,200	658,800	1,039,500	869,900	465,200	581,800
1978	736,200	583,700	753,800	989,000	1,025,400	518,600	591,600
1979	466,100	270,300	435,300	685,600	675,300	371,300	581,900
1980	499,000	363,900	383,000	596,600	671,000	385,800	569,200
1981	647,700	556,300	580,100	883,800	686,000	416,800	589,100
1982	660,300	544,900	679,900	1,039,200	992,200	588,400	718,300
1983	597,700	548,500	574,100	945,100	765,400	491,300	591,500
1984	507,000	459,900	369,900	765,000	504,500	300,300	336,600
1985	659,700	652,400	386,400	879,800	228,500	291,000	151,900
1986	1,057,900	821,300	1,015,400	1,385,800	1,115,300	575,000	735,000
1987	845,900	679,600	714,200	1,041,000	1,008,800	564,500	755,000
1988	405,400	425,200	296,800	489,800	443,700	159,200	275,200
1989	467,200	473,300	454,600	898,200	734,300	507,400	757,200
1990	1,022,500	942,700	869,500	1,230,100	1,068,500	649,000	741,500
1991	605,600	693,800	745,100	1,070,000	1,123,700	594,200	818,800
1992	994,300	654,600	881,200	1,219,500	1,104,400	553,400	625,700
1993	813,500	480,400	794,700	881,500	641,000	1,096,500	1,086,800
1994	620,000	297,300	633,500	817,400	508,200	896,400	816,700
1995	581,955	290,111	617,374	885,387	602,300	1,014,048	937,062
1996	701,263	495,982	784,001	1,118,767	708,016	1,155,581	1,255,763
1997	475,350	411,078	447,692	819,183	566,789	892,733	1,064,834
1998	513,059	363,231	544,848	857,164	475,955	923,462	984,752
1999	282,102	257,623	340,225	710,474	577,626	996,165	1,040,802
2000	609,951	444,197	465,394	822,988	474,837	972,565	988,101
2001	486,371	467,585	438,428	681,140	379,042	681,037	528,891
2002	421,397	360,381	424,874	748,799	345,805	681,673	463,842
2003	386,775	336,349	328,793	640,786	278,491	522,674	640,265
2004	397,127	295,810	384,804	515,074	472,582	668,053	975,989
2005	408,161	323,111	552,110	797,429	425,890	767,393	1,088,560
2006	632,752	410,899	486,540	892,211	375,583	643,350	876,637

(Statistics Canada, 2007)

Table D.4. Saskatchewan Wheat Production in Tonnes, CAR 3BS to 7A, 1977 to 2006

	Wheat Production in Tonnes							
	Census Agricultural Region							
	3BS	4A	4B	5A	5B	6A	6B	7A
1977	930,100	216,200	354,600	938,100	782,400	1,166,500	776,000	764,900
1978	831,300	268,100	432,000	1,012,700	908,500	1,164,600	727,600	859,100
1979	761,300	287,500	477,700	443,700	451,200	810,500	665,300	835,100
1980	733,400	270,600	420,900	665,700	745,400	838,800	600,900	742,300
1981	884,100	299,200	481,400	1,215,500	1,242,700	1,137,100	777,500	871,100
1982	1,063,600	335,800	566,200	1,043,400	1,034,300	1,474,200	1,072,000	1,088,300
1983	978,300	364,500	535,200	994,800	910,300	1,338,200	1,032,400	1,133,500
1984	663,300	162,900	339,500	1,007,500	1,032,700	917,300	662,900	756,900
1985	418,400	84,500	234,800	1,357,600	1,274,900	1,387,400	849,100	680,400
1986	1,081,800	470,900	546,800	1,301,600	1,005,800	1,555,100	1,042,200	1,183,100
1987	912,200	394,700	426,600	1,024,900	862,200	1,419,500	887,900	853,100
1988	259,700	183,900	126,100	635,500	548,100	430,700	212,800	280,300
1989	875,300	366,500	291,900	869,500	893,100	1,070,600	720,900	737,800
1990	1,038,300	375,100	174,400	1,293,000	1,071,100	1,455,400	1,108,200	731,700
1991	1,225,100	386,500	716,500	1,316,200	1,211,100	1,673,800	1,212,000	1,103,200
1992	977,700	292,300	586,300	957,300	997,200	1,462,200	1,050,400	929,000
1993	712,000	380,500	677,800	793,900	657,700	1,172,200	912,000	1,042,900
1994	608,600	322,900	588,000	625,000	571,000	956,100	680,800	862,700
1995	653,364	438,642	712,748	527,823	687,334	879,826	690,535	879,040
1996	609,399	342,225	716,138	856,630	890,023	1,221,457	1,119,287	1,118,054
1997	648,337	288,042	591,316	633,714	803,571	999,331	710,454	955,839
1998	688,026	386,044	645,399	558,243	667,532	1,016,561	625,014	926,174
1999	631,887	328,430	693,670	621,576	774,418	1,114,454	811,751	954,780
2000	631,860	280,938	582,908	732,770	753,672	1,080,506	779,595	797,049
2001	397,396	155,829	248,547	627,806	707,087	547,274	512,047	342,199
2002	513,573	233,419	312,224	552,418	558,868	543,267	281,612	90,779
2003	454,039	240,334	472,285	572,868	740,875	890,788	547,700	639,585
2004	642,565	319,315	630,061	647,904	604,400	686,717	870,590	827,263
2005	592,395	341,632	681,878	624,405	662,618	819,125	920,095	1,090,880
2006	381,342	175,899	566,681	630,121	795,675	805,399	795,905	844,287

(Statistics Canada, 2007)

Table D.5. Saskatchewan Wheat Production in Tonnes, CAR 7B to 9B, 1977 to 2006

	Wheat Production in Tonnes					
	Census Agricultural Region					
	7B	8A	8B	9A	9B	Total
1977	495,300	397,000	578,100	484,100	290,200	12,845,800
1978	515,600	413,500	574,300	437,900	264,200	13,607,800
1979	649,300	255,600	412,200	368,500	302,100	10,205,800
1980	583,500	476,400	507,900	538,200	348,400	10,940,600
1981	725,700	568,000	606,100	703,100	417,700	14,289,000
1982	824,200	504,000	867,400	754,900	586,700	16,438,000
1983	778,900	388,100	828,400	754,600	662,700	15,213,500
1984	562,000	225,000	673,400	662,900	575,200	11,485,000
1985	662,700	303,000	897,800	826,500	627,200	12,854,000
1986	1,006,400	289,400	680,000	768,600	732,500	18,370,200
1987	702,000	292,600	580,700	687,000	558,200	15,210,800
1988	413,300	161,900	269,700	430,300	410,800	6,858,300
1989	509,100	361,800	549,200	697,100	542,700	12,777,700
1990	766,600	538,300	861,400	956,000	592,600	17,486,000
1991	825,900	688,900	887,700	869,200	570,900	18,339,700
1992	645,400	425,900	711,100	672,500	451,700	16,192,100
1993	693,800	319,600	597,300	725,100	551,900	15,031,100
1994	577,500	343,400	536,900	452,700	395,700	12,110,900
1995	461,333	416,217	608,270	505,495	274,559	12,663,500
1996	848,684	451,813	795,941	762,644	595,890	16,547,000
1997	602,835	495,142	618,761	558,212	486,611	13,070,200
1998	525,251	526,943	635,484	687,435	363,103	12,913,600
1999	846,536	671,154	746,820	864,221	574,316	13,839,500
2000	656,327	665,435	647,907	647,019	498,445	13,532,600
2001	681,948	505,717	444,828	571,407	446,447	9,850,800
2002	136,029	170,011	152,112	145,719	32,838	7,169,900
2003	533,613	551,241	736,948	564,285	354,278	10,433,000
2004	729,166	532,775	650,624	670,590	739,754	12,261,200
2005	762,514	616,109	763,284	834,037	670,692	13,742,300
2006	698,374	495,504	656,755	735,504	583,186	12,482,300

(Statistics Canada, 2007)

APPENDIX E

NetLogo© Source Code (version 4.1.2)

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



;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;DEFINE VARIABLES;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


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-prod3an-list
  wheat-prod3as-list
  wheat-prod3bn-list
  wheat-prod3bs-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-freightrate-list
  cp-freightrate-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
]

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;INITIALIZATION PHASE CONTROL;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

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


  set viterra-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad
School\\Thesis\\Running Model\\Input\\Elevator Shapefiles\\SK_Viterra.shp"
  set pioneer-dataset gis:load-dataset "C:\\Users\\Russell\\Documents\\Grad
School\\Thesis\\Running Model\\Input\\Elevator Shapefiles\\SK_Pioneer.shp"
  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
```

```
    ]

  end

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
```

```
            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
```

```
                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
```

```
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

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


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
                 [setxy 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
                 [setxy 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
                 [setxy 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 pxcor 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 pxcor pycor
                  set grain-inventory random-normal farmer-start-inventory farmer-
start-inv-stdv]
                 [find-new-spot4A]

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 pxcor pycor
                  set grain-inventory random-normal farmer-start-inventory farmer-
start-inv-stdv]
                 [find-new-spot4B]]]
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 pxcor pycor
```

```
                 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


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
```

```
                 [setxy pxcor pycor
                  set grain-inventory random-normal farmer-start-inventory farmer-
start-inv-stdv]
                 [find-new-spot5B]]]
end


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

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


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
                 [setxy 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
                 [setxy 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
                 [setxy 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

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
```

```
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
                 [setxy 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

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;SIMULATION PHASE CONTROL;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


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
```

```
 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

end


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)]]
```

```
        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 [

               ifelse 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([xcor] 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 [rail-quantity] of best-railAgent
                  set elevator-inventory elevator-inventory - elevator-delivery-to-
rail2]
                 [set elevator-delivery-to-rail2 elevator-inventory
                  set elevator-inventory elevator-inventory - elevator-inventory]

            set shortage [rail-quantity] of best-railAgent - elevator-delivery-to-
rail2

end


to rail-take-delivery
```

```
     ask all-elevators [
       ask best-railAgent [
           set rail-delivery [elevator-delivery-to-rail] of myself + [elevator-
delivery-to-rail2] of myself]
     ]

     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-deliveryCG (sum [elevator-delivery-to-rail] of elevatorCGs + sum
[elevator-delivery-to-rail2] of elevatorCGs)
     set port-deliveryTR (sum [elevator-delivery-to-rail] of elevatorTRs + sum
[elevator-delivery-to-rail2] of elevatorTRs)
     set port-deliveryPH (sum [elevator-delivery-to-rail] of elevatorPHs + sum
[elevator-delivery-to-rail2] of elevatorPHs)
     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

     set elevatorTR-ship-portion monthly-ship-tonnage * 0.25    ;; TheRest elevators
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-costCG (elevator-delivery-to-rail * [rail-rate] of best-railAgent)
                          + (elevator-delivery-to-rail2 * [rail-rate] of best-
railAgent)
      set elevator-incomeCG elevator-revenueCG - elevator-costCG

 ]

  ask elevatorTRs [
      set elevator-revenueTR (elevator-basis * elevator-delivery) + (elevator-basis2
* elevator-delivery2)
      set elevator-costTR (elevator-delivery-to-rail * [rail-rate] of best-railAgent)
                          + (elevator-delivery-to-rail2 * [rail-rate] of best-
railAgent)
      set elevator-incomeTR elevator-revenueTR - elevator-costTR

 ]

  ask elevatorPHs [
      set elevator-revenuePH (elevator-basis * elevator-delivery) + (elevator-basis2
* elevator-delivery2)
      set elevator-costPH (elevator-delivery-to-rail * [rail-rate] of best-railAgent)
                          + (elevator-delivery-to-rail2 * [rail-rate] of best-
railAgent)
      set elevator-incomePH elevator-revenuePH - elevator-costPH

 ]

  ask elevatorPNs [
      set elevator-revenuePN (elevator-basis * elevator-delivery) + (elevator-basis2
* elevator-delivery2)
      set elevator-costPN (elevator-delivery-to-rail * [rail-rate] of best-railAgent)
                          + (elevator-delivery-to-rail2 * [rail-rate] of best-
railAgent)
      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-elev2 total-elevator-delivery2
   set total-farmer-inventory (total-farmer-check-inventory1 - total-farmer-del-to-
elev - total-farmer-del-to-elev2)

   export-farmer
   export-elevator
   export-railAgent
   export-observingInfo

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-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 "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-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 "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-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 "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
```

```
                 "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
```

```
                                  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-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
                        spacer elevatorTR-ship-portion spacer port-deliveryTR spacer
elevatorTR-demurr-check spacer elevatorTR-demurrage
                        spacer elevatorPH-ship-portion spacer port-deliveryPH spacer
elevatorPH-demurr-check spacer elevatorPH-demurrage
                        spacer elevatorCG-ship-portion spacer port-deliveryCG spacer
elevatorCG-demurr-check spacer elevatorCG-demurrage
                        spacer elevatorPN-ship-portion spacer port-deliveryPN spacer
elevatorPN-demurr-check spacer elevatorPN-demurrage
                        spacer elevatorVI-ship-portion spacer port-deliveryVI spacer
elevatorVI-demurr-check 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


end
```