2015-08-05

Modeling uncertain demand in wood pellet supply chains: a case study from Northern Ontario

Hughes, Natalie

MODELING UNCERTAIN DEMAND IN WOOD PELLET SUPPLY CHAINS: A CASE STUDY FROM NORTHERN ONTARIO

By:
Natalie Hughes

A Master's Thesis Submitted in
Partial Fulfillment of the Requirements for the
Degree of Master of Science in Forestry

Faculty of Natural Resources Management
Lakehead University
Thunder Bay, ON

May 2, 2014

LIBRARY RIGHTS STATEMENT

Signature:____________________________

Date:______________

A CAUTION TO THE READER

ABSTRACT

Hughes, N. 2014. Handling demand uncertainty in wood pellet supply chains: A case study from Northern Ontario. Lakehead University, Thunder Bay, Ontario. 118 pp.

Keywords: Canada, demand-driven, demand flow inventory policy, demand uncertainty, ENplus certification, forecasting, Industries Lacwood, Ontario, supply chain, value chain, wood pellets.

This thesis aims to enable Canadian wood pellet producers with the opportunity to offer competitive pricing through optimization of their value chains and supply chains, by employing an operational-level decision support tool (DST). Improving the competitiveness of Canada's individual wood pellet manufacturers will ultimately improve Canada's position amidst the rapidly developing global wood pellet market. Primary information is used from a case study of Industries Lacwood (ILW), in Hearst, ON; a firm that produces wood pellets using residue generated from processing of its primary wood items. The specific objectives of this study are to: 1) Determine how to optimize the operations of a wood pellet producer, through a comparison of three different gross margin (GM) optimization models, given uncertain demand conditions. These three models will illustrate why it is important to utilize inventory and a variable production rate, in order to most effectively optimize the GM of a pellet producer, given uncertain consumer demand. 2) Produce 100 demand datasets (to satisfy the Central Limit Theorem) for pellet 1 and pellet 2 and run these datasets through each of the three models created for objective 1. Compare the GM results of the three models and demonstrate why the operational environment specified in model 2 should be used for GM optimization of wood pellet producers, and will be used for further analysis. 3) Generate stochastic demand schedules for pellets by averaging the 100 demand datasets produced for objective 2. Use these stochastic demand schedules as the base case demand input values for model 2, along with other standard input values (obtained from ILW). Benchmark output values of production, inventory and unfulfilled demand generated from these standard inputs are compared with output values of production, inventory and unfulfilled demand generated from the variable inputs of 11 different scenarios. These comparisons will illustrate how model 2 is a comprehensive DST that the operational-level managers of wood pellet producers may use to achieve optimal GMs for the producer, under uncertain demand conditions and with other variable input factors. The results show that the model is most sensitive to fluctuations in demand, supply and inventory holding costs.

CONTENTS

TABLES

FIGURES

ACKNOWLEDGEMENTS

I would like to thank Dr. Chander Shahi for providing me with this M.Sc.F. opportunity and for his unwavering support, kindness and patience throughout each and every stage of my project. Dr. Shahi's mentorship and guidance made the successful completion of this project a reality. I would also like to thank Dr. Reino Pulkki for his steadfast support, kindness, patience and guidance throughout my project as well. Thanks also to Dr. Kevin Crowe for his time and constructive feedback in reviewing this thesis. I would also like to thank Dr. Taraneh Sowlati for her efforts and time as my external examiner for this thesis.

I would like to thank Mr. Normand Lacroix, the founder and owner of Industries Lacwood, for his time, participation and willingness to share information about his company. His contribution provided the necessary foundation to support this entire project. I would also like to thank Denise Lacroix and Bob Thomas, from Industries Lacwood, for their contributions regarding historical sales data; information that was vital for the analyses conducted in this thesis.

A special thanks to Robert Keron, M.Sc.F, for his time and effort dedicated towards the development of the optimization models used for the analyses in this thesis. This project could not have been completed without his assistance. Another special thank-you goes to Dr. Bedarul Alam for the creation of the optimization model used for preliminary analyses in this project. Thank-you to the VCO Network for providing the funding for this project and for creating opportunities to disseminate the results of this research.

Last, but definitely not least, thank-you to my parents, Joan and Michael, my faithful friend Maya, my sister Melanie, and my excellent friends; Shannon, Breanne, Jessika, Pete, Joyce and Melvin for their unconditional love and support, for keeping me motivated, and for pulling me through the muddiest waters of this voyage. I never would have completed this journey without you all!

1 INTRODUCTION

This introduction will begin by explaining why wood pellets have been selected for this study, including their production and characteristics, followed by a discussion of the value chain compared with the supply chain, after which various components of value chain and supply chain management will be examined. Literature gaps will then be identified, followed by an outline of the specific objectives of this thesis.

1.1 WHY WOOD PELLETS?

1.1.1 Industry Perspective

In a time of great uncertainty and drastic change in the global forest products industry, many companies have found it necessary to shift away from manufacturing conventional forest products and focus their attention on value-added forest products, as well as managing waste (wood) more efficiently. Specifically, the creation of renewable fuel sources for the production of energy, such as wood pellets, has become very popular in recent years (Alakangas and Virkkunen 2007; Kennedy *et al.* 2011). Wood pellets have many advantages, including high density and heat value and low moisture content, and are relatively convenient to transport and store (Obernberger and Thek 2010; Rickerson *et al.* 2009). Wood pellets are used for both residential and industrial purposes for the production of heat and/or electricity.

In Canada, many smaller, less efficient pulp mills and sawmills situated in small communities were closed permanently due to the industry's struggle. These mills were the "backbone" of many towns. These communities have turned towards utilization of the wood that has been made available from these closures, to stimulate and revitalize their local economies (Cocchi *et al.* 2011). One way these communities can once again reach economic stability, through operations still within the forestry realm, is to make the shift to value added wood product production, like wood pellets. This shift is conceivable in Ontario, as easier access to this newly freed-up wood supply for smaller industry players now exists because of the *Forest Tenure Modernization Act* of 2011, which calls for the establishment of Local Forest Management Corporations (LFMCs) (Government of Ontario 2011). The purpose of LFMCs is to ensure that "local timber supply will be better aligned with market demand. It will also be easier for entrepreneurs, First Nations and local communities to participate in the forestry industry. . ." (OMNR 2012c).

There has been an increase in global demand for wood pellets and Canada has responded to this increase by exporting large volumes of wood pellets overseas (Peng *et al.* 2010). A number of wood pellet production plants are emerging globally, thereby creating more competition. Canada is currently among the top producers and exporters of wood pellets (Ackom *et al.* 2010; Junginger *et al.* 2008); but, due to this increased competition, Canadian manufacturers must find ways to stay competitive in the global market, specifically addressing uncertain demand. This competitive edge can be achieved by optimizing production and logistics (Mahutga 2012), as well as inventory management (Wadhwa *et al.* 2009) within the supply chain and value chain.

1.1.2 Wood Pellet Production and Characteristics

Wood pellets are made of woody biomass. Raw materials for pelletization in many countries include wood shavings and sawdust from the wood processing industry

(Åsman [n.d.]; Saracoglu and Gunduz 2009; Spelter and Toth 2009). Alakangas and Virkkunen (2007) identified wood fuels as the most commonly used biomass fuels with their production chains becoming well-adopted in the market. Biomass is defined as including all plant and plant-derived materials (including animal manures, animals and algae) that can be considered a part of the present carbon cycle (Van Dyken *et al.* 2010). As such, wood pellets have been deemed carbon neutral, meaning that the amount of carbon released when they are burned (for heat) is equal to the amount of carbon that was removed from the atmosphere, while the plant that their biomass originated from was growing (OPG 2012a). Ontario Power Generation (OPG) (2012a) provides approximately 60% of Ontario's electricity and the biomass used in OPG's programs consists primarily of wood pellets (and agricultural by-products such as grain screenings and milling spoils) that can be burned to generate electricity. Biomass may be a viable large-scale renewable energy source for Ontario. Even Ontario's *Long Term Energy Plan*, *Achieving Balance*, released in December 2013, has finally given recognition to the benefits of using biomass for energy (MOE 2013).

During full-tree harvesting in Northwestern Ontario, approximately 13-14% of the woody biomass is left at roadside in slash piles (Gautam *et al.* 2012). These piles may be salvaged as biomass for the creation of wood pellets. The economic viability of using these slash piles for bioenergy depends primarily on its moisture content (MC). The quality of the slash piles is determined based on their MC, gross calorific value and ash content (Gautam *et al.* 2012). Generally, the research shows that the longer these piles are left to stand, the lower their MC % becomes, thus making them more economically viable as a bioenergy fuel source (Gautam *et al.* 2012).

The basic steps in the pellet production process (from raw materials to pellets) include: i) drying, ii) grinding, iii) conditioning, iv) pelletizing, v) screening for fine separation and vi) packaging/storing of final product (Hansen *et al.* 2009; Mäkelä *et al.* 2011; Tapaninen 2010). To create one tonne of pellets with moisture content between 7 to 10 %, an approximate volume of 7.5 m^3 of sawdust must be processed (at moisture content of 50 %) (Alakangas and Virkkunen 2007; Obernberger and Thek 2010). Once formed and cooled, pellets are either filled automatically into small (usually 40 pound) bags for residential consumers or large bags (i.e., 650 kilograms) for larger customers, or stored in bulk in silos or halls (Hansen *et al.* 2009; Obernberger and Thek 2010). Raw material costs and (when using wet raw materials) drying costs comprise the majority of total pellet production expenses (Åsman [n.d.]; Pirraglia *et al.* 2010; Uasuf and Becker 2011; Wolf *et al.* 2006). As pellet-plant size decreases, production cost increases (Alfonso *et al.* 2009; Gallagher *et al.* 2005).

Densification of wood pellets, as a result of compaction, allows for greater homogeneity of the product, enhanced combustion efficiency and efficient transport and storage (Kaliyan and Morey 2009; Mahapatra *et al.* 2007; Pirraglia *et al.* 2010; Sultana *et al.* 2010). Pa *et al.* (2011) concluded that the combustion of wood pellets requires less primary energy than the combustion of undensified wood waste and that pellets emit lower levels of harmful emissions (i.e., carbon monoxide, nitric oxide and particulate matter) than wood waste. Sultana and Kumar (2012a) used PROMTHEE (Preference Ranking Organization Method for Enrichment and Evaluation) to determine that wood pellets were superior to pellets made of other feedstocks, *viz*., straw, switchgrass, alfalfa and poultry litter. This method used 11 criteria, both quantitative and qualitative, under three differently weighted scenarios for use in large-scale heat and power generation plants. The results indicate that wood pellets were the best source of energy for all scenarios. Naik *et al.*'s (2010) study also found specifically that Canadian pinewood had the best physico-chemical characteristics and lowest detrimental emission levels as compared with other biomass samples.

Wood pellets are used for small-scale/residential systems, district heating and co-firing with coal in large-scale power plants (Mahapatra *et al.* 2007; Peng *et al.* 2010; Saracoglu and Gunduz 2009). District heating refers to a network-bound heating plant that is centrally located and connected to a number of buildings (i.e., a residential district comprised of households, or schools, smaller businesses, etc.) (Obernberger and Thek 2010). In North America, wood pellets are most commonly used in small-scale/residential heating systems, and modern versions of these small-scale systems have become automated to the point that they require only a minor amount of maintenance (Obernberger and Thek 2010; Pirraglia *et al.* 2010). High standards for pellet fuel quality are required in the residential sector, with a high level of homogeneity required to achieve fully automated operation and complete combustion in small-scale furnaces (Hansen *et al.* 2009; Obernberger and Thek 2004).

1.1.21 ENplus Certification System

Prior to the implementation of the ENplus Certification System in 2011, European, Canadian and US pellet-producing companies had significant variation in official country quality standards and guidelines (AEBIOM 2013; Garcia-Maraver *et al.* 2011; PFI 2011). Only a few publications were found regarding pellet certification, presumably because of the lack of guideline cohesiveness and only recent development of the ENplus system. The ENplus System allows for convenient and effective compliance with the European standard EN 14961-2 (EPC 2013). The purpose of this certification system is to establish a standardized quality regime for wood pellets for heating and combined heat and power (CHP) up to 1 MW output power in residential, commercial and public buildings (EPC 2013). The System will create a "level playing field" for pellet producers and will boost consumers' confidence that they are receiving a quality product (WPAC 2013). Under ENplus standards operational processes including production, logistics and delivery are controlled and made transparent by defining the requirements for technical facilities, operational procedures and documentation (EPC 2013). This transparency allows for quick and easy problem identification and solving, therefore minimizing downtime of production facilities. The German Pellet Institute (DEPI) developed the ENplus System and licensed it to the European Pellet Council (EPC), which is an organization within the European Biomass Association (AEBIOM) (EPC 2013). The specifications of the System include three classes of pellet quality: ENplus-A1, ENPlus-A2 and EN-B (EPC 2013). ENplus-A1 is used in residential boilers or stoves and is the premium class of pellets, producing the least amount of ash and meeting the highest standards (AEBIOM 2013). ENplus-A2 pellets produce a higher amount of ash during combustion and are used in larger boiler systems (AEBIOM 2013). The industrial grade of pellets under ENplus is classed as EN-B (AEBIOM 2013).

Table 1 summarizes the spectrum of the crucial pellet parameters for each class. Additives to improve fuel quality must not exceed 2 % of the total mass of the pellets (≤ 1.8 % of the total pellet mass in production and ≤ 0.2 % of the total pellet mass postproduction) (EPC 2013). Each certified producer (and trader) must display the ENplus certification seal on their product (EPC 2013). Producers and traders of wood pellets that have adopted ENplus certification standards are found in countries around the world including Austria, Belgium, Croatia, Czech Republic, Denmark, France, Germany, Italy, Lithuania, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Switzerland, the Netherlands, the US and the UK (AEBIOM 2013).

Canada is making the switch to the ENplus standard; The Wood Pellet Association of Canada (WPAC) is the licensed, national association for Canada for ENplus certification standards management (WPAC 2014). CANplus was also recently created to become the quality standard for Canadian producers, distributors and/or retailers. Only one Canadian producer has thus far been certified with the CANplus standard; Premium Pellet Ltd. in Vanderhoof, BC (WPAC 2014).

Table 1. Ranges of EN 1496-2 values for the most crucial wood pellet parameters (EPC 2013).

Property	Unit[(1)]	ENplus-A1	ENplus-A2	EN-B	Testing Standard
Diameter	mm	6 or 8	6 or 8	6 or 8	EN 16127
Length	mm	3.15 ≤ L ≤ 40 [(4)]	3.15 ≤ L ≤ 40 [(4)]	3.15 ≤ L ≤ 40 [(4)]	EN 16127
Moisture Content	w-% [(2)]	≤ 10	≤ 10	≤ 10	EN 14774-1
Ash Content	w-% [(3)]	≤ 0.7	≤ 1.5	≤ 3.0	EN 14775 (550 °C)
Mechanical Durability	w-% [(2)]	≥ 97.5 [(5)]	≥ 97.5 [(5)]	≥ 96.5 [(5)]	EN 15210-1
Fines (< 3.15mm)	w-% [(2)]	< 1	< 1	< 1	EN 15210-1
Net Calorific Value	MJ/kg [(2)]	16.5 ≤ Q ≤ 19	16.3 ≤ Q ≤ 19	16.0 ≤ Q ≤ 19	EN 14918
Bulk Density	kg/m^3	≥ 600	≥ 600	≥ 600	EN 15103
Nitrogen Content	w-% [(3)]	≤ 0.3	≤ 0.5	≤ 1.0	EN 15104
Sulfur Content	w-% [(3)]	≤ 0.03	≤ 0.03	≤ 0.04	EN 15289
Chlorine Content	w-% [(3)]	≤ 0.02	≤ 0.02	≤ 0.03	EN 15289
Ash Melting Behaviour [(5)]	°C	≥ 1200	≥ 1100	≥ 1100	EN 15370

[(1)] w-% = percentage of total pellet mass; [(2)] As received; [(3)] dry basis; [(4)] a maximum of 1 w-% of the pellets may be longer than 40 mm; no pellets > 45 mm are allowed; [(5)] deformation temperature; sample preparation at 815° C.

1.2 VALUE CHAIN VS. SUPPLY CHAIN

Figure 1 depicts the value chain; a concept introduced by Porter (1985) that describes a chain of key activities performed within an organization that generates value relating to a product (or service). The value chain tracks the activities required to bring a product (or service) from its conception to fruition in terms of the value that is added to the product (or service) as it moves through the supply chain; which consists of the set of processes required for its completion and delivery (Porter 1985). The value chain serves to create an understanding of how, where, and how much, of the value created by the product is achieved at various product refinement stages throughout the supply chain. The assumption is that each activity along the value chain will create value that exceeds the cost of providing the product (or service), therefore resulting in net profit for the company (Aoudji 2012; Lind *et al.* 2012; Walters 2012; Willem te Velde *et al.* 2006). The goal of value chain optimization is to maximize the value achieved at each stage throughout the supply chain, while minimizing costs. The value chain, even though it is based on internal operations, also has connections with suppliers and retailers, and competition between any of them will damage the entire chain (Booker *et al.* 2012). Porter (1985) also emphasized the importance of cost reduction and/or reconfiguration of the value chain in order to obtain a competitive advantage in the marketplace. Value chains differ dramatically, based on the type of product being produced, and no single chain may be used to satisfy one industry (Booker *et al.* 2012). Sathre and Gustavsson (2009) emphasized that linking product processes and by-products provides a beneficial approach for individual firms to add value and increase profit.

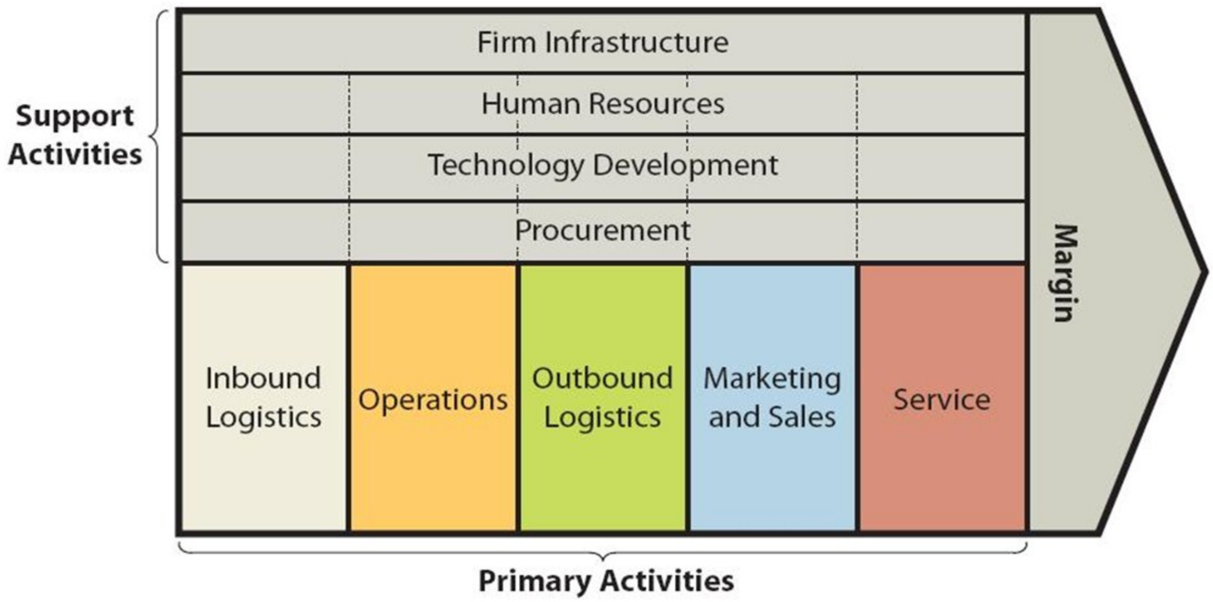


Figure 1. Michael Porter's value chain (Eddins 2014).

A set of firms or a linkage of separate agents, each with their own individual value chains that pass materials forward and bring products or services to the market, is called a supply chain (1985). During this review, it became apparent that there is some ambiguity about the concept of the value chain versus the supply chain. Many of the articles and reports reviewed offered no distinction between the two chains and in many cases used the two terms synonymously. However, Mentzer *et al.* (2001) sorted through the multitudes of definitions to provide a cohesive view of the supply chain, and defined supply chain "as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer".

The value chain and, therefore, the supply chain can become more productive and profitable if companies focus more of their attention on total supply chain costs instead of just parts of the supply chain in order to optimize performance and revenue

(Arthofer *et al.* 2012; Macfadyen *et al.* 2012; Rana and Gregory 2012; Venkateswaran and Son 2004; Von Geibler *et al.* 2010). Value chain optimization involves coordination between a (manufacturing) firm's various nodes, of the supply chain, through appropriate value chain governance at the operational level, which will allow for the overall supply chain to become more efficient as well (Mahutga 2012). Wood pellet manufacturers and other industry stakeholders need a precise understanding about distribution channels, sustainability, long-term forecasting, and methods to improve their operations within the wood pellet supply chain, to ultimately improve their value chain. Different operational management methods of the supply chain need to be identified for improvement, and the exploration of different modeling techniques will help in determining the best fit for wood pellet supply chain modeling under changing (market) conditions. Peer-reviewed literature available to date provides this identification and exploration through a summary of the existence, and merit, of modern supply chain management techniques, as well as modeling techniques to support managerial decision-making. Member-companies of supply chains, mainly producers, may benefit from soliciting advice from a consultant trained specifically in the fundamentals of value chain optimization, based on these sources, to assist them in recognizing shortcomings of their current management approaches. In general, these sources provide an excellent starting point from which an in-depth analysis of specific management techniques may be executed. Implementation of techniques most conducive to achieving improved efficiency and profitability of the operations of specific companies, and their supply chains, was the motivator for reviewing these particular references.

1.3 VALUE CHAIN AND SUPPLY CHAIN MANAGEMENT OF WOOD PELLETS

The value chain of wood pellet manufacturers includes the determination of the value associated with each stage of the supply chain, which includes raw material procurement, inbound logistics of raw materials, processing of raw materials into pellets and outbound logistics to the end consumer (Mäkelä *et al.* 2011). Procurement includes the location of raw materials, the species of raw materials in existence for wood pellet usage, and the original state of these accessible materials (i.e., roundwood, wood chips, sawdust, or wood shavings). Inbound logistics concerns the transportation required to move the raw material from its original location to the manufacturing plant for processing and includes scheduling decisions. Processing includes drying, grinding, pressing, cooling and bagging/storage. Outbound logistics concerns the transportation used to deliver the pellets to the end consumer and scheduling decisions.

Transportation scheduling (logistics) is a very important component of the wood pellet value chain. Since fuel prices and operator wages continue to increase, optimal transportation decisions are needed to control major costs. Pettersson and Segerstedt (2013) define logistics cost as “cost components related to distribution or transportation cost and cost for warehouses”. This definition was proposed to offer clarity and separate the term from “supply chain cost,” which they define as “all relevant costs in the supply chain of the company or organisation in question”. In an expansive nation such as Canada, it is not feasible to transport cutter shavings, sawdust and/or wood chips over long distances (Junginger *et al.* 2008; Rickerson *et al.* 2009). It is worthwhile to transport densified wood pellets, as they have a high BTU/volume ratio; however, the longer the haul distance for raw materials or finished pellets is, the less cost-effective it is for the producer (Junginger *et al.* 2008). Well-developed, seamless connections to marketing-sales and order-delivery processes are needed for efficient, cost-effective value chain coordination (i.e., backhauling) (Gold and Seuring 201; Klibi *et al.* 2010; Panley and Boener 2006). Rail transport is a cost-effective means of moving wood pellets; however, not all producers have direct access to railways. Railways have begun to more aggressively market their wood pellet transportation opportunities to Canadian producers (CN Rail 2012). They offer the flexibility to ship wood pellets in bulk, bags, boxcars and intermodal containers. CN Rail (2012) ships over 800,000 tonnes (t) of wood pellets annually and is ranked as "North America's #1 mover of forest products".

1.3.1 Uncertainty, Leanness and Agility

As marketplace uncertainty increases, so does the need for agility. Agility in a firm's value chain encompasses operational flexibility performance and responsiveness to changes in information, such as product volume and/or logistics scheduling fluctuations (Blackburn 2012; Ngai *et al.* 2011; Rudd *et al.* 2008; Schütz and Tomasgard 2011). When considering modeling of the (wood pellet) value chain within the manufacturing firm, agility must be achieved to account for differences in specifications and types of wood pellets, as well as differences in procurement, processing and distribution methods and location. Value chain models should be created with the intent to readily change these inputs based on market demand and should reduce operational planning cycles (Panley and Boerner 2006). Operational planning cycles include all activities that must be planned to ensure successful operation of a business in a very short-term time period (i.e., one-week) (Panley and Boerner

2006). In recent years the trend in supply chain management has been to make supply chains (and their integrated value chains) more agile, flexible and responsive (Godsell *et al.* 2011; Ivanov *et al.* 2010; Pan and Nagi 2010; Pishvaee *et al.* 2011; Yimer and Demirli 2010). Agility, or responsiveness, is highly important for a workable supply chain model, particularly considering the fact that it is a market-driven model and therefore must allow for input flexibility. Christopher and Towill (2001) emphasize that "it is supply chains that compete, not companies and the success or failure of supply chains is ultimately determined in the marketplace by the end consumer". Christopher and Towill (2001) also say that "only when the requirements and constraints of the marketplace are understood can an enterprise attempt to develop a strategy that will meet the needs of both the supply chain and the end customer".

Mathematical models have been used as decision support tools (DSTs) to assist managers in decision-making processes for strategic, tactical and operational level planning. Operational-level management must focus on short-term productivity and process optimization to meet changing market trends (Gunasekaran and Ngai 2012). Cost forecasting under uncertainty can lead to inaccurate model results; therefore, uncertainty must be reduced by increasing the clarity and accuracy of input information (Kreye *et al.* 2012). "Decisions are made under certainty when perfect information is available and under uncertainty when one has only partial (or imperfect) information" (Klibi *et al.* 2010). Deterministic models serve as a "solid foundation" for value chain network design, and sensitivity analysis is used with deterministic models to explore the effects of input uncertainties (Klibi *et al.* 2010). Therefore, stochastic models can be used to take into account stochastic factors that affect business operations, including (but not limited to) raw material prices, energy costs, market demand for the end product(s), the cost of labour, retail price(s) of the finished product(s) and exchange rates (Klibi *et al.* 2010; Papageorgiou 2009).

Leanness in a firm's value chain refers to its ability to "do more with less" and minimize (or eliminate) waste in its operations with cost leadership and cost performance strategies (Christopher and Towill 2000; Neumann *et al.* 2012; Olhager and Prajogo 2012; Schonberger 2012). Agility must also be applied not only within the individual firm's value chain but also throughout the supply chain as part of the partner selection process to create agile supply chains (Wu and Barnes 2011). Both agility and leanness are strategies useful for developing or maintaining a competitive advantage in an uncertain marketplace.

1.3.2 The Three Levels of Decision Making

The three levels of hierarchical decision making are strategic, tactical and operational. The strategic level has the broadest scope and covers the longest timeline. It considers the influence of decisions made by top-level managers of the organization (Gunasekaran *et al.* 2004). The decisions commonly made at this level involve "broad-based policies, corporate financial plans, competitiveness and level of adherence to organizational goals" (Gunasekaran *et al.* 2004). Tactical decisions are constrained by decisions made at the strategic level, and cover a shorter time period. Tactical decisions concern "resource allocation and measuring performance against targets to be met in order to achieve results specified at the strategic level" (Gunasekaran *et al.* 2004). The operational level is narrowed down even further to a short-term timeline (daily, weekly, or monthly) and is driven by direct decisions made by low-level managers

(Gunasekaran *et al.* 2004). For a (wood pellet) manufacturing facility these decisions include employee scheduling, the number of pellet presses to run each day and the duration of their daily operation, when to send out a shipment of pellets and to which customers, etc. The objectives set by the operational-level managers are put in place to achieve the objectives set out at the tactical level (Gunasekaran *et al.* 2004).

1.3.3 Managerial Involvement

Since supply and demand are dynamic processes, managing the value chain of a company should be considered as an on-going relationship between suppliers, the manufacturing firm and end consumers (Kraigher-Krainer 2012). The more involved management becomes with the value chain, the more they may visualize linkages of the value chain with the overall marketing strategy and goals of the firm, and the more likely management is to follow through with the successful application of the value chain at the operational level (Öberg 2010). Gooch (2012) found that even when value chain optimization strategies are implemented within a firm, human resistance (i.e., managerial resistance) is inevitable and can seriously detract from the effectiveness of a plan, and consequently, the overall performance of the firm. Failure to realize when a value chain model is being used improperly can prevent (managerial) support for the model and may delay, or prevent, its execution (Schonberger 2012). Therefore, training is required to ensure acceptance and proper implementation of a value chain model within an organization.

When dealing with complex value chains, identification of the critical value network locations is a useful managerial approach (Engelhardt-Nowitzki *et al.* 2012). Lind *et al.* (2012) emphasized that managing the working capital (short-term finance flow) of a company and its supply chain should be a major focus instead of just managing the flow of goods through the supply chain. Cantor and Macdonald (2009) reviewed management problem-solving approaches within the supply chain and found that a more abstract approach to decision making may actually achieve better overall results than a more concrete approach. Cantor and Macdonald (2009) discussed the fact that having complex, system-wide knowledge (more information) overwhelmed many managers, leading to poor decision making. Therefore, the use of a decision support system can simplify the overload of information and help managers make better decisions while still having all available information at their fingertips

1.3.4 Demand-Driven Management Approach

Demand-driven supply networks aim to link the supply/production rate directly to the level of actual demand for a specified time period in order to enable the manufacturer to respond in real-time to shifts in the level of demand and gain insight into general demand trends for their product(s) (Panley and Boerner 2006; Subramanian and Reddy 2012). The upstream component of the manufacturing value chain is the origin of the raw materials used in a product and the transportation of these materials to the processing facility. The downstream component of the value chain follows processing to distribution of the final product to the end consumers (An *et al.* 2011). Most companies, by default, examine their supply chains and value chains from an upstream to downstream perspective (as a directional flow), meaning that they operate by creating the product based on capacity, with some concept of forecasted market demand, and push the product out into the marketplace, and also examine associated value creation in this manner (Chandra and Kumar 2000; Mizgier *et al.* 2012; Toppinen and Kuuluvainen 2012). Neumann *et al.* (2012) conducted surveys of various companies only to find that even when it came to incorporating lean production techniques, very few companies used a demand-pull strategy.

Demand-driven management adopts the value chain's downstream to upstream perspective (as a directional flow) and applies it to the supply chain. This application allows for production to become a reactive process based on the signals sent by real-time demand to the upstream (procurement) end of the supply chain and the product is pulled through the supply chain and/or value chain by the quantity demanded, instead of being pushed out into the market (Ayoub and Yuji 2012; Wöhrle 2009). Wadhwa *et al.* (2009) conclude that there is a need to study supply chains under dynamic demands. Demand-driven models, used to support demand-driven management techniques, are very advantageous for many reasons. These models can reduce or eliminate inefficiencies throughout the supply chain and allow for a "smooth product flow". Demand-driven models have also been used to improve utilization, inventory management, production capacities, and response to supply fluctuations (Ayoub *et al.* 2009; Wöhrle 2009).

1.3.5 Demand Forecasting

Demand forecasting uses smoothing to remove random variation (noise) from historical demand to allow better identification of patterns (primarily trend and seasonality) and levels that can be used to estimate future demand. Demand forecasts are crucial to provide input for demand-driven planning systems. Multiple approaches are available to forecast demand. Vinterbäck (2004), and Hosoda, and Disney (2012) discuss some of these approaches, including exponential smoothing, the naïve approach, moving average, autoregressive (AR), autoregressive integrated moving average (ARIMA), autoregressive extra (ARX), vector autoregressive (VAR), neural networks and the quantile regression method. However, these methods have not been proven to be overly effective and still allow for inaccurate demand prediction at each level throughout the supply chain, resulting in the bullwhip effect, which is amplification in demand variability when moving upstream through a value chain or supply chain (Trapero *et al.* 2012). There are new approaches currently being researched to increase the forecasting accuracy. Multilayer perception (MLP) is an approach that generalizes either linear or non-linear functional relationships between inputs and outputs (Trapero *et al.* 2012). Yousefi *et al.* (2011) designed a comprehensive demand response (CDR) model for a retail energy provider agent in an agent-based retail environment to offer real-time energy prices to customers. Yousefi *et al.* (2011) found that the CDR model gave a better representation of customers' historical behavior for future demand prediction.

A general demand pattern may be initially understood for wood pellets used for heating in North America, simply by observing seasonal trends. Specifically, wood pellets used for heating will be purchased more frequently in the colder seasons of (late fall, winter and early spring) when the heating systems are experiencing high frequency of usage. Seasonality may be generalized as a pattern of repetitive increases or decreases in demand values throughout a time series, and trend is the tendency of the data along a steady increase, or decrease, throughout the time series. Exponential smoothing is a method of demand forecasting that may be used to address both trend and seasonality. This method uses a weighted average that gives more weight to the most recent changes in demand patterns and smooths out fluctuations caused by pure randomness (McKenzie and Gardener 2010). It is very useful for demand sets with seasonal, predictable patterns, instead of those exhibiting completely random fluctuations (McKenzie and Gardener 2010). It is a fairly popular method and though it may not be as effective as the newer ones discussed above, exponential smoothing has many benefits, including a minimal data requirement and ease of applicability, and the availability of many software packages that contain this forecasting method (McKenzie and Gardener 2010). Exponential smoothing becomes quite effective once a damped trend has been added into the model (McKenzie and Gardener 2010). Damping the trend means subduing the tendency of the demand to continue along a steady path of increasing or decreasing as the forecast horizon increases. This damping effect has proven to perform well in a variety of experimental studies (Li *et al.* 2014; McKenzie and Gardener 2010). Wood pellet demand exhibits strong patterns of seasonality and therefore exponential smoothing may be a useful forecasting technique for it, especially using a damped trend.

1.3.6 Demand for Wood Pellets and Other Biofuels

North America began producing wood pellets for a small niche market in the 1930s, with a significant market growth spurt occurring in the 1970s, followed by rapid market development in the 1990s as a result of increased consumption in Europe (Hillring and Vinterback 1998; Lofstedt 1996). In Canada pellet production in 1997 was only 173,000 tonnes (t), of which roughly two-thirds were exported to the U.S.; but from 1997 to 2007, Canada went from exporting 0 % to 63 % of its pellets to the European market, which displaced the U.S. from its position as Canada’s major trade partner (Obernberger and Thek 2010). In 2010, wood pellet production was less than 70% of design capacity in Europe, implying a lack of natural resources for pellet production and, therefore, indicating a need for pellet import (Peng *et al.* 2010). Imported biomass comprises between 21% and 43% of Europe's total available biomass (Junginger *et al.* 2008). Canada is now one of the world's leaders with regards to production and trade success of wood pellets because of many contributing factors, including its surplus of natural resources, low-cost mill residue, excess pellet production capacity, and abundance of export opportunities (Alakangas *et al.* 2012; Cocchi *et al.* 2011; Schroeder 2011; Verhoest and Ryckmans 2012). Obernberger and Thek's (2010) prognosis for Canada was for 5.5 million tonnes (Mt) to be produced in 2010. However, the production capacity of Canada in 2010 was only 2.08 Mt per year and in 2011 it expanded to 3.22 Mt per year (a 55 % growth from 2010 to 2011). However, not all production plants are (or were) operating at full capacity due to market conditions (Bradley and Bradburn 2012; Bradley and Thiffault 2012). Figure 2 shows the pellet mills that were operating, under construction and proposed in Canada as of March 2013.

Market studies on Canada and other relevant countries show that Canada is lacking in domestic wood pellet demand compared with other countries; therefore, most of Canada's pellet production is exported (Bradley and Bradburn 2012; Selkimäki *et al.* 2010). However, some of these studies have noted that there is a rising trend in Canada's domestic consumption of wood pellets and that Canada has great potential for growth with regards to domestic pellet consumption (Cocchi *et al.* 2011; Junginger *et al.* 2011; Verhoest and Ryckmans 2012). Junginger *et al.* (2008; 2011) identify logistics as the most influential trade barrier for wood pellets, while development of technical standards presents itself as a major opportunity for wood pellet trade. Wolf *et al.* (2006) identified the need to more efficiently produce biomass in order to meet expanding market demand and studied the effectiveness and feasibility of biofuel production in the forestry industry.

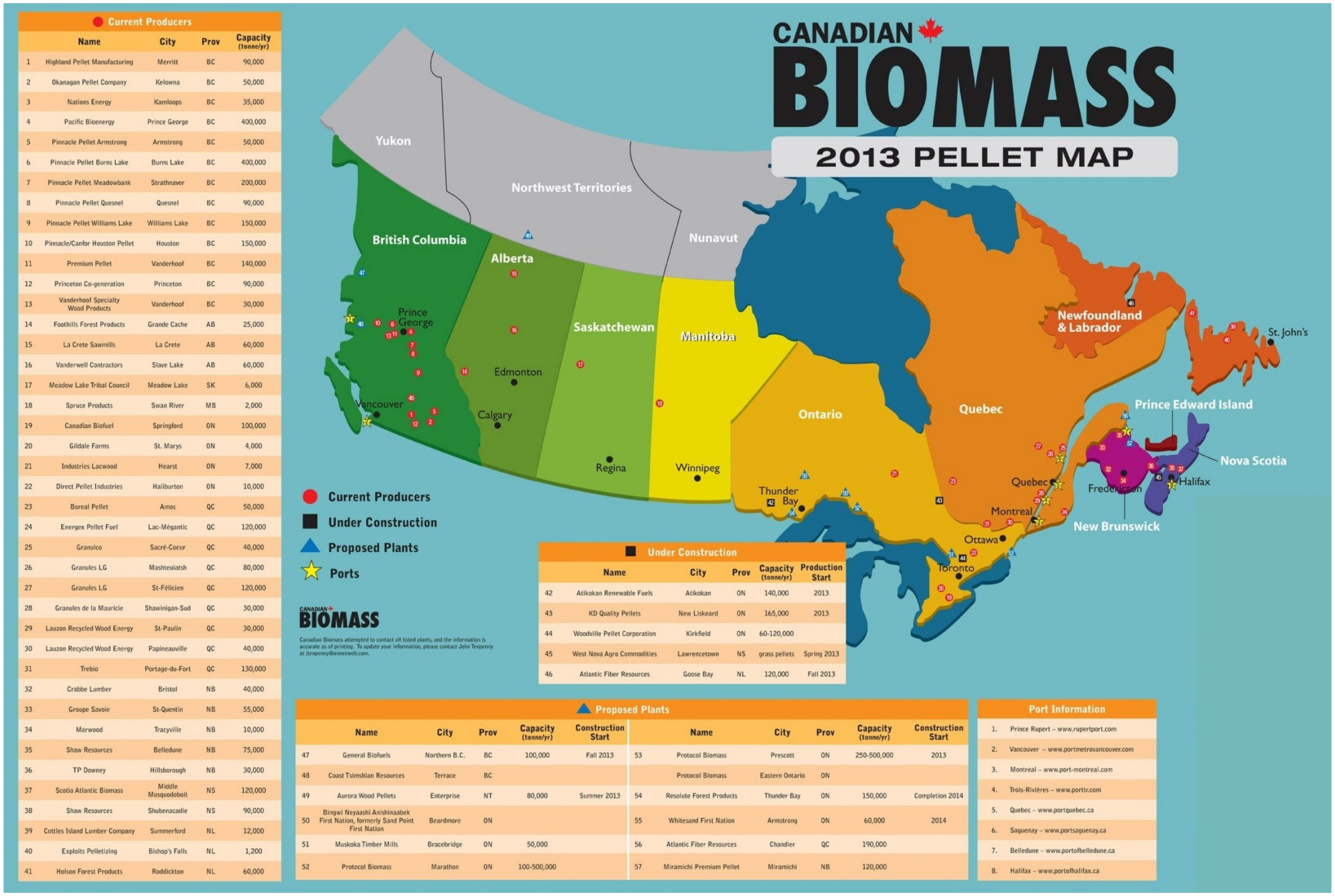


Figure 2. Location of wood pellet mills that were operational, under construction and proposed as of March 2013 (Canadian Biomass 2013).

There has been rapid growth in the worldwide production and consumption of wood pellets and other biomass within the last decade (Ince *et al.* 2011; Lamers *et al.* 2012). Canada, the US, Korea, and countries throughout Europe exhibit this global trend (Karkania *et al.* 2012; Lu and Rice 2010; Monteiro *et al.* 2012; Moon *et al.* 2011; Olsson *et al.* 2011; Palladini 2010; Sopha *et al.* 2010; Trømborg *et al.* 2011; Van Dam *et al.* 2009; Verma *et al.* 2009). A factor contributing to the onset of this trend is favourable government policy implementation, which has allowed for an effective increase in pellet production and consumption (Ince *et al.* 2011). Provincial governments throughout Canada have successfully implemented various initiatives to promote renewable energy production and usage. For example, Ontario's *Green Energy Act* of 2009 applied a Feed-in-Tariff (FIT) program that offers price incentives for new electrical generating stations that are fueled by renewable resources, and as mentioned earlier, the focus of Ontario's new *Long Term Energy Plan* is on renewable energy sources as well (MOE 2013; Yatchew and Baziliauskas 2011). Aboriginal, or First Nation, communities in Ontario have also begun the process of adopting renewable energy initiatives. The community of Pic River First Nation has various current and future renewable energy projects and is actively participating in knowledge and information sharing with other First Nations communities across Ontario and Canada (Krupa 2012).

Average worldwide demand (consumption) for wood pellets increased from 3.28 Mt in 2003 to 10.54 Mt in 2007 (a 41.7 % increase), average worldwide production increased from 3.38 Mt in 2003 to 10.54 Mt in 2007 (a 40.5% increase) and average worldwide capacity increased from 4.5 Mt in 2003 to 15.0 Mt in 2007 (a 43.1%

increase) (Peng *et al.* 2010). Sweden is one of the world's largest producers and consumers of wood pellets, due mainly to its favourable taxation system towards biofuels, ubiquitous district heating systems and abundance of raw materials (Selkimäki *et al.* 2010). Pellet usage for heating/energy allows for improved fuel supply security (from a renewable resource viewpoint) and stimulates local and regional job creation and overall economic development (Palladini 2010). Generally, the availability of forest resources, the demand for forest fuels, machine, labour and transportation costs are the defining factors behind (wood pellet) prices (Alfonso *et al.* 2009; Mahapatra *et al.* 2007). Other factors contributing to the global success of the wood pellet industry include the automation of heating systems, logistics infrastructure, national funding systems coupled with marketing programs and public awareness campaigns, and price increases in the oil and gas sector (Uran 2010). As the marketplace expands and demand for wood pellets increases, if the demand for pellets exceeds the current capacity of production plants, they will have to increase capacity in order to satisfy demand and remain competitive (Alfonso *et al.* 2009).

1.3.7 Demand Flow Inventory Policy

Demand flow inventory policy is defined by Wadhwa *et al.* (2009) as a policy which "transfers the actual demand from one node to another without transforming it. The demand only gets delayed by the time equal to the ordering lead time". Wadhwa *et al.* (2009) explain that the worst shortcoming of demand flow policy is the delay in demand information in accordance with other lead times. They also stress that modern technology allows demand information to be sent almost instantaneously through the

Internet as it is intercepted, and transportation lead times may be reduced through the use of efficient logistical planning.

Demand flow inventory can address the issue of demand uncertainty within the operational level of wood pellet production. Demand uncertainty arises from many factors, as were explored in section 1.3.1. Godsell *et al.* (2011) emphasize that a challenge exists “to create a supply chain capability that combines both market segment considerations and product characteristics”. A dynamic model is needed to address demand uncertainty, as the flexibility in its design will allow for demand fluctuation input and adjustment of inventory levels on a per-period basis, in order to maintain a maximized level of profit for the pellet producer when dealing with uncertain demand.

1.3.8 Supply Chain and Value Chain Models

Papageorgiou (2009) identifies two broad categories for supply chain models: 1) mathematical programming models and 2) simulation models. The mathematical models optimize high-level decisions with an aggregate view of operational processes; while simulation-based models are more precise since they are used to study detailed, dynamic operations under uncertainty (Papageorgiou 2009).

Many general supply chain models have been developed, covering a wide variety of products. Using the broad definition of biomass from section 1.1.1, there have also been many supply chain models created relating to biomass. Few academic research papers were found specifically on value chain modeling (Shabani and Sowlati 2013; Christensen *et al.* 2011). There were three studies found on wood pellet value chain analysis (Mäkelä *et al.* 2011; Pirraglia *et al.* 2010; Uran 2010). Other sources found were five feasibility studies for actual biomass and wood pellet production facilities (BW Mc Cloy & Associates Inc. 2009; Campbell 2007; Murray 2010; NEOS Corporation 1995; Oo *et al.* 2012) and three university theses on wood pellet production and feasibility (Blom 2009; Ravn and Engstrøm 2010; Urbanowski 2005). Only two papers were uncovered discussing and utilizing demand-driven approaches to modeling (Ayoub *et al.* 2009; Wöhrle 2009) and these were both supply chain models, with no connection to the value chain. Table 2 summarizes the model-types discovered through the literature review, based on Papageorgiou's (2009) broad-scale categorization of simulation models and mathematical programming models.

Table 2. Categorization of Model-Types in Reviewed Papers.

Type of Study		Broad Modeling Category	Type of Modeling Approach	Authors Using the Modeling Approach
Supply Chain Models	Biomass Supply Chain Models	Simulation	Simulation	(Singer and Donoso 2008; Mobini *et al.* 2011; Mobini *et al*. 2013)
			Demand-driven	(Ayoub *et al.* 2009; Wöhrle 2009)
			Simulation-based fuzzy inventory	(Mahnam *et al.* 2009)
			Integrated biomass supply and logistics (ISBAL) modeling environment - dynamic simulation	(Sokhansanj *et al.* 2008)
Supply Chain Models	Biomass Supply Chain Models	Mathematical Programming	Dynamic, non-linear mixed-integer	(Alam *et al.* 2012; Upadhyay *et al.* 2012)
			Dynamic, linear mixed-integer	(Van Dyken *et al.* 2010; Nagel 2000)
			Scenario-based optimization	(Alfonso *et al.* 2009; Kumar *et al.* 2003)
			Agent-based models (ABMs)	(Sopha *et al.* 2011)
			Land-suitability model (LSM) using analytic hierarchy process (AHP)	(Sultana and Kumar 2012b)
			Power function utilization	(Gallagher *et al.* 2005)
			Spatial partial equilibrium	(Sjølie *et al.* 2011)
			Techno-economic	(Sultana *et al.* 2010; Jenkins 1997)
			Game theoretic approach	(Nasiri and Zaccour 2009)
			Mixed-integer	(Aydinel *et al.* 2008)
			Mixed integer linear programming (MILP)	(Gunnarsson *et al.* 2004)
			Linear programming network	(Velazquez-Marti and Fernandez-Gonzalez 2010)
			Process network synthesis (PNS) two-level process graph (P-graph) approach	(Wolf *et al.* 2006; Lam *et al.* 2010)
			Newsvendor economic	(Jones and Ohlmann 2008)

Table 2. (continued)

Type of Study		Broad Modeling Category	Type of Modeling Approach	Authors Using the Modeling Approach
Supply Chain Models	Biomass Supply Chain Models	Mathematical Programming	Integrated optimization	(Carlsson and Ronnqvist 2005)
Supply Chain Models	General Supply Chain Models	Simulation	Simulation	(Venkateswaran and Son 2004; Pitty *et al.* 2008; Koo *et al.* 2008)
Supply Chain Models	General Supply Chain Models	Mathematical Programming	Demand-driven	(Ayoub and Yuji 2012)
			Agent-based models (ABMs)	(Mizgier *et al.* 2012)
			Closed-loop optimization	(Pishvaee *et al.* 2011)
			Mixed integer	(Ahumada and Villalobos 2011)
			Lead-time inventory	(Blackburn 2012; Fang *et al.* 2012; Garcia *et al.* 2012)
			Stochastic network	(Li and Lu 2012)
			Fuzzy programming	(Mitra *et al.* 2009)
			Mixed integer linear programming (MILP)	(Gomes da Silva *et al.* 2006; Luathep *et al.* 2011; Naraharisetti *et al.* 2008)
			Integrated business planning (IBP) matrix	(Hahn and Kuhn 2012)
			Genetic algorithms	(Yimer and Demirli 2010; Sadegheih and Drake 2008; Ko and Evans 2007)
Value Chain Models	General Value Chain Models	Mathematical Programming	Mixed integer non-linear programming	(Bashiri *et al.* 2012; Shabani and Sowlati 2013)
			Object oriented programming approach with ecological mass-balance	(Christensen *et al.* 2011)
			Analytic Network Process (ANP)	(Kayakutlu and Buyukozkan 2011)
Value Chain Models	Wood Pellet Value Chain Models	Simulation	Inventory management (Pell-Sim)	(Vinterback 2004)

Table 2. (continued)

Type of Study		Broad Modeling Category	Type of Modeling Approach	Authors Using the Modeling Approach
Value Chain Models	Wood Pellet Value Chain Models	Mathematical Programming	Win-win optimization	(Uran 2010)
			Techno-economic	(Pirraglia *et al.* 2010)
			Static partial equilibrium	(Mäkelä *et al.* 2011)
Other	Wood Pellet Theses	Mathematical Programming	Linear multi-commodity network flow	(Ravn and Engstrøm 2010)
			Scenario-based financial	(Blom 2009; Urbanowski 2005)
Other	Biomass Business Plans	Mathematical Programming	Financial-based	(Oo *et al.* 2012; Campbell 2007)
Other	Wood Pellet Business Plans	Mathematical Programming	Financial-based	(BW McCloy & Associates Inc. 2009; Murray 2010)

1.4 LITERATURE GAPS

There is a need for more (Canadian) studies about wood pellet production methods and characteristics. The low number of Canadian-based value chain and supply chain studies indicates a rather large gap that needs to be filled as well. These studies are necessary for the most successful advancement of the wood pellet market in Canada, in order to remain globally competitive and achieve market differentiation by offering wood pellets to consumers at competitive prices. There is a need for more value chain models in general but especially those relating to wood pellet production. Going hand-in-hand with the value chain gap is the gap relating to managerial involvement, as defined in section 1.3.2. This gap presents an opportunity for future studies focused on value chain optimization that can be paired with guidelines for convenient and effective managerial execution.

There is also a great need for dynamic, demand-driven models within the value chain and the supply chain. This need may be coupled with the necessity of more accurate and effective demand forecasting methods. By employing capacity-optimization techniques similar to those outlined in previous studies (i.e., Jenkins 1997; Nagel 2000; Pa *et al.* 2011; Sokhansanj *et al.* 2008), pellet production costs may be minimized as a function of plant capacity, utilizing real-time information and emulating stochastic market demand. Following the lead of Trapero *et al.* (2012) and Yousefi *et al.* (2011) and building upon their results would produce cutting-edge demand forecasting methods to improve demand-driven modeling approaches. The literature review conducted for this thesis has been published as, "A review of the wood pellet value chain, modern value/supply chain management approaches, and value/supply chain models" in the Journal of Renewable Energy, Vol. 2014, Article ID 654158, 14 pages, http://dx.doi.org/10.1155/2014/654158.

1.5 THESIS OBJECTIVES

This project aims to fill the literature gaps specified in section 1.4. In order to address the need for more Canadian studies about the wood pellet value chain, primary information from a case study of Industries Lacwood (ILW), a wood pellet producer in Hearst, Ontario, Canada is used in this thesis. Dynamic, demand-driven models are created to optimize the value chain of ILW, by maximizing its gross margin (GM) under uncertain (stochastic) demand conditions, and are compared for their efficacy. The most effective model is used for the demonstration of operational-level management techniques that may be employed to achieve optimization of the wood pellet producer's value chain, given uncertain demand. The model acts as a DST for operational-level managers of wood pellet production facilities and utilizes a demand-driven, upstream perspective of the manufacturing value chain, as opposed to the conventional product push, or downstream perspective. This project will allow for transparency in the wood pellet value chain, which is an important factor for success (Alakangas *et al.* 2012). This transparency will assist other Canadian wood pellet producers by offering methods through which their operational costs may be minimized, therefore allowing them the opportunity to sell their wood pellets at competitive prices and achieve market differentiation. Improving the competitiveness of Canada's individual wood pellet manufacturers will ultimately improve Canada's wood pellet market as a whole. Specifically, the objectives of this thesis are to:

1) Determine how to optimize the operations of a wood pellet producer, through a comparison of three different gross margin (GM) optimization models, given uncertain demand conditions.
    a. These three models will illustrate why it is important to utilize inventory and a variable production rate, in order to most effectively optimize the GM of a pellet producer, given uncertain consumer demand.
1) Produce 100 demand datasets for pellet 1 and pellet 2 and run these datasets through each of the three models created for objective 1. Compare the GM results of the three models and demonstrate why the operational environment specified in model 2 should be used for the GM optimization of wood pellet producers, and will be used for further analysis.
    a. The generation of 100 demand datasets satisfies the Central Limit Theorem; providing a sufficiently large population sample of possible

demand values that may be received from the pellet manufacturer in each period.

2) Generate stochastic demand schedules for pellets by averaging the 100 demand datasets produced for objective 2. Use these stochastic demand schedules as the base case demand input values for model 2, along with other standard input values (obtained from ILW). Benchmark output values of production, inventory and unfulfilled demand generated from these standard inputs will be compared with output values of production, inventory and unfulfilled demand generated from the variable inputs of 11 different scenarios. These comparisons will illustrate how model 2 is a comprehensive DST that the operational-level managers of wood pellet producers may use to achieve optimal GMs for the producer, under uncertain demand conditions and with other variable input factors.

    a. A normal demand distribution will be calculated for pellet 1 and pellet 2 from the averages of the 100 demand datasets from Objective 2a. These averages will be used to emulate a stochastic demand schedule for pellet 1 and pellet 2. Because the averages will be calculated from a large sample size of 100 datasets, they will be representative of the expected demand for each period.

1.6 ORGANIZATION OF THE PAPER

The paper has been organized as follows; the Methods section describes and presents the steps that were followed in order to meet each objective. The Results section explains the outcome of the methodology, and displays the output in tabular and graphical formats, while the Discussion section explores the results, and the Conclusion identifies the benefits and shortcomings of the study and suggests future studies to build upon this research.

2 METHODS

This project required the identification of a wood pellet manufacturer to be used as a case study, the creation of stochastic demand using the exponential smoothing forecasting method and probabilistic distribution amongst retailers, followed by the creation of three gross margin (GM) optimization models in Mathematical Programming Language (MPL®), and the use of the most effective model for further analysis.

2.1 CASE STUDY

Case studies have proven beneficial for the application of models as they allow the researcher to study companies and events in context and do so in an explorative manner (Aydinel *et al.* 2008; Öberg 2010; Pirraglia *et al.* 2010). For these reasons, and also for the purpose of adding an element of realism to this research, a case study was employed. This case study focused on the pellet manufacturing operations of Industries Lacwood (ILW), a small-scale manufacturing firm in Hearst, Ontario. Specifically ILW primarily manufactures wood products from spruce and pine lumber, and the residue generated from the processing of these primary wood products is used to manufacture wood pellets. ILW's primary products include wood-mining core boxes, compost boxes, and a line of organizational products called 'EZ n'Organized'. The 'EZ n’Organized’ product line consists of beautifully crafted shelving and storage units, storage chests and crates, recycling centres and bottle racks. ILW is an innovative and environmentally friendly company, as its operations are founded on a “zero-waste” policy. The term zero-waste is earned through the utilization of their waste wood from the creation of the aforementioned products to manufacture kindling wood, wood pellets for residential-scale heating systems, and bedding pellets for horse stalls. This zero-waste production process is an excellent example of what other wood products manufacturers should be doing. Not only does it add to their profitability, but it is a sustainable practice that aligns with the environmental concerns of our modern age.

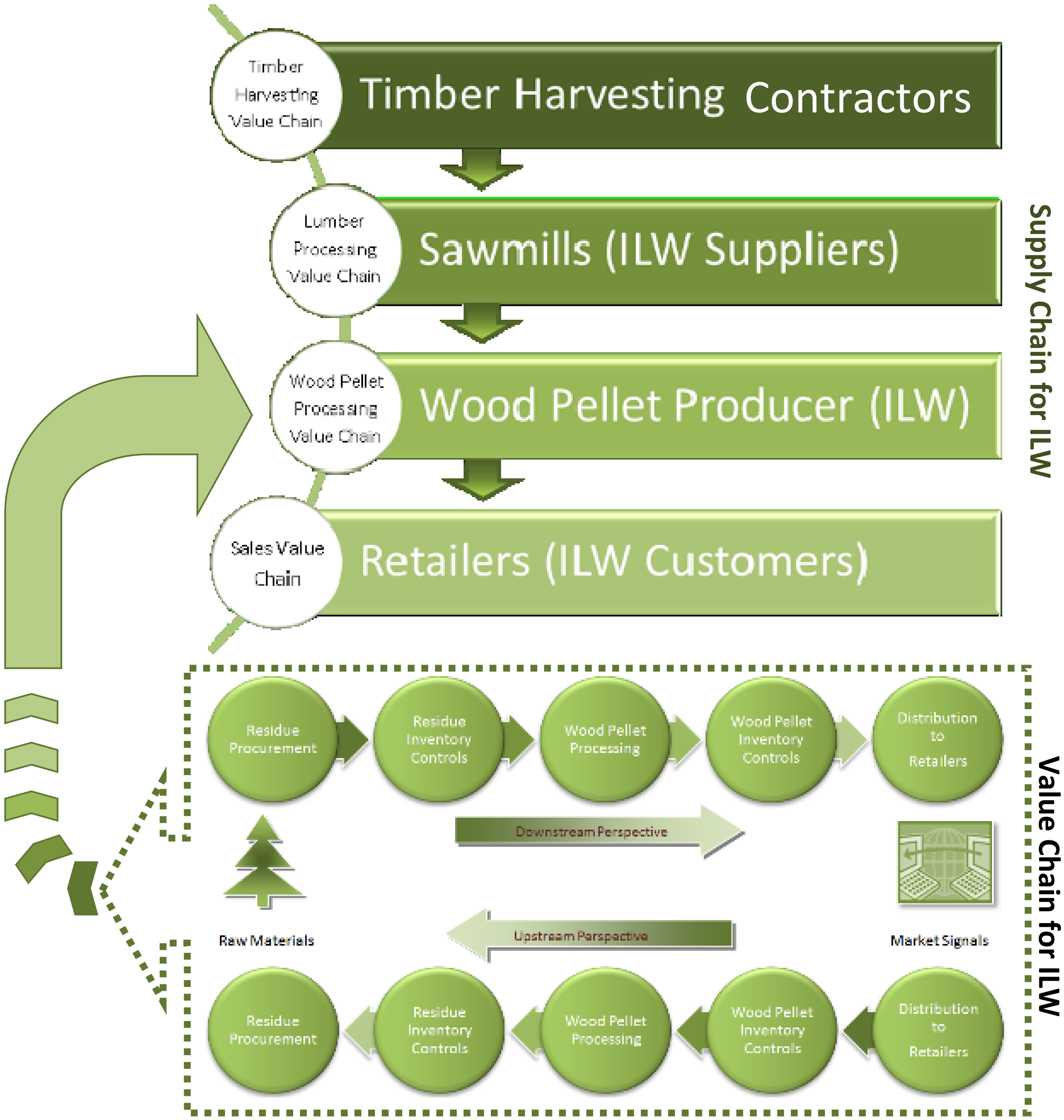


Figure 3. The supply chain and value chain of Industries Lacwood (ILW).

As defined in section 1.2, the (wood pellet) value chain is a set of key activities within an organization that generate value (for wood pellets) and that a (wood pellet) supply chain is a set of firms, or a linkage of separate agents, each with their own individual value chains that pass materials forward and bring products (in this case, wood pellets) or services to the market. Figure 3 depicts the supply chain (top) and value chain (bottom) of ILW. The supply chain of ILW consists of the following agents: timber harvesting contractors, two lumber suppliers, one wood pellet producer (ILW) and 40 retailers. Each agent is linked to the other through a network flow of inbound/outbound logistics. Note in Figure 3 that each agent has its own value chain, and where the value chain for ILW fits in to the supply chain schematic. The value chain of ILW consists of residue procurement from the two suppliers (Appendix I), residue inventory controls, wood pellet processing, wood pellet inventory controls and distribution to the 40 retailers (Appendix I).

Primary information regarding ILW's wood pellet manufacturing operations was retrieved from the company's owner, Normand Lacroix, in order to create the framework for developing the three optimization models. Information about pricing/revenue, costs (processing, wages, packaging and transportation), production capacity, and retailers was obtained and compiled into a model framework. For ease of reference, wood pellets produced for heating are referred to as pellet 1, and wood pellets produced for animal bedding are referred to as pellet 2.

2.1.1 Wood Pellet Specifications

Pellet 1 is made from a combination of spruce and pine residue from wood processing waste. Pellet 2 is made only from pine residue from wood processing waste. The available specifications for pellet 1 are shown in Table 3 and are compared with the acceptable range of quality standards as specified by the ENplus-A1 certification discussed in section 1.1.11. Table 3 demonstrates that all available specifications for pellet 1 are within the acceptable quality ranges for ENplus certification.

Table 3. Ranges of EN 14961-2 values for ENplus-A1 standards and a comparison of the available specifications of pellet 1 manufactured by ILW (EPC 2013; Normand Lacroix, pers. comm. September 18, 2012 and July 17, 2013).

Property	Unit (1)	ENplus-A1	ILW	Testing Standard
Diameter	mm	6 or 8	6	EN 16127
Length	mm	3.15 ≤ L ≤ 40 (3)	3.15 ≤ L ≤ 40 (3)	EN 16127
Moisture Content	w-% (2)	≤ 10	5.5	EN 14774-1
Ash Content	w-% (3)	≤ 0.7	0.3	EN 14775 (550 °C)
Fines (< 3.15mm)	w-% (2)	< 1	< 1	EN 15210-1
Net Calorific Value	MJ/kg (2)	16.5 ≤ Q ≤ 19	18.3	EN 14918
Bulk Density	kg/m^3	≥ 600	640.7	EN 15103

(1) w-% = percentage of total pellet mass; (2) As received; (3) Dry basis; 4) A maximum of 1 w-% of the pellets may be longer than 40 mm, no pellets > 45 mm allowed.

2.1.2 Overhead Costs

Normal operating costs of the pellet facility, including maintenance were estimated by Normand Lacroix (pers. comm. October 26, 2012) to be $5,000 per month.

2.1.3 Transportation

Transportation cost was provided by Normand Lacroix (pers. comm. September 18, 2012) on a per-km basis; a value of $1.83/km (Appendix I). This value was used for both residue transportation from the two suppliers to ILW and for pellet transportation from ILW to their 40 retailers.

2.1.4 Pellet Processing Data

Pellet processing cost was calculated based on values provided by Normand Lacroix (pers. comm. September 18, 2012). The processing cost includes the sum of the drying, grinding, pelletizing packaging and operator wage rate, on a per-tonne basis, and is the same for both pellet 1 and pellet 2 (Appendix I). The wood pellet production capacity of ILW is 720 tonnes per period (month).

2.1.5 Supply Data

ILW has two raw material suppliers (Appendix I). Both spruce residue and pine residue are used as raw materials for wood pellet production. The supply of wood residue cost was estimated at $45/tonne, for both spruce and pine. The transportation cost from the lumber suppliers to ILW was included in this model as well. Recall that ILW uses their own wood waste from their operations and that their raw material suppliers are actually supplying lumber (not residue); however, the purchase costs and the transportation costs were included for ease of future applicability to other producers. The supply of wood residue was specified at a constant rate per period (Appendix I).

2.1.6 Demand Data

ILW has only initiated pellet production from their wood-waste in recent years. July 2010 was the beginning of their official pellet 1 sales data. The historical domestic market demand data although sparse, was made available by ILW's marketing department for this study (Appendix I). The data was provided as tonnes per month, per retailer. Demand data only from those retailers located in Ontario were considered in this thesis; a total of 40 retailers. ILW is also exploring the pellet 2 market and will be putting forth efforts to expand pellet 2 sales in the near future.

2.1.7 Bedding Pellet Demand

Since the historical sales data for ILW's bedding pellets (pellet 2) was not available, the demand for pellet 2 was estimated using random number generation based on a projected demand range for certain retailers. This demand range was obtained by a basic market estimation process. This process involved an Internet search of the location of each of ILW's 40 pellet 1 retailers in tandem with a search for equestrian centres within a 20 km radius of each retailer. If there was an equestrian centre within 20 km of a retailer, then that particular retailer was marked as having potential pellet 2 demand. In total, 19 out of the 40 retailers were found to meet the pellet 2 demand criteria. Random number generation was used with a minimum value of zero tonnes and a maximum value of 5 tonnes, to generate a demand dataset for these 19 retailers using Microsoft Excel®. There are many factors that have not been considered in this pellet 2 demand estimation; however, it is important to note that this is not an accurate estimate to be used for future planning, but a means of illustrating how this pellet 2 demand can affect future operations, once accurate market demand data has been obtained.

2.2 METHODS FOR OBJECTIVE 1

Three models were used to calculate optimal GMs for producers, under uncertain demand conditions. Model 1 was created without inventory parameters and with a variable production rate, model 2 was created with demand flow inventory holding parameters and a variable production rate, and model 3 was created with demand flow inventory parameters and with a specified, constant, per-period rate of pellet production. This per-period rate of production was set to the maximum amount possible, given ILW's specified per-period supply of residue. These three models have an almost identical structure, except for minor differences that will be explained in sections 2.2.11, 2.2.12 and 2.2.13. All three models allow for easy modification of demand values, or any other input value, and for instant retrieval of updated solution output values (i.e., GM, inventory levels, etc.).

The purpose of creating these three different models is to illustrate how wood pellet producers may adjust input values to account for unexpected increases or decreases in demand, based on the type of inventory and/or production constraints under which they operate. The comparison of these models will illustrate why model 2 is the preferred choice for maximizing the GM of a wood pellet producer.

2.2.1 The Models

This section explains the components of each of the three optimization models created in MPL®. These three separate formulations were employed to illustrate the expected GM of a pellet producer with demand uncertainty, in three different operational environments; one without an inventory management system and a variable rate of production (model 1), one with an inventory management system and a variable rate of production (model 2), and one with an inventory management system and a constant rate of production.

2.2.11 Model 1: No Inventory

There are only minor modifications required to change this model's formulation to that of the demand flow inventory model (model 2), and also the demand flow inventory model with a constant rate of production (model 3). These modifications are specified in sections 2.2.12 and 2.2.13.

2.2.11.1 Indices

i = 1, 2 (Residue types)

j = 1, 2 (Pellet types)

k = 1, 2 (Suppliers)

l = 1 to 40 (Retailers)

t = 1 to 12 (One-month time periods)

2.2.11.2 Parameters

OC_t = Overhead costs for pellet facility in period t ($)

D_{jt} = Cost of manufacturing pellet j in period t ($/tonne)

C_{ik}= Cost of shipping residue type i, from supplier k, to pellet producer ($/tonne)

A_{jl} = Cost of shipping pellet j to retailer l ($/tonne)

$R_{jl} =$ Revenue from sale of pellet type j to retailer l ($/tonne)

E_j = Cost of storing pellet j ($/tonne)

F_i = Cost of storing residue type i ($/tonne)

G_{jlt} = Demand for pellet type j from retailer l in period t (tonnes)

H_{ikt} = Supply of residue type i from supplier k in period t (tonnes)

N_j = Penalty cost for not meeting demand for pellet type j ($/tonne)

2.2.11.3 Objective Function

Z = Max (Revenue – fixed overhead costs - pellet storage cost – residue storage cost – pellet manufacturing cost – residue transportation cost – pellet transportation cost – unfulfilled demand penalty cost)

[1]

$$Z = Max\left(\sum_{j=1}^{2}\sum_{l=1}^{40} R_{jl} \sum_{j=1}^{2}\sum_{l=1}^{40}\sum_{t=1}^{12} W_{jlt}\right)$$

$$-\left(\sum_{t=1}^{12} OC_t\right)$$

$$-\left(\sum_{j=1}^{2} E_j \sum_{j=1}^{2}\sum_{t=1}^{12} Z_{jt}\right)$$

$$-\left(\sum_{i=1}^{2} F_i \sum_{i=1}^{2}\sum_{k=1}^{2}\sum_{t=1}^{12} U_{ikt}\right)$$

$$-\left(\sum_{j=1}^{2}\sum_{t=1}^{12} Y_{jt} D_{jt}\right)$$

$$-\left(\sum_{i=1}^{2}\sum_{k=1}^{2} C_{ik} \sum_{i=1}^{2}\sum_{k=1}^{2}\sum_{t=1}^{12} V_{ikt}\right)$$

$$-\left(\sum_{j=1}^{2}\sum_{l=1}^{40} A_{jl} \sum_{j=1}^{2}\sum_{l=1}^{40}\sum_{t=1}^{12} W_{jlt}\right)$$

$$-\left(\sum_{j=1}^{2} N_j \sum_{j=1}^{2}\sum_{l=1}^{40}\sum_{t=1}^{12} UFD_{jlt}\right)$$

2.2.11.4 Variables

X_{ijt} = Amount of residue type i used for pellet type j in period t (tonnes)

U_{ikt} = Amount of residue type i, from supplier k, stored in period t (tonnes)

V_{ikt} = Amount of residue type i purchased from supplier k in period t (tonnes)

Y_{jt} = Amount of pellet type j produced in period t (tonnes)

Z_{jt} = Amount of pellet type j stored in period t (tonnes)

UFD_{jlt} = Amount of unfulfilled demand of pellet type j demanded by retailer l in period t (tonnes)

W_{jlt} = Amount of pellet type j sold and shipped to retailer l in period t (tonnes)

2.2.11.5 Constraints

1) Pellet Inventory Constraints

   a. For period 1: The amount of pellets produced in the current period, minus the sum of the amount of pellets sold and shipped to all 40 retailers in the current period, minus the amount of pellets stored this period must equal zero:

[2] $$Y_{jt} - \sum_{l=1}^{40} W_{jlt} - Z_{jt} = 0$$ for each j = 1, 2; and t = 1,…,12

   b. For each subsequent period: The amount of pellets produced in the current period, plus the amount of pellets stored in the previous period, minus the sum of the amount of pellets sold and shipped to all 40 retailers in the current period, minus the amount of pellets stored this period must equal zero:

[3] $$Y_{jt} + Z_{j(t-1)} - \sum_{l=1}^{40} W_{jlt} - Z_{jt} = 0$$ for each j = 1, 2; and t = 1,…,12

2) Residue Inventory Constraints

a. For period 1: The amount of residue used in the current period for both pellet types, plus the amount of residue stored in the current period, minus the amount of residue purchased from the two suppliers in the current period must equal zero:

[4] $$\sum_{j=1}^{2} X_{ijt} + U_{ikt} - \sum_{k=1}^{2} V_{ikt} = 0$$ for each i = 1,2; and t = 1,…,12

b. For each subsequent period: The amount of residue used in the current period for both pellet types, plus the amount of residue stored in the current period, minus the amount of residue stored in the previous period, minus the amount of residue purchased from the two suppliers in the current period must equal zero:

[5] $$\sum_{j=1}^{2} X_{ijt} + U_{ikt} - U_{ik(t-1)} - \sum_{k=1}^{2} V_{ikt} = 0$$ for each i = 1,2; j= 1,2; and t = 1,…,12

3) Primary information from ILW indicated that pellet yield from residue is approximately 98%; therefore, 1.02 times more residue is required than the quantity of pellets produced The amount of residue used must be 1.02 times more than the amount of pellets produced:

[6] $$\sum_{\mathrm{i=1}}^{2} \mathrm{X_{ijt}} - 1.02\mathrm{Y_{jt}} = 0$$ for each j = 1, 2; and t = 1,…,12

4) The amount of pellets sold in one period, plus the unfulfilled demand in the same period must equal the demand for that period:

[7] $$W_{jlt} + UFD_{jlt} = G_{jlt}$$ for each j = 1, 2; l = 1,…,40; and t = 1,…,12

5) The amount of residue purchased in one period cannot exceed the available supply of residue for that period:

[8] $$V_{ikt} \leq H_{ikt}$$ for each i=1,2; j = 1, 2; and t = 1,…,12

6) Pellet type j = 2 must be composed entirely of residue type i = 2:

[9] $$X_{(i=2)jt} = 1.02Y_{(j=2)t}$$ for each t = 1,…,12

7) Primary information from ILW indicated that there are three pellet presses available for processing, each with a per-period capacity of 240 tonnes; therefore the sum of all pellets produced in period t cannot exceed 720 tonnes:

[10] $$\sum_{j=1}^{2} Y_{jt} \leq 720$$ for each t = 1,…,12

8) The amount of residue type i from supplier k stored in period t must equal zero:

[11] $$U_{ikt} = 0$$ for each i = 1,2; k = 1,2; and t = 1,…,12

9) Amount of residue type i purchased from supplier k in period t must be greater than or equal to zero:

[12] $$V_{ikt} \geq 0$$ for each i = 1,2; k = 1,2; and t = 1,…,12

10) Amount of pellet type j sold and shipped to retailer l in period t must be greater than or equal to zero:

[13] $$W_{jlt} \geq 0$$ for each j = 1,2; l = 1,…,40; and t = 1,…,12

11) Amount of residue type i used to make pellet type j in period t must be greater than or equal to zero:

[14] $X_{ijt} \geq 0$ for each i = 1,2; j = 1,2; and t = 1,…,12

12) Amount of pellet type j produced in period t must be greater than or equal to zero:

[15] $Y_{jt} \geq 0$ for each j = 1,2; and t = 1,…,12

13) Amount of pellet type j stored in period t must be equal to zero:

[16] $Z_{jt} = 0$ for each j = 1,2; and t = 1,…,12

2.2.12 Model 2: Demand Flow Inventory Policy with Variable Production

To create model 2, the following two constraints were modified from model 1:

8) The amount of residue type i stored from supplier k in period t must be greater than or equal to zero:

[17] $U_{ikt} \geq 0$ for each i = 1,2; k = 1,2; and t = 1,…,12

13) The amount of pellet type j stored in period t must be greater than or equal to zero:

[18] $Z_{jt} \geq 0$ for each j = 1,2; and t = 1,…,12

2.2.13 Model 3: Demand Flow Inventory Policy with Constant Production

To create model 3, the following three constraints were modified from model 1:

7) The sum of all pellet type j produced in period t must equal 500 tonnes:

[19] $$\sum_{j=1}^{2} Y_{jt} = 500$$ for each t = 1,…,12

8) The amount of residue type i stored from supplier k in period t must be greater than or equal to zero:

[20] $$U_{ikt} \geq 0$$ for each i = 1,2; k = 1,2; and t = 1,…,12

13) The amount of pellet type j stored in period t must be greater than or equal to zero:

[21] $$Z_{jt} \geq 0$$ for each j = 1,2; and t = 1,…,12

2.3 METHODS FOR OBJECTIVE 2

Demand values are treated as random, or stochastic, variables subject to variations due to chance. In order to mimic this level of randomness in the creation of the stochastic demand set, the historical demand data was first input into a forecasting model; PeerForecaster® which allows for the end-user to select seasonal and trend specifications for the dataset, from which the software applies the most applicable and effective forecasting method. The approximate two-year historical demand dataset obtained from ILW for pellet 1 was input into this model (Appendix I). As explained in section 2.1.6, the demand for pellet 2 had no original observed data, and therefore did not have its demand forecasted using the PeerForecaster® software. Specifically, the seasonal additive Holt-Winters method was used for the linear time series with constant (additive) seasonal variations, with dampened increasing trend. The PeerForecaster® software required minimal data and was very easy to use.

These total forecast values for pellet 1, from the 24 periods were averaged to give a starting per-period total demand schedule, from which 100 subsequent demand sets were generated. These 100 sets were created using random number generation in Microsoft Excel®, using the RANDBETWEEN (bottom, top) function for each of the total demand values. The RANDBETWEEN (bottom, top) function returns a uniformly distributed integer, between the possible minimum (bottom) and maximum (top) values specified. The maximum and minimum values were generated for each period's total demand output from the forecasting software, with a 95% confidence interval (Appendix II). The total demand values for each period were spread amongst each of the 40 pellet 1 retailers based on an average proportion that was calculated from the distribution of the original observed demand dataset. The demand values for pellet 2 were also calculated 100 times, for the 19 retailers identified as having potential pellet 2 demand. The RANDBETWEEN (bottom, top) function was used for the minimum (bottom) value of 0 tonnes, and the maximum (top) value of 5 tonnes, to generate pellet 2 demand figures. The pellet 2 demand values were then combined with the demand values for pellet 1, to create 100 total demand datasets. These 100 datasets were run through each of the three models as 100 iterations, to determine how the GM is affected with fluctuating demand. The GM results for each of the three models were graphed together for a visual comparison of the performance of each model (Figure 5). This comparison illustrates why the operational environment specified in model 2 should be selected for GM optimization by wood pellet producers. This model will be subjected to further analysis with 11 different scenarios, as specified in section 2.4.

2.4 METHODS FOR OBJECTIVE 3

Stochastic demand schedules were created for pellet 1 and pellet 2. In order to create the schedule for pellet 1, the total demand values in the 100 datasets (explained in section 2.3) were averaged and applied to each of the 40 pellet 1 retailers based on the aforementioned calculated proportional distribution. The stochastic demand schedule for pellet 2 was created by averaging the total demand values for pellet 2, obtained from random number generation (explained in section 2.3). The factors that the producers have the ability to manipulate in order to obtain optimal GMs under uncertain demand scenarios include: inventory levels (of both pellets and residue), production capacity, production rates and the delivery schedule of the finished pellets to different retailers (which affects unfulfilled demand). Eleven plausible scenarios were developed and applied to the chosen model, using the stochastic demand set as the base demand input values. The scenarios contain altered input values for various model components. The results of these scenario runs were compared with the output from the stochastic demand set in order to determine the sensitivity of the model to changes in particular input factors.

2.4.11 Scenarios

This section explains each scenario that was applied to the chosen model, and is organized according to the affected parameter.

2.4.21 Demand

1) Scenario 1: Monthly demand for heating pellets increases by 25%.

    a. Given the recent popularity of wood pellets for heating, the likelihood of a retailer increasing their future demand is high (WPAC 2014). Therefore, in an effort to demonstrate the impact this may have on the producer, the demand schedule for heating pellets is increased by 25% for each retailer.

2) Scenario 2: Bedding pellet demand is only 50% of projected.

    a. The demand for bedding pellets was created based on pure estimates, without historical demand data, as described in section 2.1.4. Therefore, it is likely that the actual level of demand will vary. To showcase the effect an incorrect estimation may have on the GM and the inventory levels of the pellet producer, demand levels for bedding pellets were cut by 50%.

2.4.22 Supply

3) Scenario 3: Supply shortage from supplier 1 for last three periods of the year.

    a. The lumber received from the suppliers depends on timber yield from specific Forest Management Units (FMUs) in Ontario that the suppliers have licences to harvest from. There are many factors, both natural and man-made, that may affect timber yield. These may include forest fires, insect outbreaks, and poor management techniques (whether from inexperience of employees, or incorrect data). The point is that planned supply of residue needed to manufacture the wood pellets is subject to uncertainty, and cannot be assumed to remain stable. Therefore, this scenario has been employed to explore the effects of supply shortages, on GM and inventory levels. It is assumed that forest fires eradicated part of supplier 1's timber license at the end of August. The supplier still has enough timber in storage to supply the pellet manufacturer with the normal amount of wood through September, but lumber supply (and therefore, residue supply for pellets) for the months of October, November, and December is significantly reduced, to only 25% of normal supply. This reduction is made to enable the supplier to spread out their remaining stock so all of their customers receive at least a portion of their required supply. Supplier 1 gains access to a different FMU in December, and is able to resume normal supply levels to all manufacturers at the beginning of January.

1) Scenario 4: The manufacturer amplifies its intake of lumber by 50%, in order to create more of its primary wood products, as a response to a stable increase in market demand of those primary wood products. The amount of available residue increases in tandem with this additional production.

   b. Results from the model show that (all other things remaining equal) the pellet manufacturer has available capacity to produce more wood pellets and is currently only limited in doing so by its residue supply.

The model also indicates that given its current level of wood pellet production, the producer is not able to meet current levels of heating pellet demand. Therefore, this scenario illustrates the outcome of the producer having access to more wood residue. Since the wood pellet producer's supply of residue is generated directly from the wood waste of its processing operations for primary wood products, the feasibility of this scenario depends on an increase in production of those primary wood products.

c. The producer is assumed to maintain a continual rate of primary wood product production, using all of its purchased lumber each period in order to maintain this rate. This continual production level yields a consistent amount of residue per period for wood pellet production. Therefore, in order for the amount of residue to increase, the amount of lumber for primary wood product manufacturing must increase.

2) Scenario 5: Unlimited residue supply.

a. This scenario builds on scenario 4, assuming the producer has expanded their operations to intake a substantially higher quantity of lumber from which residue is created and/or they have entered into a purchase agreement with a residue supplier. The outcome is that a constant supply of residue is available that exceeds production capacity each period.

b. This scenario has been executed in order to determine the sensitivity of the model to residue availability once production capacity has been reached.

2.4.23 <u>Costs</u>

Costs are influenced by many factors. Transportation costs are influenced by volatile gasoline and diesel prices, while production costs are hugely influenced by the cost of electricity, which has been steadily increasing and is forecast to continue along this rising trend (Leslie 2013). The cost of holding inventory is minimal for wood pellets and residue for this manufacturer, as the storage space requires minimal upkeep due to the characteristics of the non-perishable residue and pellet products being stored (Normand Lacroix, pers. comm. July 15, 2013). The unfulfilled demand penalty is calculated based on money borrowed, and may change depending on the size of the loan and/or the interest rate on the loan (Normand Lacroix, pers. comm. July 15, 2013). The following cost-based scenarios are used to explore how cost fluctuations can affect the GM and/or inventory levels of the pellet manufacturer.

3) Scenario 6: Residue holding costs double
4) Scenario 7: Inventory holding costs double
5) Scenario 8: Transportation costs for residue and pellets increases by 25%
6) Scenario 9: Production costs increase by 50%
7) Scenario 10: unfulfilled demand penalty increases by 50%

2.4.24 <u>Revenue</u>

8) Scenario 11: Revenue from heating pellet sales decreases by 15%, to approximately $190 per tonne.

c. With the advancements in Ontario's bioeconomy (BIC 2013), specifically the rising popularity of wood pellets, future pellet prices are assumed to decrease, in order for manufacturers to become more competitive as wood pellets shift towards becoming a commodity item. Once ENplus certification takes hold in Canada and all manufacturers are required to abide by the same production standards (Table 1), producers will have to compete more intensely. Since the unstable economy also means less job stability and less income for the average Ontario family more opportunities for cost savings will be seized by consumers (LIEN 2013).

2.4.12 Assumptions

In order to illustrate the applicability of the model some data was estimated to fill in knowledge gaps and create a solid premise for this study. The following assumptions were made:

1) Bedding pellet demand estimation as explained in section 2.1.7.
2) Unfulfilled demand was not carried over into the next period, instead all unfulfilled demand incurred is assumed to be filled by alternate wood pellet producers in the required period.
3) Consistent residue supply available in each period (Appendix I)
4) Both residue purchase cost and transportation cost factors were included in the model in order for it to be more representative of other wood pellet producers who must purchase and transport residue to their manufacturing facility, even though ILW uses their own wood residue and therefore does not incur residue

purchase or transportation cost for wood pellet production. This assumption was made because it is much easier to already have those parameters incorporated into the model than to omit them from this study entirely and then have to construct them later on for future studies of producers who do incur these costs.

5) The exact distance between ILW and GG's Tru Hardware in Moose Factory, ON could not be calculated from Google Maps ® and was therefore estimated as the distance between ILW in Hearst, ON and Cochrane, ON, plus an additional 250 km.
6) Variable production rates were assumed to be a feasible option for ILW, in order to illustrate the effect that variable demand has on production levels. This assumption is realistic for ILW because wood pellets are a secondary product and much of their operating revenue is realized through the manufacture of their primary wood items.

3 RESULTS

This section presents the results from the analysis in order to achieve each specific objective outlined in section 1.5.

3.1 RESULTS FROM OBJECTIVE 1

A non-inventory, GM maximization model (model 1) and two GM maximization models with demand flow inventory policies were created using MPL®. One inventory model was created with a variable rate of pellet production for each period (model 2) and the other inventory model was created with a specified, constant rate of pellet production for each period (model 3). This constant level of production was set to the maximum possible level, based on monthly residue supply (Appendix I). Refer to Appendix III for the MPL® syntax of the three models.

3.2 RESULTS FROM OBJECTIVE 2

Historical, observed demand data for ILW were compiled (Appendix I) and graphed (see Figure 4). Note the seasonal pattern followed by this demand in Figure 4. These demand data were input into PeerForecaster® in order to obtain a demand forecast output (Appendix II). Through the PeerForecaster® software, the Holt-Winters exponential smoothing method with damped trend was applied. This method uses a weighted average, with more weight given to the most recent observations, while taking seasonality and trend into account. The damped trend reduced (damped) the tendency of the demand to increase over the forecast horizon, thus increasing the forecast accuracy. This demand forecast output was then used to generate 100 subsequent datasets, using the RANDBETWEEN (bottom, top) function in Microsoft Excel®, between the minimum and maximum values for each period, specified by PeerForecaster®.

As indicated by Figure 5, the GM for model 2 – demand flow inventory with variable production is consistently higher than both models 1 and 3, throughout the 100 iterations. The average GM for model 1 is $459,239, the average GM for model 2 is $499,642, and the average GM for model 3 is $313,050. The average GM for model 2 is approximately 8% greater than that of model 1, and approximately 37% greater than that of model 3. Model 2 also has a lower degree of variability between values than the other two models.

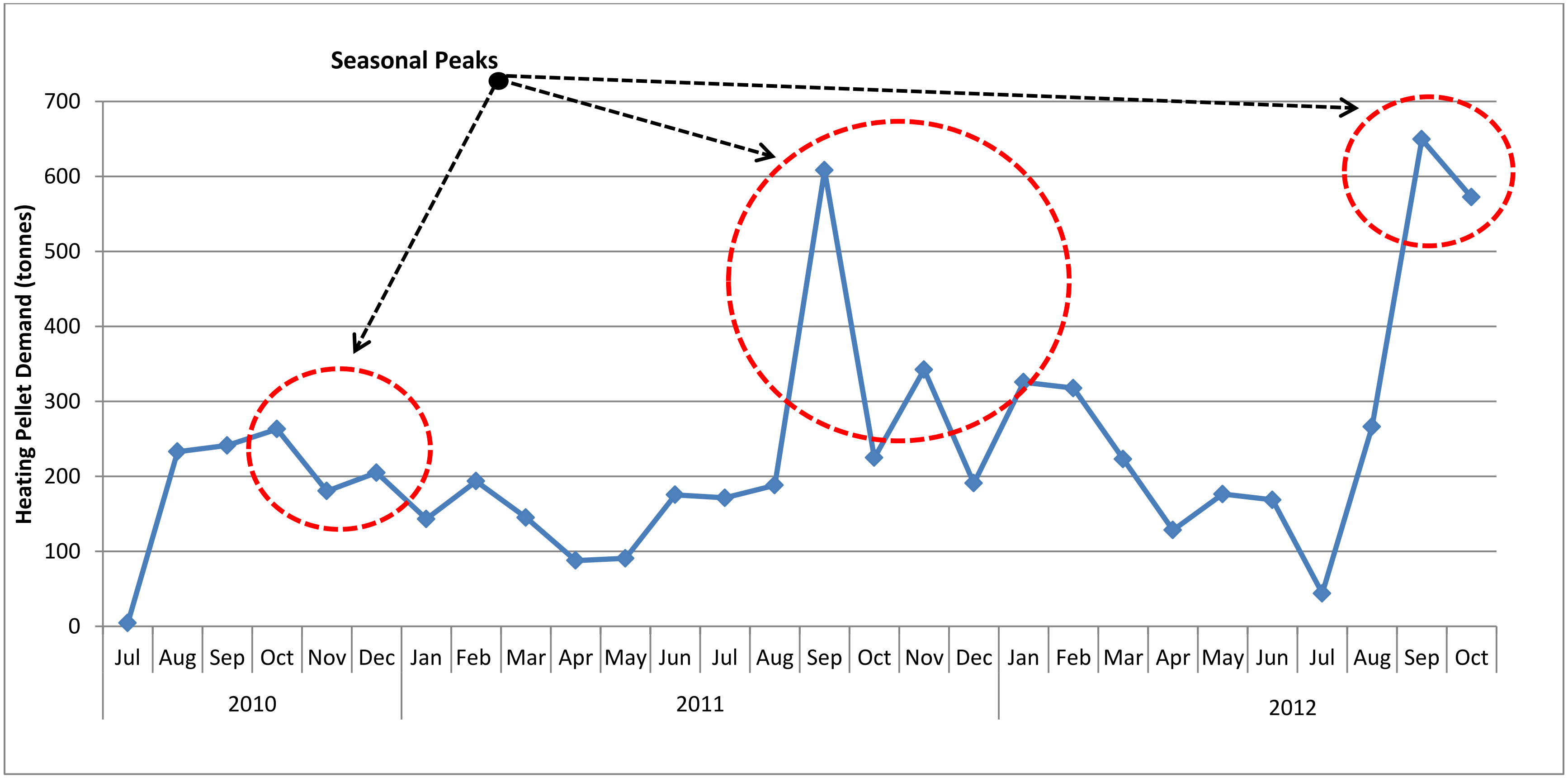


Figure 4. Original historical demand values from ILW, demonstrating a pattern of seasonality (Appendix I).

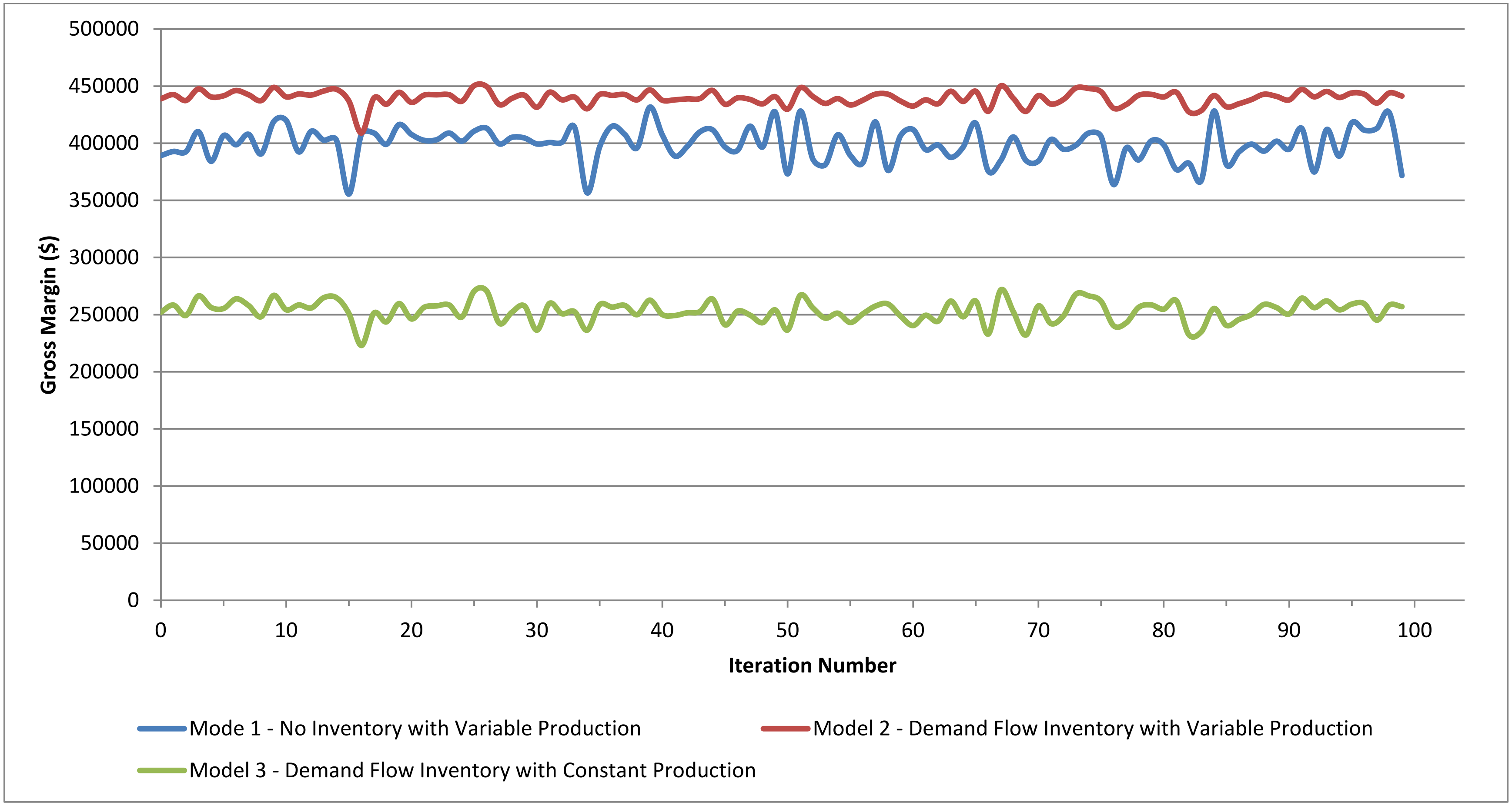


Figure 5. A comparison of GM results for each of the 100 iterations, from each of the three models (Appendix III).

3.3 RESULTS FROM OBJECTIVE 3

The 100 datasets from objective 2 were averaged to obtain one dataset used as a stochastic demand schedule (Table 4). This demand schedule was run through model 2 – demand flow inventory with variable production, and the output (Table 5) was used as the benchmark to compare the outputs from model 2 runs for each of the eleven scenarios explained in section 2.4.11.

Table 4. Stochastic demand schedule for each period and both pellet types.

Period	Corresponding month	Stochastic demand for pellet 1 (tonnes)	Stochastic demand for pellet 2 (tonnes)
1	Jan	359	44
2	Feb	368	55
3	Mar	296	33
4	Apr	207	56
5	May	239	49
6	Jun	278	38
7	Jul	218	43
8	Aug	376	41
9	Sep	664	61
10	Oct	493	48
11	Nov	377	54
12	Dec	327	62

The results of each scenario have been summarized in chart format and in graphical format to clearly identify and contrast the demand, production, inventory levels and unfulfilled demand for pellet 1 and pellet 2.

Table 5. Output from the inventory model using the stochastic demand schedule from Table 4.

GM = $447,384

Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300	7	11	33	33		
4	207	300		104	56	56		
5	239	300		165	49	49		
6	278	300	32	219	38	38		
7	218	300	19	320	43	43		
8	376	300	9	253	41	41		
9	664	300	147	36	61	61		
10	493	300	157		48	48		
11	377	300	77		54	54		
12	327	300	27		62	62		

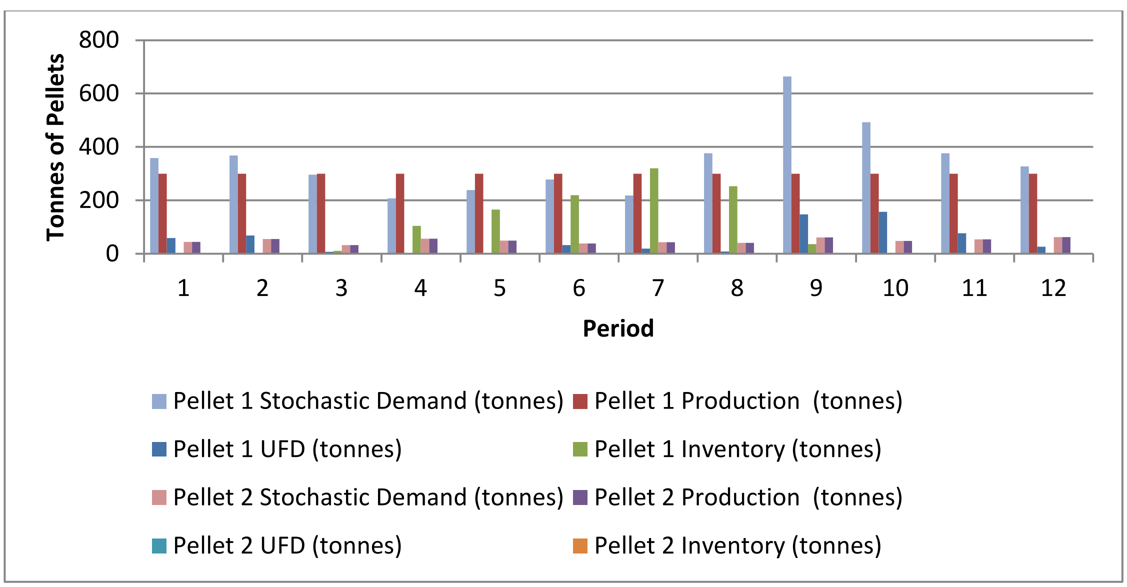


Figure 6. Graphical representation of the base case output from model 2.

3.3.1 Demand

Table 6. Scenario 1: Monthly demand for heating pellets increases by 25%.

GM = $444,035								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	448.75	300	148.75		44	44		
2	460	300	160		55	55		
3	370	300	70		33	33		
4	258.75	300	13.75	55	56	56		
5	298.75	300		56.25	49	49		
6	347.5	300	40	48.75	38	38		
7	272.5	300	26.25	102.5	43	43		
8	470	300	238.75	171.25	41	41		
9	830	300	376.25	17.5	61	61		
10	616.25	300	298.75		48	48		
11	471.25	300	171.25		54	54		
12	408.75	300	108.75		62	62		

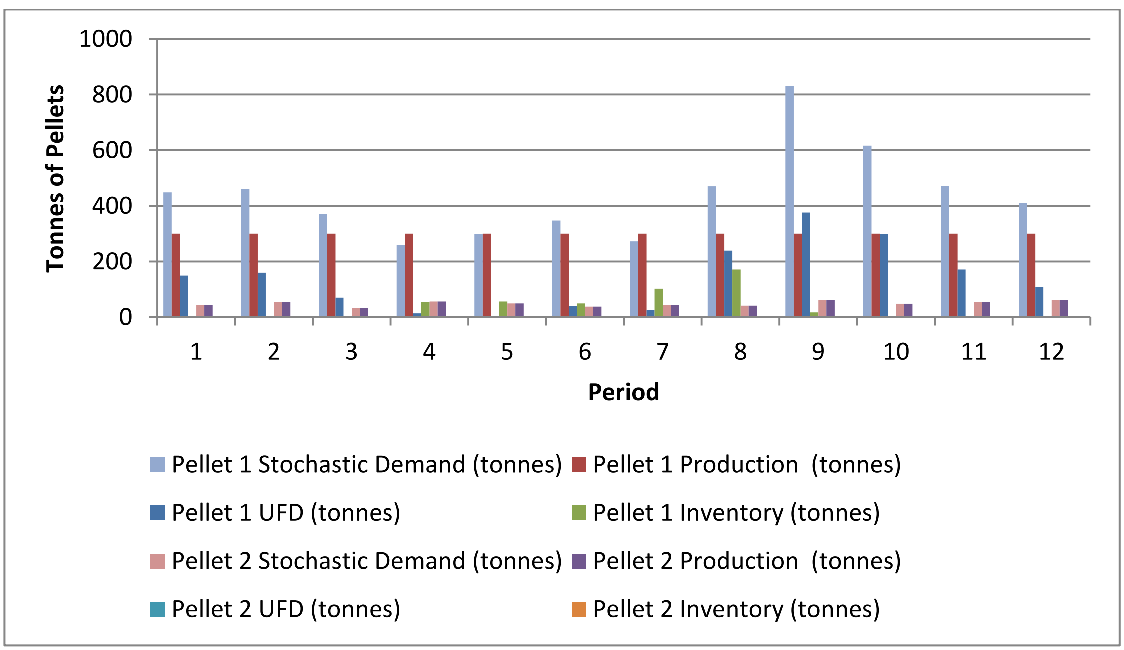


Figure 7. Graphical representation of scenario 1 output from model 2.

Table 7. Scenario 2: Bedding pellet demand is only 50% of projected.

GM = $404,807								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		22	22		
2	368	300	68		27.5	27.5		
3	296	300	7	11	16.5	16.5		
4	207	300		104	28	28		
5	239	300		165	24.5	24.5		
6	278	300	32	219	19	19		
7	218	300	19	320	21.5	21.5		
8	376	300	9	253	20.5	20.5		
9	664	300	147	36	30.5	30.5		
10	493	300	157		24	24		
11	377	300	77		27	27		
12	327	300	27		31	31		

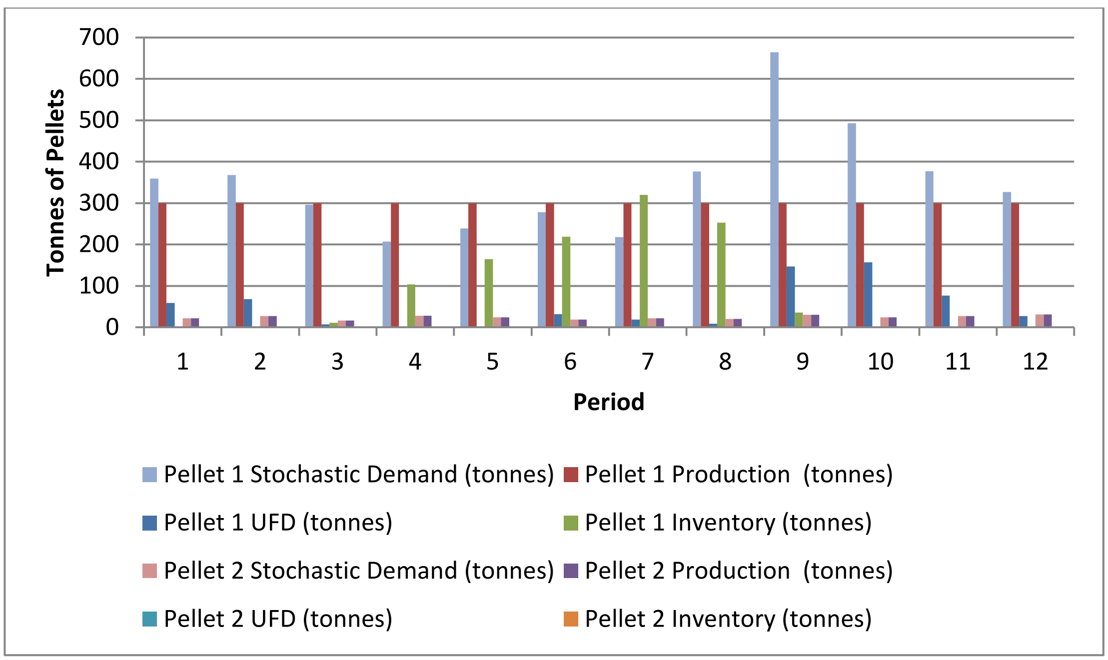


Figure 8. Graphical representation of scenario 2 output from model 2.

3.3.2 Supply

Table 8. Scenario 3: Supply shortage from supplier 1 for the last three periods of the year.

GM = $362,445								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300	7	11	33	33		
4	207	300	11	115	56	56		
5	239	300		176	49	49		
6	278	300	39	237	38	38		
7	218	300	62	381	43	43		
8	376	300	191	496	41	41		
9	664	300	301	433	61	75		14
10	493	75	239	254	48	50		16
11	377	75	176	128	54	50		12
12	327	75	124		62	50		

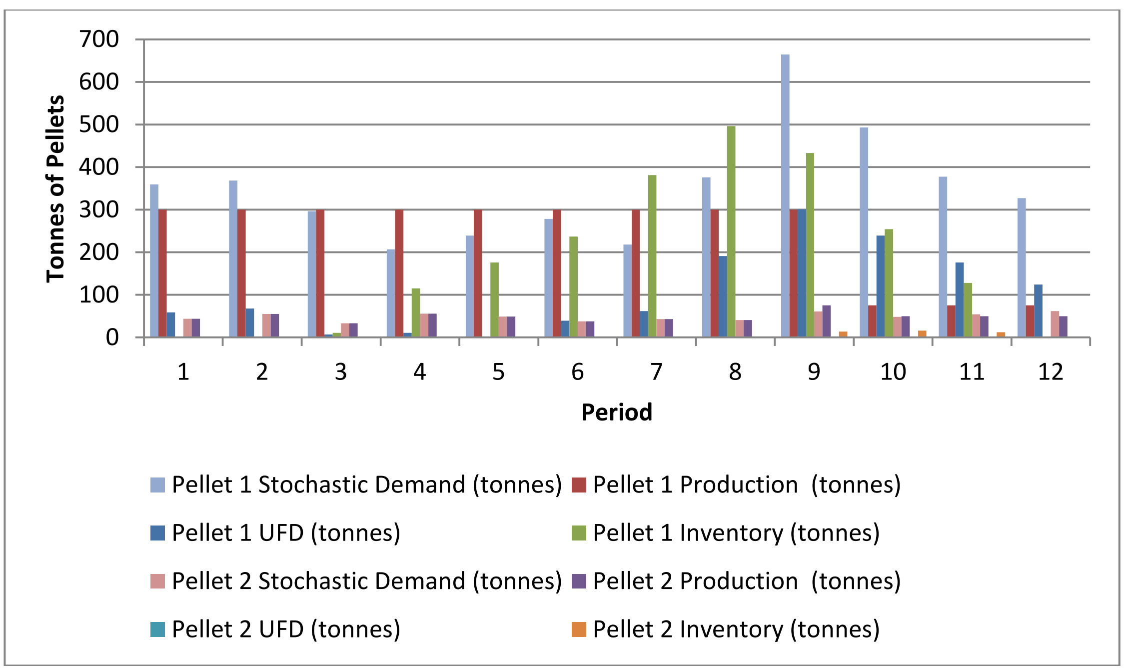


Figure 9. Graphical representation of scenario 3 output from model 2.

Table 9. Scenario 4: The manufacturer increases its intake of lumber from the two suppliers by 50%.

GM = $519,075								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	359			44	44		
2	368	368			55	55		
3	296	296			33	33		
4	207	207			56	56		
5	239	239			49	49		
6	278	278			38	38		
7	218	401		183	43	43		
8	376	450		257	41	41		
9	664	450		43	61	61		
10	493	450			48	48		
11	377	377			54	54		
12	327	327			62	62		

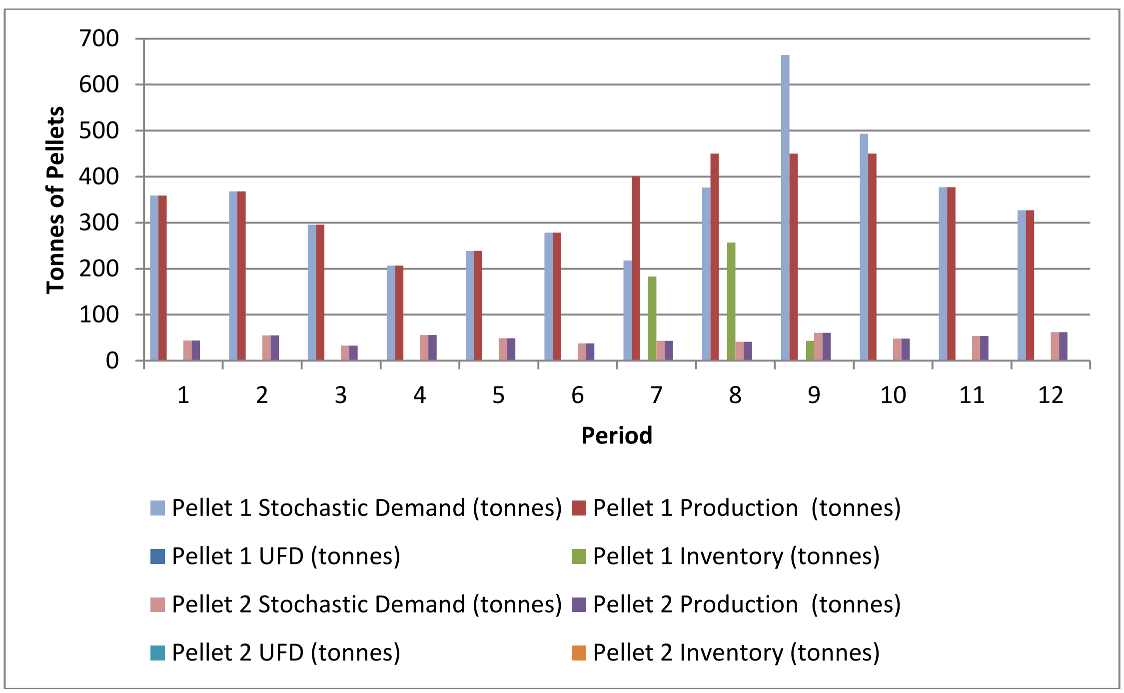


Figure 10. Graphical representation of scenario 4 output from model 2.

Table 10. Scenario 5: Unlimited residue supply.

GM = $519,945								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	359			44	44		
2	368	368			55	55		
3	296	296			33	33		
4	207	207			56	56		
5	239	239			49	49		
6	278	278			38	38		
7	218	218			43	43		
8	376	376			41	46		5
9	664	664			61	56		
10	493	493			48	48		
11	377	377			54	54		
12	327	327			62	62		

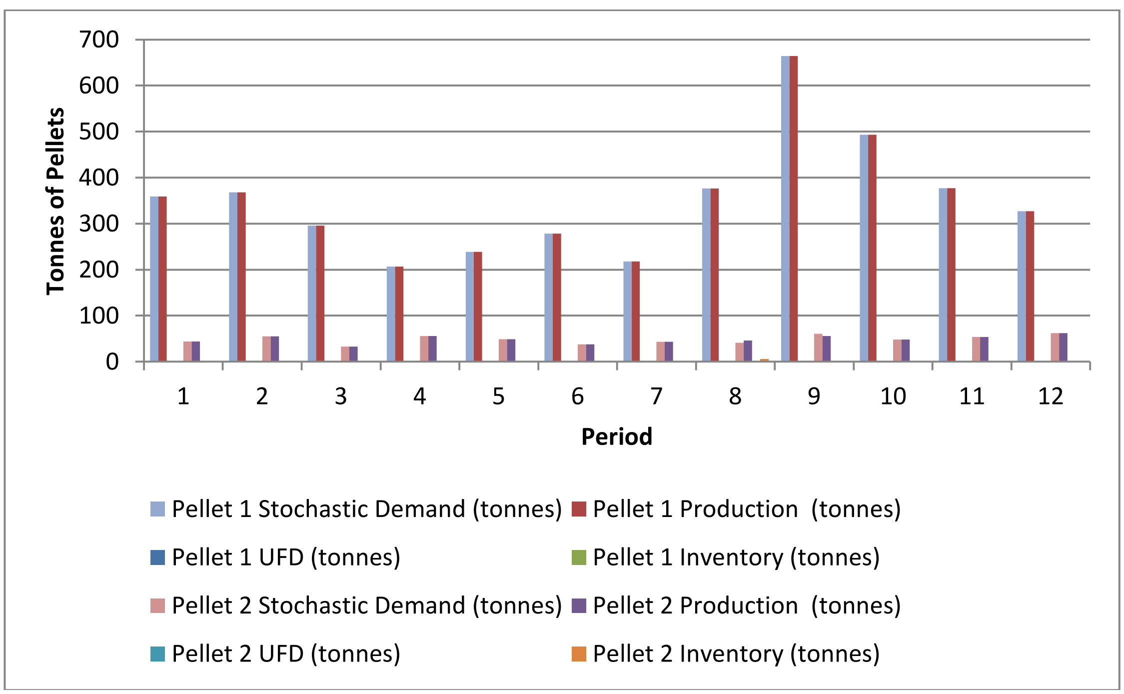


Figure 11. Graphical representation of scenario 5 output from model 2.

3.3.3 Costs

Table 11. Scenario 6: Residue holding costs double.

GM = $447,384								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300	7	11	33	33		
4	207	300		104	56	56		
5	239	300		165	49	49		
6	278	300	32	219	38	38		
7	218	300	19	320	43	43		
8	376	300	9	253	41	41		
9	664	300	166	55	61	61		
10	493	300	138		48	48		
11	377	300	77		54	54		
12	327	300	27		62	62		

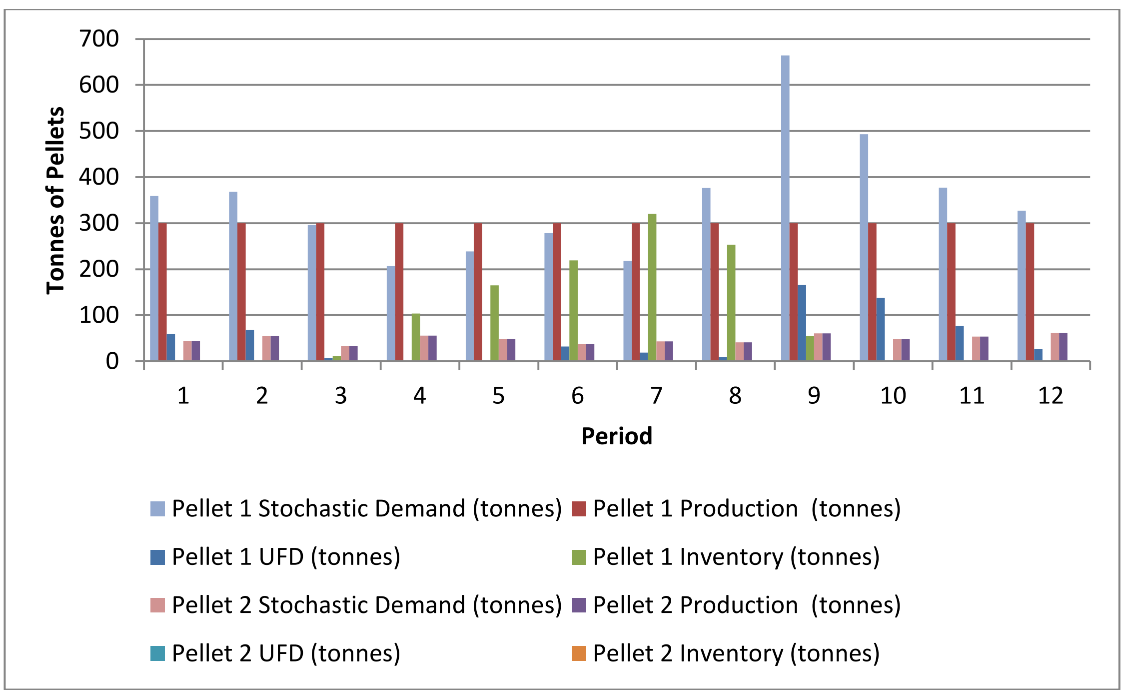


Figure 12. Graphical representation of scenario 6 output from model 2.

Table 12. Scenario 7: Inventory holding costs double.

GM = $445,540								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300		4	33	33		
4	207	300		97	56	56		
5	239	300		158	49	49		
6	278	300	32	212	38	38		
7	218	300		294	43	43		
8	376	300	9	227	41	41		
9	664	300	137		61	61		
10	493	300	193		48	48		
11	377	300	77		54	54		
12	327	300	27		62	62		

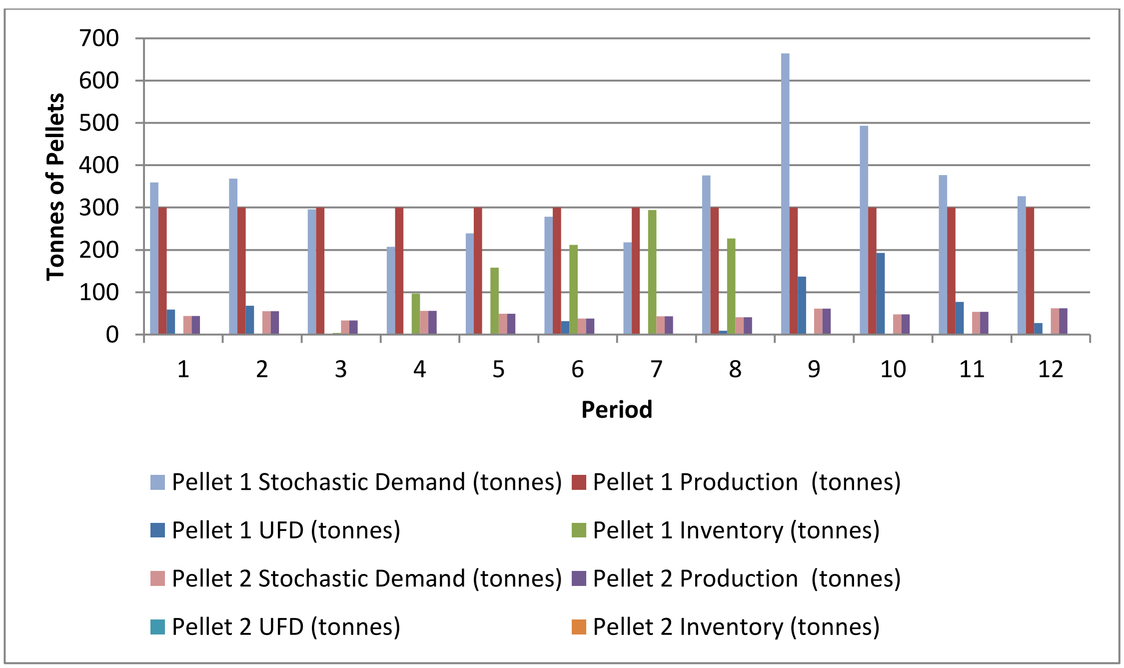


Figure 13. Graphical representation of scenario 7 output from model 2.

Table 13. Scenario 8: Transportation costs for residue and pellets increase by 25%.

GM = $405,220								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300	7	11	33	33		
4	207	300		104	56	56		
5	239	300		165	49	49		
6	278	300	32	219	38	38		
7	218	300	19	320	43	43		
8	376	300	9	253	41	41		
9	664	300	166	55	61	61		
10	493	300	138		48	48		
11	377	300	77		54	54		
12	327	300	27		62	62		

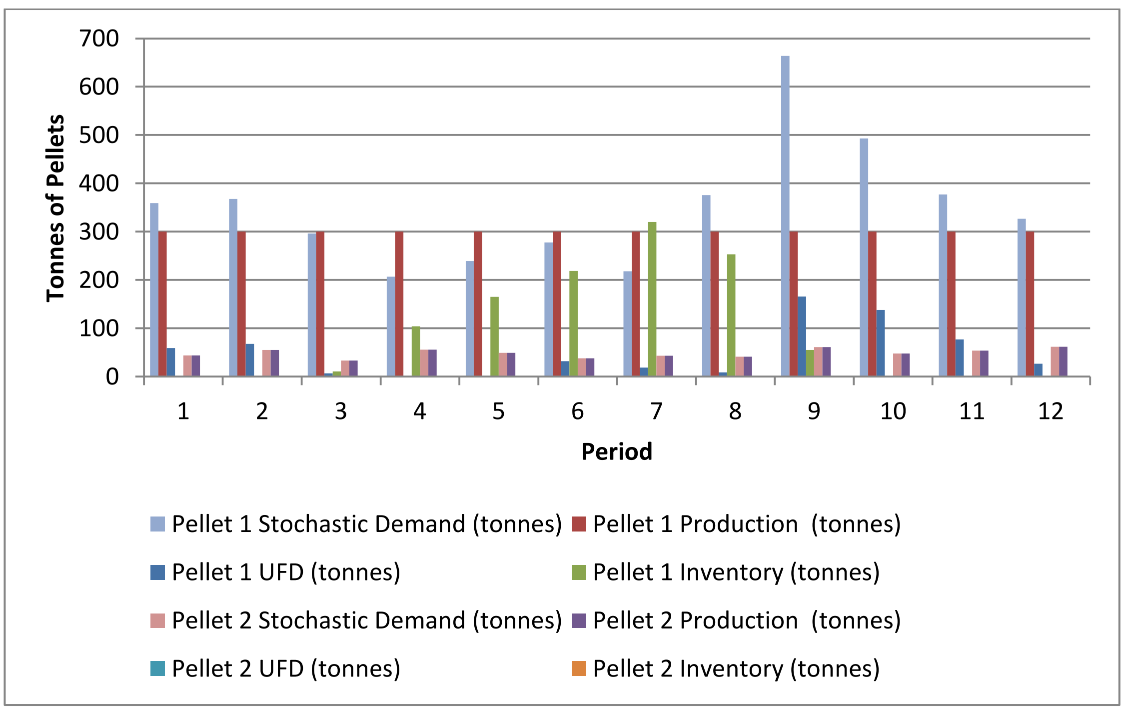


Figure 14. Graphical representation of scenario 8 output from model 2.

Table 14. Scenario 9: Production costs increase by 50%.

GM = $311,404								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300	7	11	33	33		
4	207	300		104	56	56		
5	239	300		165	49	49		
6	278	300	32	219	38	38		
7	218	300	19	320	43	43		
8	376	300	9	253	41	41		
9	664	300	147	36	61	61		
10	493	300	157		48	48		
11	377	300	77		54	54		
12	327	300	27		62	62		

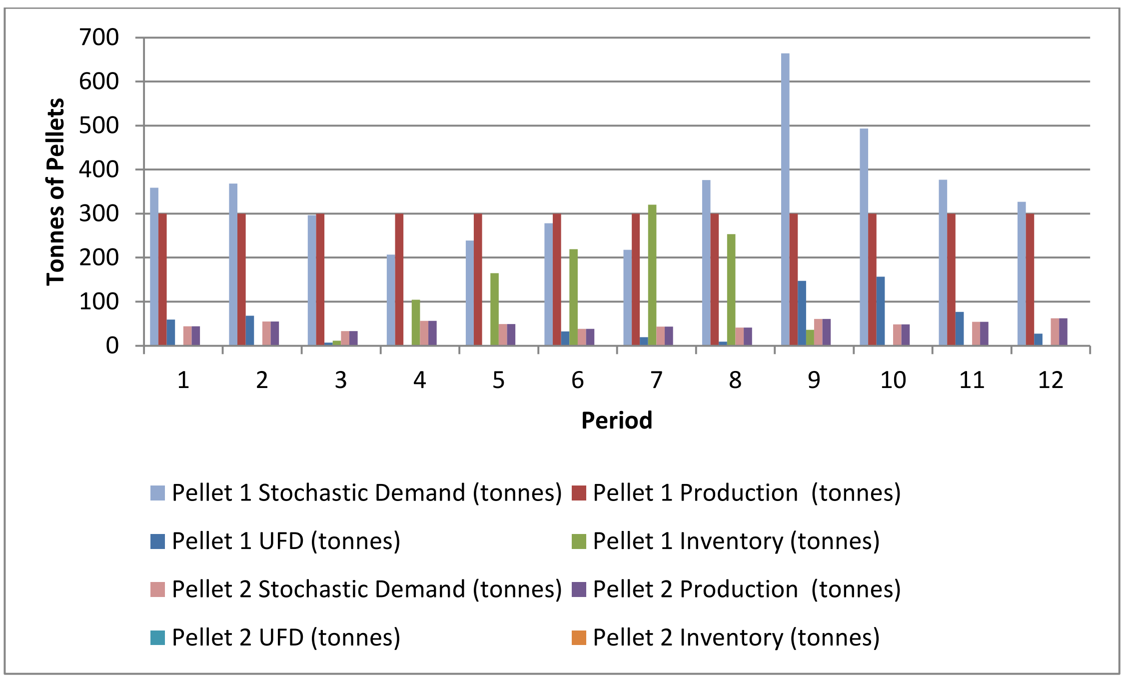


Figure 15. Graphical representation of scenario 9 output from model 2.

Table 15. Scenario 10: unfulfilled demand penalty increases by 50%.

GM = $445,354								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300	7	11	33	33		
4	207	300		104	56	56		
5	239	300		165	49	49		
6	278	300	32	219	38	38		
7	218	300	19	320	43	43		
8	376	300	9	253	41	41		
9	664	300	147	36	61	61		
10	493	300	157		48	48		
11	377	300	77		54	54		
12	327	300	27		62	62		

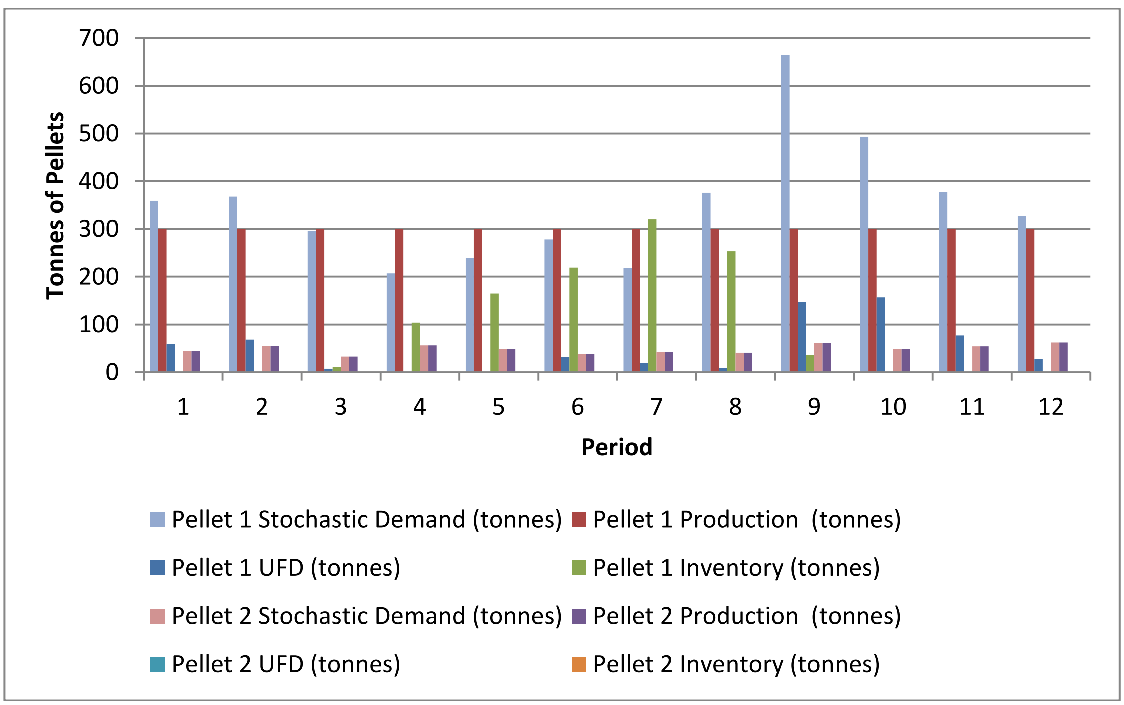


Figure 16. Graphical representation of scenario 10 output from model 2.

3.3.4 Revenue

Table 16. Scenario 11: Revenue from heating pellet sales decreases by 15%.

GM = $326,846								
Period	Pellet 1 stochastic demand (tonnes)	Pellet 1 production (tonnes)	Pellet 1 unfulfilled demand (tonnes)	Pellet 1 inventory (tonnes)	Pellet 2 stochastic demand (tonnes)	Pellet 2 production (tonnes)	Pellet 2 unfulfilled demand (tonnes)	Pellet 2 inventory (tonnes)
1	359	300	59		44	44		
2	368	300	68		55	55		
3	296	300	7	11	33	33		
4	207	300		104	56	56		
5	239	300		165	49	49		
6	278	300	32	219	38	38		
7	218	300	19	320	43	43		
8	376	300	9	253	41	41		
9	664	300	147	36	61	61		
10	493	300	157		48	48		
11	377	300	77		54	54		
12	327	300	27		62	62		

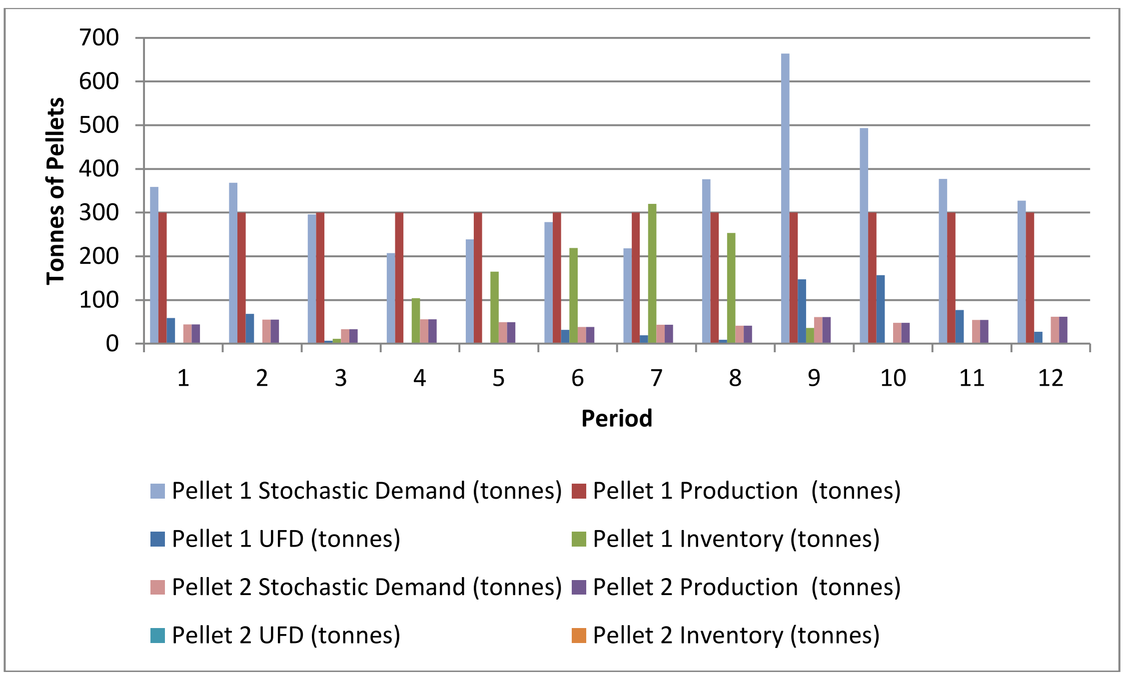


Figure 17. Graphical representation of scenario 11 output from model 2.

Table 17. Summary of the sensitivity exhibited by model 2 for each of the 11 scenarios.

Scenario	GM	Scenario factor test	Sensitivity	What changed?
1	$444,035	pellet 1 demand	high	pellet 1 inventory, pellet 1 unfulfilled demand
2	$404,807	pellet 2 demand		pellet 2 production[(1)]
3	$362,455	residue supply decrease	high	pellet 1 inventory, pellet 1 production, pellet 1 unfulfilled demand
4	$519,075	residue supply increase	high	pellet 1 inventory, pellet 1 production, pellet 1 unfulfilled demand
5	$519,945	unlimited residue supply	high until production capacity reached[(2)]	pellet 1 inventory, pellet 1 production, pellet 1 unfulfilled demand
6	$447,384	residue inventory holding costs increase	low	pellet 1 inventory
7	$445,540	pellet inventory costs increase	moderate	pellet 1 inventory, pellet 1 unfulfilled demand
8	$405,220	transportation cost increase	low	pellet 1 inventory, pellet 1 unfulfilled demand
9	$311,404	production cost increase		
10	$445,354	unfulfilled demand penalty increase		
11	$326,846	revenue from pellet 1 decrease		

(1) Production decreased in tandem with the change in scenario 2 and is therefore not considered a sensitivity indicator in this case.
(2) The sensitivity to the supply increase was high until the production capacity was reached. Then, supply availability increases to the magnitude of 999,999 tonnes had no effect on the model's output. Therefore, model 2 is considered to be insensitive to an unlimited supply of residue.

4 DISCUSSION

Model 2 – demand flow inventory with variable production consistently outperformed models 1 and 3 with its optimal GM outputs, therefore illustrating the importance of a variable rate of production and inventory control for the wood pellet facility. The use of 11 scenarios with variable inputs illustrated the operational-level decisions that may be made by managers with respect to levels of production, inventory and unfulfilled demand. This section of the paper compares the results from each of the eleven scenarios to the results from the stochastic demand dataset, then discusses the sensitivity determination for the comparison, followed by a discussion about the expected versus the actual results and provides an overview of potential future applications of model 2.

4.1 SCENARIOS

4.1.1 Base Case: Using the stochastic demand schedule

The GM calculated for the stochastic demand set from Table 4 is $447,384. The model output for the stochastic demand set utilized the maximum rate of production for pellet type 1, still the model was unable to produce enough pellets to meet the required demand, and unfulfilled demand penalties were incurred in all periods except 4 and 5 (Table 5). In some periods, even though demand was not satisfied, some inventory was still stored for pellet 1, which indicates it was a more cost-effective approach in those periods to incur some unfulfilled demand penalty costs and store some pellets to carry over to the next period. Inventory for pellet type 1 was held in periods 3 to 9, inclusive. In each period, the amount of pellets produced equaled the amount demanded for pellet 2. Therefore, no unfulfilled demand penalties, or inventory holding costs were incurred for pellet 2 in any of the 12 periods. The stochastic demand set is used as a basis for comparison with all of the following eleven scenarios.

4.1.2 Scenario1: Heating pellet demand increases by 25%

The GM decreased from $447,384 to $444,035. Even though demand increased, the supply of residue remained constant. Therefore, more unfulfilled demand penalty costs were incurred, as compared to those shown in Table 5. The inventory levels for pellet 1 changed as well; no inventory was held in period 3, and the levels of inventory were different for periods 4 to 9, inclusive, as compared to the same periods in Table 5. The model is sensitive to demand increases for heating pellets, and shows that some inventory level modifications can be made in order to optimize the GM of the producer.

4.1.3 Scenario 2: Bedding pellet demand is only 50% of projected

The GM decreased from $447,384 to $404,807. Since the supply did not change, the production level for pellet 1 remained constant, while the production level for pellet 2 decreased to meet demand in each period. Inventory was not held in any period for pellet 2, and inventory levels for pellet type 1 did not deviate from those in Table 5. The model shows some sensitivity to a decrease in bedding pellet demand; however, the changes are not surprising since the production level of pellet 2 in each period directly corresponds to the demand figures for pellet 2.

4.1.4 Scenario 3: Supply shortage from supplier 1 for the last three periods of the year

The GM decreased from $447,384 to $362,455. The production schedule for pellet 1 remained at its supply-induced maximum for periods 1 through 9, but decreased to 75 tonnes in the last three periods of the year; in-line with the supply shortage. Unfulfilled demand penalties were incurred in every period, except period 5, and inventory was held in periods 3 to 11, inclusive. The values for unfulfilled demand and pellet inventory vary significantly from those in Table 5. The amount of pellet 2 produced remained equal to the demand schedule for pellet 2 in periods 1 through 8, and in period 12. Periods 9, 10 and 11 had varying levels of production, and held inventory to maximize the GM. The model is also highly sensitive to decreases in residue supply, since supply dictates the manufacturer's ability to create the pellets being demanded.

4.1.5 Scenario 4: Residue supply increase of 50%

The GM increased from $447,384 to $519,075. The increased supply of residue caused more pellet 1 to be produced per-period than in Table 5, and demand was satisfied in every period. Inventory levels were also altered; inventory was held in periods 7, 8 and 9, indicating that it is more efficient to over-produce in these periods and carry some inventory forward to meet future demand. The production levels for pellet 2 remained equal to the demand schedule in each period; therefore unfulfilled demand penalty costs were not incurred in any of the 12 periods, nor was inventory held in any of the 12 periods for pellet 2. The model is highly sensitive to increases in supply of residue, and will continue to be so, until the maximum level of production is reached, based on the production capacity constraint for both pellet types (Appendix III).

4.1.6 Scenario 5: Unlimited residue supply

The GM increased from $447,384 to $519,945. The exact amount of pellet 1 demanded in each period was produced in that period, therefore no pellet 1 inventory was held, and there was no unfulfilled demand for pellet 1. Pellet 2 also had the same quantity produced each period as was demanded, except in periods 8 and 9; an inventory of 5 tonnes was held in period 8, and carried over to period 9. There was no unfulfilled demand for pellet 2 in any of the 12 periods. The model is only sensitive to supply fluctuations, as long as the production capacity has not been exceeded. Once production capacity was exceeded, the model sensitivity disappeared. The input factor for the available supply was increased to 999,999 tonnes to prove this point. This scenario illustrates that it does not matter how much residue is available if the producer has exhausted its capacity to utilize that residue for the production of more pellets.

4.1.7 Scenario 6: Residue inventory holding costs double

The GM remained the same, at $447,384. No residue inventory is held from period to period; therefore a change in price is inconsequential to the output of the model, with all other inputs remaining equal. All outputs remained consistent with the values in Table 5. However, the model may actually be sensitive to increases residue holding costs, but its inputs would have to be modified to cause residue retention, and then the outcome would require an assessment.

4.1.8 Scenario 7: Inventory holding costs double

The GM decreased from $447,384 to $445,540. Production remained at its maximum for pellet 1 in each period; however the unfulfilled demand and inventory values for pellet 1 changed significantly from the values in Table 5. Unfulfilled demand penalties were incurred in periods 1, 2, 6, and 8 through 12, while inventory was held in periods 3 through 8. Pellet 2 had production levels equal to demand levels in each of the 12 periods, and did not incur unfulfilled demand penalty costs, or have inventory held in any of the 12 periods. The model is sensitive to increases in inventory holding costs and will produce an altered inventory schedule based on these cost increases.

4.1.9 Scenario 8: Transportation costs for residue and pellets increase by 50%

The GM decreased from $447,384 to $405,220. The production schedule for pellet 1 remained at its maximum for this scenario as well. The amount of unfulfilled demand was similar, but there was an increase from 147 tonnes to 166 tonnes in period 9 and a decrease from 157 tonnes to 138 tonnes in period 10, as compared with Table 5. The inventory amounts were also very similar, except for an increase from 36 tonnes to 55 tonnes in period 9; corresponding to the unfulfilled demand fluctuations. The production levels for pellet 2 remained equal to the demand in all 12 periods, with no unfulfilled demand penalty costs, or inventory held in any of the 12 periods. The transportation costs do affect the model somewhat, and would undoubtedly have more of an effect on the model output if the costs were higher.

4.1.10 Scenario 9: Production costs increase by 50%

The GM decreased from $447,384 to $311,404. Analogous with scenario 6, everything remained consistent with the values in Table 5. The model is also not sensitive to production price increases, and will produce the same output, only with a lower GM to account for the increase in production costs.

4.1.11 Scenario 10: unfulfilled demand penalty increases by 50%

The GM decreased from $447,384 to $445,354. In-line with scenarios 6 and 9, everything remained consistent with the values in Table 5. The model is also not sensitive to increases in unfulfilled demand penalty costs, and will produce the same output, only with a lower GM to account for the increase in unfulfilled demand penalty costs.

4.1.12 Scenario 11: Revenue from heating pellet sales decreases by 15%

GM decreased from $447,384 to $326,846. Parallel to the results of scenarios 6, 9 and 10, everything remained consistent with the values in Table 5. The model is also not sensitive to decreases in revenue for pellet 1, and will produce the same output, only with a lower GM to account for the decrease in revenue per tonne of pellet 1.

4.2 SENSITIVITY

Model 2's level of sensitivity was determined not by the fluctuation in the GM, but by the fluctuation in the production, inventory and unfulfilled demand values; as the purpose of the model is to provide decision support regarding these operational-level components. The reason GM fluctuation is not monitored is because if only costs or revenue were to change, obviously the GM would change based on the new values, while production, inventory and unfulfilled demand values could remain equal. Therefore, GM is not an accurate measure of changes occurring within the model. Knowledge of the GM under different conditions is of course important, however, as it allows the pellet producer to plan around its expected future financial position.

Table 18 displays the percentage fluctuation corresponding to the different levels of sensitivity. The level of sensitivity was determined by observing the average values of production, pellet inventory and unfulfilled demand over the 12 periods, for the model 2 output from each scenario. The highest average value of the three indicators was considered for comparison with the sensitivity level.

Table 18. Model sensitivity bounds.

Sensitivity	Average percentage (%) fluctuation of either pellet inventory, production, or unfulfilled demand
Low	± 1 – 10%
Moderate	± 11 – 50%
High	± ≥ 51%

The price of raw material greatly affects the cost of pellet production (Obernberger and Thek 2010). ILW, therefore, experiences a great cost savings by utilizing their waste wood as raw material for pellets. However, as mentioned in section 2.1.5, the cost per tonne of residue was also incorporated into the model, with a conservative price estimate of $45/tonne (Normand Lacroix, pers. comm. October 26, 2012). Transportation costs from the suppliers to the manufacturer were also included in the model formulation for ease of malleability with other producers who must ship in residue instead of using their own. Scenario 9 illustrates that model 2 is not sensitive to pellet processing cost increases, as the only factor that changed was the GM, which decreased only to account for the higher processing expense.

It is important to realize that the sensitivity of the model to these factors will change depending on location and market conditions. For example, raw material supply may be more expensive in other areas, or the transportation distance may be increased or decreased. Revenue per tonne is bound to fluctuate depending on location and the level of competition experienced in a different location as well; there will be less revenue realized in a more competitive marketplace, and more revenue realized in a less competitive marketplace, with fewer pellet producers working to meet the demand.

5 CONCLUSIONS

Model 2 - inventory with variable production, serves as a basic operational-level DST for managers of Canadian/Ontarian wood pellet manufacturing plants. This model illustrates that a wood pellet manufacturer operating under uncertain demand conditions, with a variable production rate and inventory controls will be most sensitive to changes in demand and supply, with moderate sensitivity to inventory holding costs.

This model contains a great deal of practical value, as it will serve to improve the efficiency and effectiveness of wood pellet producers by helping them to change their input/output activities according to market signals and to maximize their GM for a given level of market demand. It is very adaptable and comprehensive; input values and dimensions may be easily modified based on changing information, which is especially important when working with uncertain demand. This model may be easily re-modified for use with other wood pellet manufacturers, in other jurisdictions as well.

This project successfully filled the following literature gaps specified in section 1.4: The need for additional Canadian studies about the wood pellet value chain; the need for more dynamic, demand-driven models for value chain optimization (under uncertain demand conditions); and the need for more managerial involvement at the operational level. This project has the potential to improve the competitiveness of Canadian wood pellet manufacturers, which will ultimately improve the overall competitiveness of the Canadian wood pellet market. This expectation appears reasonable because of the simplicity of the ultimate goal of the project; market differentiation. Wood pellet producers will directly benefit by operating at their most efficient level possible, which translates into reduced costs and cheaper end products for consumers.

5.1 LIMITATIONS OF RESEARCH

As previously mentioned, this model is an excellent stepping stone; however, its extent is limited. There are factors that were not incorporated into the model structure that may affect cost, and ultimately GM. For example, if provisions to include the specific pellet standards for ILW were taken into consideration (Table 3), factors such as MC percentage will affect drying costs of the raw materials. As stated in section 1.1.2 raw material costs and (when using wet raw materials) drying costs comprise the majority of total pellet production expenses, therefore these parameters would have a significant effect on the GM. Further scenario studies may also show that production costs do affect production levels, inventory and/or unfulfilled demand under certain conditions.

There was a strong assumption incorporated into the modeling process with the pellet 2 demand estimation. This estimation may be very far off from actual future demand figures and, therefore, has the potential to drastically affect the actual GM of ILW. However, the benefit of the model used in this study is that it may be easily modified to incorporate such changes.

5.2 FUTURE STUDIES

Additional studies conducted using this model with different pellet producers in various locales would help to improve its level of agility and utility; as would pairing with an extremely user-friendly, guided interface, like Visual Basic®, through which the end-user is prompted for specific input values. Also recommended are more scenario tests for each parameter and more results comparisons, to get a better handle on how these components of the wood pellet value chain will affect the producer. Multiple demand scenarios should be run with multiple supply scenarios, and with other varying inputs. However, this level of scenario testing is out of the scope of this project. This model was created as a stepping stone for other, larger models and (Canadian) forestry industry studies.

Future studies incorporating an analysis of various demand forecasting techniques and their proven abilities with this model will also help to improve its accuracy and precision. Though demand forecasting is an extremely important component of supply chain and value chain modeling, it is vital to note that this project was not undertaken to study the effectiveness of different forecasting techniques; the forecasted dataset was used for illustrative purposes to determine how demand affects the results of the optimization model.

6 LITERATURE CITED

Ackom, E.K., Mabee, W.E., and J.N. Saddler. 2010. Industrial sustainability of competing wood energy options in Canada. Applied Biochemical Biotechnology, 162: 2259-2272.

AEBIOM (European Biomass Association). 2012. ENplus Newsletter March 2012. AEBIOM. Brussels, Belgium. 6 pp.

AEBIOM (European Biomass Association). 2013. ENplus. AEBIOM. Brussels, Belgium. http://www.enplus-pellets.eu/. June 5, 2013.

Ahumada, O. and J.R. Villalobos. 2011. Operational model for planning the harvest and distribution of perishable agricultural products. Int. J. Production Economics, 133: 677-687.

Alakangas, E. and M. Virkkunen. 2007. EUBIONET II - Biomass fuel supply chains for solid biofuels, from small to large scale. VTT Technical Research Centre of Finland, Jyväskylä, Finland. 30 pp.

Alakangas, E., Junginger, M., van Dam, J., Hinge, J., Keränen, J., Olsson, O., Porsö, C., Martikainen, A., Rathbauer, J., Sulzbacher, L., Vesterinen, P. and J. Vinterbäck. 2012. EUBIONET III – Solutions to biomass trade and market barriers. Renewable and Sustainable Energy Reviews, 16: 4277-4290.

Alam, M.B., Pulkki, R., Shahi, C. and T. Upadhyay. 2012. Modeling woody biomass procurement for bioenergy production at the Atikokan Generating Station in Northwestern Ontario, Canada. Energies, 5: 5065-5085.

Alfonso, D., Perpiñá, C., Pérez-Navarro, A., Peñalvo, E., Vargas, C. and R. Cárdenas. 2009. Methodology for optimization of distributed biomass resources evaluation, management and final energy use. Biomass and Bioenergy, 33: 1070-1079.

An, H., Wilhelm, W.E. and S.W. Searcy. 2011. Biofuel and petroleum-based fuel supply chain research: A literature review. Biomass and Bioenergy, 35: 3763-3774.

Aoudji, A.K.N., Adégbidi, A., Agbo, V., Atindogbé, G., Toyi, M.S.S., Yêvidé, A.S.I., Ganglo, J.C. and P. Lebailly. 2012. Functioning of farm-grown timber value chains: Lessons from the smallholder-produced teak (Tectona grandis L.f.) poles value chain in Southern Benin. Forest Policy and Economics, 15: 98-107.

Arthofer, K., Engelhardt-Nowitzki, C., Feichtenschlager, H.P. and D. Girardi. 2012. Servicing Individual Product Variants Within Value Chains with an Ontology. Pp. 331-352 *in*; Jodlbauer, H., Olhager, J. and R.J. Schonberger (eds.) 2012. Modelling value, Contributions to Management Science: selected papers of the 1st International Conference on Value Chain Management, May 4th-5th, 2011, University of Applied Sciences in Upper Austria, School of Management, Steyr, Austria. Springer-Verlag Berlin Heidelberg. 418 p.

Åsman, P. (n.d.). Pellet Tool Kit, a basic how-to guide prior to starting your pellet project. Northern Ontario Value Added Initiative; FP Innovations, Timmins, Ontario. 12 pp.

Aydinel, M., Sowlati, T., Cerda, X., Cope, E. and M. Gerschman. 2008. Optimization of production allocation and transportation of customer orders for a leading forest products company. Mathematical and Computer Modelling, 48: 1158-1169.

Ayoub, N. and N. Yuji. 2012. Demand-driven optimization approach for biomass utilization networks. Computers & Chemical Engineering, 36: 129-139.

Ayoub, N., Seki, H. and Y. Naka. 2009. Superstructure-based design and operation for biomass utilization networks. Computers & Chemical Engineering, 33: 1770–1780.

Bashiri, M., Badri, H. and J. Talebi. 2012. A new approach to tactical and strategic planning in production-distribution networks. Applied Mathematical Modelling, 36: 1703-1717.

Biomass Innovation Centre (BIC). 2013. Biomass Projects in Canada. BIC, North Bay, ON. http://www.biomassinnovation.ca/casestudies.html. December 16, 2013.

Blackburn, J. 2012. Valuing time in supply chains: Establishing limits of time-based competition. Journal of Operations Management, 30: 396-405.

Blom, G. 2009. The feasibility of a wood pellet plant using alternate sources of wood fibre. B.Sc.F. thesis, University of British Columbia, Vancouver, BC. 28 p.

Booker, A. Johnston, D. and M. Heinrich. 2012. Value chains of herbal medicines – Research needs and key challenges in the context of ethnopharmacology. Journal of Ethnopharmacology, 140: 624-633.

Bradley, D and K. Bradburn. 2012. Economic Impact of Bioenergy in Canada – 2011. Canadian Bioenergy Association. 26 p.

Bradley, D. and E. Thiffault. 2012. IEA Bioenergy Task 40 Country Report, Canada 2011. Canadian Bioenergy Association. 63 p.

BW McCloy & Associates Inc. 2009. NWT Wood Pellet Pre-feasibility Analysis. FPInnovations – Forintek Division. 25 p.

Campbell, K. 2007. A Feasibility Study Guide for an Agricultural Biomass Pellet Company. Agricultural Utilization Research Institute. St. Paul, Minnesota. 127 p.

Canadian Biomass. 2013. Canadian Biomass 2013 Pellet Mill Map. Annex Business Media, Simcoe ON. http://www.canadianbiomassmagazine.ca/content/view/4035/57/. January 10, 2014.

Cantor, D.E. and J.R. Macdonald. 2009. Decision-making in the supply chain: Examining problem solving approaches and information availability. Journal of Operations Management, 27: 220-232.

Carlsson, D. and M. Ronnqvist. 2005. Supply chain management in forestry-case studies at Sodra Cell AB. European Journal of Operational Research, 163: 589-616.

Chandra, C. and S. Kumar. 2000. Supply chain management in theory and practice: a passing fad or a fundamental change? Industrial Management & Data Systems, 100(3): 100-114.

Christensen, V., Steenbeek, J. and P. Failler. 2011. A combined ecosystem and value chain modeling approach for evaluating societal cost and benefit of fishing. Ecological Modelling. 222: 857-864.

Christopher, M. and D. Towill. 2000. Supply chain migration from lean and functional to agile and customized. Supply Chain Management: An International Journal, 5(4): 206-213.

CN Rail. 2012. Wood Pellets. http://www.cn.ca/en/shipping-alternative-energy-products-wood-pellets.htm. March 28, 2012.

Cocchi, M., Nikolaisen, L., Junginger, M., Goh, C.S., Heinimö, J., Bradley, D., Hess, R., Jacobson, J., Ovard. L.P., Thrän, D., Hennig, C., Deutmeyer, M., Schouwenberg, P.P. and D. Marchal. 2011. Global Wood Pellet Industry

Market and Trade Study. IEA Bioenergy, Task 40: Sustainable International Bioenergy Trade, Utrecht University, Netherlands.190 pp.

Eddins, B. 2014. Porter's Value Chain. IFS305 – Management Information Systems Spring 2014. York College of Pennsylvania, York, PA. http://faculty.ycp.edu/~weddins/305/s12%20IFS305%20Porter'sValue%20Chain.PNG. February 14, 2014.

Engelhardt-Nowitzki, C., Arthofer, K. and Kryvinska, N. and C. Strauss. 2012. Supporting value chain integration through ontology-based modeling pp. 191-197 *in* Barolli, L., Xhafa, F., Vitabile, S. and M. Uehara. Proceedings 2012 Sixth International Conference on Complex, Intelligent, and Software Intensive Systems. July 4th-6th 2012. IEEE Computer Society, Sanpaolo Palace Hotel, Palermo, Italy.

EPC (European Pellet Council). 2013. EN Plus: European Pellet Council Handbook for the Certification of Wood Pellets for Heating Purposes, Version 2.0. European Pellet Council, European Biomass Association. Brussels, Belgium. 43 pp.

Fang, X., Zhang, C., Robb, D.J. and J.D. Blackburn. 2012. Decision support for lead time and demand variability reduction. Omega, 41(2): 390-396.

Gallagher, P.W., Brubaker, H. and H. Shapouri. 2005. Plant size: Capital cost relationships in the dry mill ethanol industry. Biomass and Bioenergy, 28: 565-571.

Garcia, C.A., Ibeas, A., Herrera, J. and R. Vilanova. 2012. Inventory control for the supply chain: An adaptive control approach based on the identification of the lead-time. Omega, 40: 314-327.

Garcia-Maraver, A., Popov, V. and M. Zamorano. 2011. A review of European standards for pellet quality. Renewable Energy, 36: 3537-3540.

Godsell, J., Diefenbach, T., Clemmow, C., Towill, D. and M. Christopher. 2011. Enabling supply chain segmentation through demand profiling. International Journal of Physical Distribution & Logistics Management 41(3): 296-314.

Gold, S. and S. Seuring. 2011. Supply chain and logistics of bio-energy production. Journal of Cleaner Production. 19: 32-42.

Gomes da Silva, C., Figueira, J., Lisboa, J. and S. Barman. 2006. An interactive decision support system for an aggregate production planning model based on multiple criteria mixed integer linear programming. Omega, 34: 167–177.

Gooch, M. 2012. Evaluating the effectiveness of experiential learning for motivating value chain stakeholders to adopt new ways of capturing value, pp. 49-64 *in*; Jodlbauer, H., Olhager, J. and R.J. Schonberger (eds.) 2012. Modelling value, Contributions to Management Science: selected papers of the 1st International Conference on Value Chain Management, May 4th-5th, 2011, University of Applied Sciences in Upper Austria, School of Management, Steyr, Austria. Springer-Verlag Berlin Heidelberg. 418 p.

Government of Ontario. 2011. Strengthening Forestry's Future – Forest Tenure Modernization in Ontario. Queen's Printer for Ontario, Toronto, ON. 20 pp. http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@forests/documents/document/stdprod_092158.pdf. February 14, 2014.

Gunasekaran, A. and E.W.T. Ngai. 2012. The future of operations management: An outlook and analysis. Int. J. Production Economics, 135: 687-701.

Gunasekaran, A., Patel, C. And R.E. McGaughey. 2004. A framework for supply chain performance measurement. International Journal of Production Economics. 87: 333 – 347.

Gunnarsson, H., Ronnqvist, M. and J.T. Lundgren. 2004. Supply chain modelling of forest fuel. European Journal of Operational Research, 158: 103-123.

Hahn, G.J. and H. Kuhn. 2012. Designing decision support systems for value-based management: A survey and an architecture. Decision Support Systems. 53: 591-598.

Hansen, M.T., Jein, A.R., Hayes, S. and P. Bateman. 2009. English Handbook for Wood Pellet Combustion. PELLETSATLAS, Denmark. 86pp.

Hillring, B. and J. Vinterback. 1998. Wood pellets in the Swedish residential market. Forest Products Journal, 48(5): 67-72.

Hosoda, T. and S.M. Disney. 2012. A delayed demand supply chain: Incentives for upstream players. Omega, 40: 478-487.

Ince, P.J., Kramp, A.D., Skog, K.E., Yoo, D. and V.A. Sample. 2011. Modeling future U.S. forest sector market and trade impacts of expansion in wood energy consumption. Journal of Forest Economics, 17: 142-156.

Ivanov, D., Sokolov, B. and J. Kaeschel. 2010. A multi-structural framework for adaptive supply chain planning and operations control with structure dynamics considerations. European Journal of Operational Research, 200: 409-420.

Jenkins, B.M. 1997. A comment on the optimal sizing of a biomass utilization facility under constant and variable cost scaling. Biomass and Bioenergy, 13(1): 1-9.

Jones, P.C. and J.W. Ohlmann. 2008. Long-range timber supply planning for a vertically integrated paper mill. European Journal of Operational Research, 191: 557-570.

Junginger, M., Bolkesjø, T., Bradley, D., Dolzan, P., Faaij, A., Heinimö, J., Hektor, B., Leistad, Ø., Ling, E., Perry, M., Piacente, E., Rosillo-Calle, F., Ryckmans, Y., Schouwenberg, P.P., Solberg, B., Trømborg, E., da Silva Walter, A. and M. de Wit. 2008. Developments in international bioenergy trade. Biomass and Bioenergy, 32: 717-729.

Junginger, M., Van Dam, J., Zarrilli, S., Mohamed, F.A., Marchal, D. and A. Faaij. 2011. Opportunities and barriers for international bioenergy trade. Energy Policy, 39: 2028-2042.

Kaliyan, N. and Morey, R.V. 2009. Factors affecting strength and durability of densified biomass products. Biomass and Bioenergy, 33: 337-359.

Karkania, V., Fanara, E. and A. Zabaniotou. 2012. Review of sustainable biomass pellets production – A study for agricultural residues pellets' market in Greece. Renewable and Sustainable Energy Reviews. 16: 1426-1436.

Kayakutlu, G. and G. Buyukozkan. 2011. Assessing performance factors for a 3PL in value chain. Int. J. Production Economics, 131: 441-452.

Kennedy, M. Wong, R., Vandenbroek, A., Lovekin, D. and M. Raynolds. 2011. Biomass Sustainability Analysis, an assessment of Ontario-sourced forest-based biomass for electricity generation. The Pembina Institute, Drayton Valley, Alberta. 138 pp.

Klibi, W., Martel, A. and A. Guitouni. 2010. The design of robust value-creating supply chain networks: A critical review. European Journal of Operational Research, 203: 283-293.

Ko, H. J. and G.W. Evans. 2007. A genetic algorithm-based heuristic for the dynamic forward/reverse logistics network for 3PLs. Computers & Operations Research Reverse Logistics, 34: 346–366.

Koo, L.Y., Adhitya, A., Srinivasan, R. and I.A. Karimi. 2008. Decision support for integrated refinery supply chains: Part 2. Design and operation. Computers and Chemical Engineering, 32: 2787-2800.

Kraigher-Krainer, J. 2012. Habit, affect and cognition: A constructivist model on how they shape decision making, pp. 189-206 *in*; Jodlbauer, H., Olhager, J. and R.J. Schonberger (eds.) 2012. Modelling value, Contributions to Management Science: selected papers of the 1st International Conference on Value Chain Management, May 4th-5th, 2011, University of Applied Sciences in Upper Austria, School of Management, Steyr, Austria. Springer- Verlag Berlin Heidelberg. 418 p.

Kreye, M.E., Goh, Y.M., Newnes, L.B. and P. Goodwin. 2012. Approaches to displaying information to assist decisions under uncertainty. Omega, 40: 682-692.

Krupa, J. 2012. Blazing a new path forward: A case study on the renewable energy initiatives of the Pic River First Nation. Environmental Development, 3: 109-122.

Kumar, A., Cameron, J.B and P.C. Flynn. 2003. Biomass power cost and optimum plant size in western Canada. Biomass and Bioenergy, 24: 445-464.

Lam, H.L., Varbanov, P.S. and J.J. Klemeš. 2010. Optimisation of regional energy supply chains utilising renewables: P-graph approach. Computers and Chemical Engineering, 34: 782-792.

Lamers, P, Junginger, M., Hamelinck, C and A. Faaij. 2012. Developments in international solid biofuel trade-An analysis of volumes, policies, and market factors. Renewable and Sustainable Energy Reviews, 16: 3176-3199.

Leslie, K. 2013. Ontario's electricity rates to rise 33% in three years under Liberal's long-term energy plan. Canadian Press, Toronto, ON. http://business.financialpost.com/2013/12/02/ontario-electricity-rates-to-keep-rising-as-long-term-energy-plan-released/. December 3, 2013.

Li, C. 2009. Toward full, multiple, and optimal wood fibre utilization: A modeling perspective. Forestry Chronicle, 85(3): 377-381.

Li, C. and S. Liu. 2012. A stochastic network model for ordering analysis in multi-stage supply chain systems. Simulation Modelling Practice and Theory. 22: 92-108.

Li, Q., Disney, S.M. and G. Gaalman. 2014. Avoiding the bullwhip effect using Damped Trend forecasting and the Order-Up-To replenishment policy. International Journal of Production Economics. 149: 3-16.

Lind, L., Pirttilä, M., Viskari, S., Schpp, F. and T. Kärri. 2012. Working capital management in the automotive industry: Financial value chain analysis. Journal of Purchasing & Supply Management, 18: 92-100.

Lofstedt, R. 1996. The use of biomass energy in a regional context: the case of Vaxko Energi, Sweden. Biomass and Bioenergy, 11(1): 33-42.

Lu, N. and R.W. Rice. 2010. Characteristics of wood fuel pellet manufacturers and markets in the United States, 2010. Forest Products Journal. 61(4): 310-315.

Luathep, P., Sumalee, A., Lam, W.H.K., Li, Z.-C. and H.K. Lo. 2011. Global optimization method for mixed transportation network design problem: A mixed-integer linear programming approach. Transportation Research Part B, 45: 808–827.

Macfadyen, G., Nasr-Alla, A.M., Al-Kenawy, D., Fathi, M. Hebicha, H., Diab, A.M., Hussein, S.M., Abou-Zeid, R.M. and G. El-Naggar. 2012. Value-chain analysis - An assessment methodology to estimate Egyptian aquaculture sector performance. Aquaculture, 362-363: 18-27.

Mahapatra, K., Gustavsson, L. and R. Madlener. 2007. Bioenergy innovations: The case of wood pellet systems in Sweden. Technology Analysis & Strategic Management, 19(1): 99-125.

Mahnam, M., Yadollahpour, M.R., Famil-Dardashti, V. and S.R. Hejazi. 2009. Supply chain modeling in uncertain environment with bi-objective approach. Computers & Industrial Engineering. 56: 1535-1544.

Mahutga, M.C. 2012. When do value chains go global? 2012. A theory of the spatialization of global value chains. Global Networks. 12(1): 1-21.

Mäkelä, M., Lintunen, J., Kangas, H.L. and J. Uusivuori. 2011. Pellet promotion in the Finnish sawmilling industry: cost-effectiveness of different policy instruments. Journal of Forest Economics, 17: 185-196.

Mani, S., Sokhansanj, S., Bi, X. and A. Turhollow. 2006. Economics of producing pellets from biomass. Applied Engineering in Agriculture. 22(3): 421-426.

McKenzie, E. and E.S. Gardener. 2010. Damped trend exponential smoothing: A modelling viewpoint International Journal of Forecasting 26: 661 – 665.

Mentzer, J.T, DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D. and Z.G. Zacharia. 2001. Defining supply chain management. Journal of Business Logistics, 22(2): 1-25.

Mitra, K., Gudi, R.D., Patwardhan, S.C. and G. Sardar. 2009. Towards resilient supply chains: Uncertainty analysis using fuzzy mathematical programming. Chemical Engineering Research and Design. 87: 967-981.

Mizgier, K.J., Wagner, S.M. and J.A. Holyst. 2012. Modeling defaults of companies in multi-stage supply chain networks. Int. J. Production Economics, 135: 14-23.

Mobini, M., Sowlati, T. and S. Sokhansanj. 2011. Forest biomass logistics for a power plant using the discrete-event simulation approach. Applied Energy, 88: 1241-1250.

Mobini, M., Sowlati, T. and S. Sokhansanj. 2013. A simulation model for the design and analysis of the wood pellet supply chain. Applied Energy, 111: 1239-1249.

Monteiro, E., Mantha, V. and A. Rouboa. 2012. Portuguese pellets market: Analysis of the production and utilization constraints. Energy Policy, 42: 129-135.

Moon, J.-H., Lee, J.-W. and U.-D. Lee. 2011. Economic analysis of biomass power generation schemes under renewable energy initiative with Renewable Portfolio Standards (RPS) in Korea. Bioresource Technology, 102: 9550-9557.

Murray, G. 2010. Lillooet Biomass Energy Corporation Business Plan for a Wood Pellet Plant. Gordon Murray Corporate Finance Ltd., Revelstoke, BC. 74 p.

Nagel, J. 2000. Determination of an economic energy supply structure based on biomass using a mixed-integer linear optimization model. Ecological Engineering, 16: 91-102.

Naik, S., Goud, V.V., Rout, P.K, Jacobson, K. and A.K. Dalai. 2010. Characterization of Canadian biomass for alternative renewable fuel. Renewable Energy, 35: 1624-1631.

Naraharisetti, P.K., Karimi, I.A. and R. Srinivasan. 2008. Supply chain redesign through optimal asset management and capital budgeting. Computers and Chemical Engineering, 32: 3153-3169.

Nasiri, F. and G. Zaccour. 2009. An exploratory game-theoretic analysis of biomass electricity generation supply chain. Energy Policy, 37: 4514-4522.

NEOS Corporation. 1995. Wood Pelletization Sourcebook: A Sample Business Plan for the Potential Pellet Manufacturer. Great Lakes Regional Biomass Energy Program Report No. DE-FG05-83R21390 (44).

Neumann, C., Kohlhuber, S. and S. Hanusch. 2012. Lean production in Austrian industrial companies: An empirical investigation pp. 293-312 *in*; Jodlbauer, H., Olhager, J. and R.J. Schonberger (eds.) 2012. Modelling value, Contributions to Management Science: selected papers of the 1st International Conference on Value Chain Management, May 4th-5th, 2011, University of Applied Sciences in Upper Austria, School of Management, Steyr, Austria. Springer-Verlag Berlin Heidelberg. 418 p.

Ngai, E.W.T., Chau, D.C.K. and T.L.A. Chan. 2011. Information technology, operational, and management competencies for supply chain agility: Findings from case studies. Journal of Strategic Information Systems, 20: 232-249.

Öberg, C. 2010. What happened with the grandiose plans? Strategic plans and network realities in B2B interaction. Industrial Marketing Management, 39: 963-974.

Obernberger, I. and G. Thek. 2004. Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behavior. Biomass and Bioenergy, 27: 653-669.

Obernberger, I. and G. Thek. 2010. The Pellet Handbook; The Production and Thermal Utilisation of Pellets. Earthscan, London, UK. 593 pp.

Olhager, J. and D.I. Prajogo. 2012. The impact of manufacturing and supply chain improvement initiatives: A survey comparing make-to-order and make-to-stock firms. Omega, 40: 159-165.

Olsson, O., Hillring, B. and J. Vinterbäck. 2011. European wood pellet market integration – A study of the residential sector. Biomass and Bioenergy, 35: 153-160.

OMNR (Ontario Ministry of Natural Resources). 2012c. Ontario Creates First Local Forest Management Corporation. Queens Printer for Ontario, Toronto, ON: http://news.ontario.ca/mnr/en/201206/ontario-creates-first-local-forest-management-corporation.html

Oo, A., Kelly, J. and C. Lalonde. 2012. Assessment of Business Case for Purpose-Grown Biomass in Ontario. The Western University Research Park, Sarnia, ON. 44 pp.

Pa, A., Xiaotao, T.B. and S. Sokhansanj. 2011. A life cycle evaluation of wood pellet gasification for district heating in British Columbia. Bioresource Technology, 102: 6167-6177.

Palladini, J. 2010. Canada's Wood Products Industry. Conference Board of Canada. Ottawa, ON. 11pp.

Pan, F. and R. Nagi. 2010. Robust supply chain design under uncertain demand in agile manufacturing. Computers & Operations Research, 37: 668-683.

Panley, M. and S. Boerner. 2006. Demand-driven supply networks: Advancing supply chain management. SAP AG, Germany. 16 pp.

Papageorgiou, L.G. 2009. Supply chain optimisation for the process industries: Advances and opportunities. Computers and Chemical Engineering. 33: 1931-1938.

Peng, J.H., Bi, H.T., Sokhansanj, S., Lim, J.C. and S. Melin. 2010. An economical and market analysis of Canadian wood pellets. International Journal of Green Energy, 7(2): 128-142.

Pettersson, A.I. and A. Segerstedt. 2013. Measuring supply chain cost. International Journal of Production Economics, 143(2): 357-363.

PFI (Pellet Fuels Institute). 2011. Pellet Fuels Institute Standard Specification for Residential/Commercial Densified Fuel. PFI, Arlington, VA. 10 pp.

Pirraglia, A., Gonzalez, R. and D. Saloni. 2010. Techno-economical analysis of wood pellets production for US manufacturers. BioResources, 5(4): 2374-2390.

Pishvaee, M.S., Rabbani, M. and S.A. Torabi. 2011. A robust optimization approach to closed-loop supply chain network design under uncertainty. Applied Mathematical Modelling. 35: 637-649.

Pitty, S.S., Li, W., Adhitya, A., Srinivasan, R. and I.A. Karimi. 2008. Decision support for integrated refinery supply chains: Part 1. Dynamic simulation. Computers and Chemical Engineering, 32: 2767-2786.

Porter, M. 1985. Competitive Advantage: Creating and Sustaining Superior Performance. Collier-Macmillan, New York. 557 pp.

Rana, D. and M. Gregory 2012. Exploring the Role of Business Support Agencies in Value Chain Management of the Medical Device Industry pp. 393-416 *in*; Jodlbauer, H., Olhager, J. and R.J. Schonberger (eds.) 2012. Modelling value, Contributions to Management Science: selected papers of the 1st International Conference on Value Chain Management, May 4th-5th, 2011, University of Applied Sciences in Upper Austria, School of Management, Steyr, Austria. Springer-Verlag Berlin Heidelberg. 418 p.

Ravn, A. and S.P. Engstrøm. 2010. Modelling of wood pellet production and distribution for energy consumption. MSc Thesis, Technical University of Denmark, DTU Management Engineering, Kongens Lyngby, Denmark. 249 p.

Rickerson, W., Halfpenny, T and S. Cohan. 2009. The emergence of renewable heating and cooling policy in the United States. Policy and Society. 27: 365-377.

Rudd, J.M., Greenly, G.E., Beatson, A.T. and I.N. Lings. 2008. Strategic planning and performance: Extending the debate. Journal of Business Research, 61: 99-108.

Sadegheih, A. and P.R. Drake. 2008. System network planning expansion using mathematical programming, genetic algorithms and tabu search. Energy Conversion and Management, 49: 1557–1566.

Saracoglu, N. and G. Gunduz. 2009. Wood pellets – Tomorrow's fuel for Europe. Energy Sources, Part A, 31: 1708 – 1718.

Sathre, R. and L. Gustavsson. 2009. Process-based analysis of added value in forest product industries. Forest Policy and Economics, 11: 65-75.

Schonberger, R.J. 2012. Measurement of lean value chains: Efficiency and effectiveness pp. 65-75 *in*; Jodlbauer, H., Olhager, J. and R.J. Schonberger (eds.) 2012. Modelling value, Contributions to Management Science: selected papers of the 1st International Conference on Value Chain Management, May 4th-5th, 2011, University of Applied Sciences in Upper Austria, School of Management, Steyr, Austria. Springer-Verlag Berlin Heidelberg. 418 p.

Schroeder, L. 2011. Go Pellets Canada Pushes Domestic Market Sales. Canadian Bioenergy Association. Ottawa, Ontario. 1 p.

Schűtz, P. and A. Tomasgard. 2011. The impact of flexibility on operational supply chain planning. Int. J. Production Economics, 134: 300-311.

Selkimäki, M., Mola-Yudego, B., Röser, D., Prinz, R. and L. Sikanen. 2010. Present and future trends in pellet markets, raw materials, and supply logistics in Sweden and Finland. Renewable and Sustainable Energy Reviews, 14: 3068-3075.

Shabani, N. and T. Sowlati. 2013. A mixed integer non-linear programming model for tactical value chain optimization of a wood biomass power plant. Applied Energy. 104: 353-361.

Singer, M. and P. Donoso. 2008. Upstream or downstream in the value chain? Journal of Business Research, 61: 669-677.

Sjølie, H.K., Latta, G.S., Adams, D.M. and B. Solberg. 2011. Impacts of agent information assumptions in forest sector modeling. Journal of Forest Economics. 17:169-184.

Sokhansanj, S., Turhollow, A. and E. Wilkerson. 2008. Integrated biomass supply and logistics: A modeling environment for designing feedstock supply systems for biofuel production. Resource: Engineering & Technology for a Sustainable World. 15(6): 15-18.

Sopha, B.M., Klöckner, C.A. and E.G. Hertwich. 2011. Exploring policy options for a transition to sustainable heating system diffusion using an agent-based simulation. Energy Policy. 39: 2722-2729.

Sopha, B.M., Klöckner, C.A., Skjevrak, G. and E.G. Hertwich. 2010. Norwegian households' perception of wood pellet stove compared to air-to-air heat pump and electric heating. Energy Policy 38: 3744-3754.

Spelter, H. and D. Toth. 2009. North America's wood pellet sector. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, Wisconsin. 21pp.

Subramanian, B.G.P.S. and V.S. Reddy. 2012. Transforming data driven SCM to demand driven SCM through lead time optimization pp. 1036-1041 *in* Ninth AIMS International Conference on Management; Pune, India, January 1 – 4 2012.

Sultana, A. and A. Kumar. 2012 b. Optimal sizing of bioenergy facilities using geographic information system. Applied Energy, 94: 192-201.

Sultana, A. and A. Kumar. 2012a. Ranking of biomass pellets by integration of economic, environmental and technical factors. Biomass and Bioenergy. 39: 344-355.

Sultana, A., Kumar, A. and D. Harfield. 2010. Development of agri-pellet production cost and optimum size. Bioresource Technology, 101: 5609-5621.

Tapaninen, A. 2010. Adoption of innovation: Wood pellet heating system in the renewable residential energy context. Faculty of Business and Technology Management. Tampere University of Technology. Tampere, Finland. 70pp.

Toppinen, A. and J. Kuuluvainen. 2010. Forest sector modelling in Europe – the state of the art and future research directions. Forest Policy and Economics, 12: 2-8.

Trapero, J.R., Kourentzes, N. and R. Fildes. 2012. Impact of information exchange on supplier forecasting performance. Omega, 40: 738-747.

Trømborg, E., Havskjold, M., Lislebø, O. and P.K. Rørstad. 2011. Projecting demand and of forest biomass for heating in Norway. Energy Policy, 39: 7049-7058.

Uasuf, A. and G. Becker. 2011. Wood pellets production costs and energy consumption under different framework conditions in Northeast Argentina. Biomass and Bioenergy. 35: 1357-1366.

Upadhyay, T.P., Shahi, C., Leitch, M. and R. Pulkki. 2012. Economic feasibility of biomass gasification for power generation in three selected communities of northwestern Ontario, Canada. Energy Policy. 44: 235-244.

Uran, V. 2010. A model for establishing a win-win relationship between a wood pellets manufacturer and its customers. Biomass and Bioenergy, 34: 747-753.

Urbanowski, E. 2005. Strategic analysis of a pellet fuel opportunity in Northwest British Columbia. M.B.A. thesis, Simon Fraser University, BC. 94p.

Van Dam, J., Faaij, A.P.C., Hilbert, J., Petruzzi, H. and W.C. Turkenburg. 2009. Large-scale bioenergy production from soybeans and switchgrass in Argentina Part A: Potential and economic feasibility for national and international markets. Renewable and Sustainable Energy Reviews. 13: 1710-1733.

Van Dyken, S., Bakken, B.H. and H.I. Skjelbred. 2010. Linear mixed-integer models for biomass supply chains with transport, storage and processing. Energy. 35: 1338-1350.

Velazquez-Marti, B. and E. Fernandez-Gonzalez. 2010. Mathematical algorithms to locate factories to transform biomass in bioenergy focused on logistic network construction. Renewable Energy. 35: 2136-2142.

Venkateswaran, J. and Y.J. Son. 2004. Impact of modeling approximations in supply chain analysis – an experimental study. Int. J. Prod. Res. 42(15): 2971-2992.

Verhoest, C. and Y. Ryckmans. 2012. Industrial Wood Pellets Report. PellCert. 30 p.

Verma, V.K., Bram, S. and J. De Ruyck. 2009. Small scale biomass heating systems: Standards, quality labeling and market driving factors – An EU outlook. Biomass and Bionergy. 33: 1393-1402.

Vinterback, J. 2004. Pell-Sim- dynamic model for forecasting storage and distribution of wood pellets. Biomass and Bioenergy. 27: 629-643.

Von Geibler, J., Kristof, K. and K. Bienge. 2010. Sustainability assessment of entire forest value chains: Integrating stakeholder perspectives and indicators in decision support tools. Ecological Modelling. 221: 2206-2214.

Wadhwa, S., Bibhushan and F.T.S. Chan. 2009. Inventory performance of some supply chain inventory policies under impulse demands. International Journal of Production Research. 47(12): 3307-3332.

Walters, D. 2012. Competition, collaboration, and creating value in the value chain pp. 3-36 *in*; Jodlbauer, H., Olhager, J. and R.J. Schonberger (eds.) 2012. Modelling value, Contributions to Management Science: selected papers of the 1st International Conference on Value Chain Management, May 4th-5th, 2011, University of Applied Sciences in Upper Austria, School of Management, Steyr, Austria. Springer-Verlag Berlin Heidelberg. 418 p.

Willem te Velde, D., Rushton, J., Schreckenberg, K., Marshall, E., Edouard, F., Newton, A. and E. Arancibia. 2006. Entrepreneurship in value chains of non-timber forest products. Forest Policy and Economics. 8: 725-741.

Wöhrle, T. 2009. Supply chain at western digital. Supply chain Europe, 18(3): 46-47.

Wolf, A., Vidlund, A. and E. Andersson. 2006. Energy-efficient pellet production in the forest industry – a study of obstacles and success factors. Biomass and Bioenergy, 20: 38-45.

WPAC (Wood Pellet Association of Canada). 2013. Sustainable Biomass Production. Annex Business Media. http://www.pellet.org/wpac-news/sustainable-biomass-production. June 5, 2013.

Wu, C. and D. Barnes. 2011. A literature review of decision-making models and approaches for partner selection in agile supply chains. Journal of Purchasing & Supply Management. 17: 256-274.

Yatchew, A. and A. Baziliauskas. 2011. Ontario feed-in-tariff programs. Energy Policy. 39: 3885-3893.

Yimer, A. D. and K. Demirli. 2010. A genetic approach to two-phase optimization of dynamic supply chain scheduling. Computers & Industrial Engineering. 58: 411-422.

Yousefi, S., Moghaddam, M.P. and V.J. Majid. 2011. Optimal real time pricing in an agent-based retail market using a comprehensive demand response model. Energy. 36: 5716-5727.

APPENDICES

APPENDIX I

PRIMARY INFORMATION

Historical demand values:

Year and Month		Period	PeerForecaster® Period	Observed Demand (tonnes)
2010	Jul	7	1	5
	Aug	8	2	233
	Sep	9	3	241
	Oct	10	4	263
	Nov	11	5	181
	Dec	12	6	205
2011	Jan	1	7	143
	Feb	2	8	194
	Mar	3	9	145
	Apr	4	10	88
	May	5	11	91
	Jun	6	12	176
	Jul	7	13	171
	Aug	8	14	188
	Sep	9	15	608
	Oct	10	16	225
	Nov	11	17	342
	Dec	12	18	191
2012	Jan	1	19	326
	Feb	2	20	318
	Mar	3	21	223
	Apr	4	22	128
	May	5	23	176
	Jun	6	24	169
	Jul	7	25	44
	Aug	8	26	266
	Sep	9	27	650
	Oct	10	28	572

Retailer purchase price for heating pellets (j = 1):

1) Total of $4.05 per 40 pound bag
    a. $3.35 per 40 pound bag
    b. $35 per 50 bags for delivery; $0.70 per bag
2) Per-tonne price: $223.22

Retailer purchase price for bedding pellets (j = 2):

1) Total of $4.80 per 40 pound bag
    a. $4.10 per 40 pound bag
    b. $35 per 50 bags for delivery; $0.70 per bag
2) Per-tonne price: $264.55

Raw Materials:

ILW has two lumber suppliers. This lumber is used to manufacture ILW's primary items, and the residue created from this process is used as the raw material for wood pellet production.

1) Suppliers:
    a. Olav Haavalssrud Timber Co. Ltd, Hornepayne, Ontario (k = 1)
        i. Approximately 133 km from ILW (Google Maps 2013)
        ii. 600,000 board feet per month of spruce and jack pine
    b. Rosko Forestry Operations Ltd., Kirkland Lake, Ontario (k = 2)
        i. Approximately 364 km from ILW (Google Maps 2013)
        ii. 400,000 board feet per month of spruce and jack pine
2) The material arrives as 2" x 4" x 16' lumber
    a. Both suppliers are assumed to provide a 60/40 mixture of spruce/pine lumber to ILW, once a month
    b. Shavings are produced from the manufacture of primary wood products
    c. Approximately 50 tonnes of pellets are created from the processing of 100,000 board feet
3) The yield of pellets per tonne of residue is 98%; therefore the amount of residue required to make 1 tonne of pellets is 1.02 tonnes
4) Assumed that constant supply of 1,000,000 board feet is received per month
    a. Based on yield specified in 3) above, this translates into 510 tonnes of residue received per month, and 500 tonnes of pellets produced each month
5) Purchase cost of $45/tonne for residue

Processing:

1) Annual pelletizing production capacity of approximately 10,000 tonnes
2) There are three pellet presses with a throughput capacity of 0.5 tonnes per hour
    a. All three presses are used at once; total throughput of 1.5 tonnes per hour
3) Employees
    a. One employee needed at any given time to ensure proper pellet processing
    b. The shifts for each pellet employee are 8 hours, 5 days a week, 50 weeks per year
    c. The average wage for employees is $21/hr

4) Drying:
    a. $35 per thousand board feet
    b. Done prior to processing of primary wood products
5) Pelletizing:
    a. Electricity
        i. $16/hr
6) Packaging:
    a. $15/tonne

Facility:

1) Heating/cooling:
    a. $15 per day
2) Overhead Costs:
    a. $5,000 per month

Transportation:

1) Trucking is the type of transportation used for lumber shipment and pellet distribution
    a. Total transportation cost: $1.83/km:
        i. Operator (driver): $0.30/km
        ii. Fuel: $0.73/km
        iii. Other operating costs: $0.80/km

Retailers[1,2]:

1) Combermere Home Hardware (l =1)
   a. Combermere, ON
   b. Approximate distance from ILW: 880 km

2) Ellis Bio Energy (l = 2)
   a. Dorion, ON
   b. Approximate distance from ILW: 439 km
3) Yvon Lacroix Enterprises Ltd. (l = 3)
   a. Dubreuville, ON
   b. Approximate distance from ILW: 314 km
4) Earlton Country Store (l = 4)
   a. Earlton, ON
   b. Approximate distance from ILW: 404 km
5) Goulais Country Store (l = 5)
   a. Goulais River, ON
   b. Approximate distance from ILW: 521 km
6) Armand H. Couture (l = 6)
   a. Hearst, ON
   b. Approximate distance from ILW: 1 km
7) Island Lumber Co. Ltd. (Tim-Br Mart) (l= 7)
   a. Hilton Beach, ON
   b. Approximate distance from ILW: 610 km
8) Hornepayne Home Hardware (l = 8)
   a. Hornepayne, ON
   b. Approximate distance from ILW: 132 km
9) Iroquois Falls Home Hardware (l = 9)
   a. Iroquois Falls, ON
   b. Approximate distance from ILW: 263 km
10) Levack Home Hardware (l = 10)
   a. Levack, ON
   b. Approximate distance from ILW: 517 km
11) Manitouwadge Home Hardware (l = 11)
   a. Manitouwadge, ON
   b. Approximate distance from ILW: 228 km
12) May's Gifts (l = 12)
   a. Marathon, ON
   b. Approximate distance from ILW: 325 km

13) Shannon Home Hardware (l = 13)
    a. Matheson, ON
    b. Approximate distance from ILW: 293 km
14) Mindemoya Home Hardware (l = 14)
    a. Mindemoya, ON
    b. Approximate distance from ILW: 700 km
15) GG's Tru Hardware (l = 15)[3]
    a. Moose Factory, ON
    b. Approximate distance from ILW: 464 km
16) Green Acres Contracting (l = 16)
    a. Red Lake, ON
    b. Approximate distance from ILW: 1,062 km
17) Enviroheat & Supplies Ltd. (l = 17)
    a. Redbridge, ON
    b. Approximate distance from ILW: 613 km
18) Goulard Lumber (Castle Bldg. Supply) (l = 18)
    a. Sturgeon Falls, ON
    b. Approximate distance from ILW: 585 km
19) Terrace Bay Home Hardware (l = 19)
    a. Terrace Bay, ON
    b. Approximate distance from ILW: 399 km
20) Wawa Rent-All & Repair (l = 20)
    a. Wawa, ON
    b. Approximate distance from ILW: 328 km
21) Spadoni's Home Hardware (l = 21)
    a. White River, ON
    b. Approximate distance from ILW: 233 km
22) Home Hardware Belleville (l = 22)
    a. Belleville, ON
    b. Approximate distance from ILW: 1,016 km
23) Blind River Home Hardware (l = 23)
    a. Blind River, ON
    b. Approximate distance from ILW: 689 km
24) Millar Feed and Seed (l = 24)
    a. Cobden, ON
    b. Approximate distance from ILW: 824 km
25) Bell Country Heating (l = 25)
    a. Cookstown, ON
    b. Approximate distance from ILW: 860 km

26) Gravenhurst Home Hardware (l = 26)
    a. Gravenhurst, ON
    b. Approximate distance from ILW: 762 km
27) Pinehill Lumber (Castle Bldg. Supply) (l = 27)
    a. Lively, ON
    b. Approximate distance from ILW: 558 km

28) Bolduc/Gateway Home Hardware (l = 28)
    a. North Bay, ON
    b. Approximate distance from ILW: 584 km
29) Ferris Home Hardware (l = 29)
    a. North Bay, ON
    b. Approximate distance from ILW: 590 km
30) Home Hardware Orillia (l = 30)
    a. Orillia, ON
    b. Approximate distance from ILW: 800 km
31) BRT Group (Northern Wood Supplies Ltd.) (l = 31)
    a. Peterborough, ON
    b. Approximate distance from ILW: 917 km
32) Quality Hardwoods Ltd. (bulk retailer) (l = 32)[4]
    a. Powassan, ON
    b. Approximate distance from ILW: 610 km
33) Renfrew Home Hardware Bldg. (l = 33)
    a. Renfrew, ON
    b. Approximate distance from ILW: 855 km
34) Lyon's Tim-Br Mart (Main Store) (l = 34)
    a. Sault Ste. Marie, ON
    b. Approximate distance from ILW: 546 km
35) Lyon's Tim-Br Mart (l = 35)
    a. Sault Ste. Marie, ON
    b. Approximate distance from ILW: 547 km
36) Porcupine Pro Hardware (l = 36)
    a. South Porcupine, ON
    b. Approximate distance from ILW: 268 km
37) The Fire Place (l = 37)
    a. Sudbury, ON
    b. Approximate distance from ILW: 553 km
38) Kidd's Home Hardware (l = 38)
    a. Sundridge, ON
    b. Approximate distance from ILW: 654 km

39) Maier Hardware (l = 39)
    a. Thunder Bay, ON
    b. Approximate distance from ILW: 511 km
40) Armand H. Couture (l = 40)
    a. Timmins, ON
    b. Approximate distance from ILW: 261 km

[1]All approximate distances retrieved from Google Maps (2013)
[2]Retailers 22 to 40 fit the criteria as potential heating pellet (pellet 2) retailers and therefore have both heating pellet (pellet 1) and bedding pellet demand, while retailers 1 to 19 did not fit the bedding pellet criteria and therefore have only heating pellet demand.
[3]The exact distance between GG's Tru Hardware in Moose Factory, ON and ILW in Hearst, ON was not available from Google Maps (2013). Therefore, the distance was estimated by retrieving the distance between ILW and Cochrane from Google Maps (2013) and adding another estimated distance of 250 km, between Cochrane and Moose Factory, for a total distance of 464 km.
[4]Pellets are sold to this bulk retailer at the standard, per-bag price.

APPENDIX II

PEERFORECASTER® OUTPUT

Forecasts & 95% prediction intervals

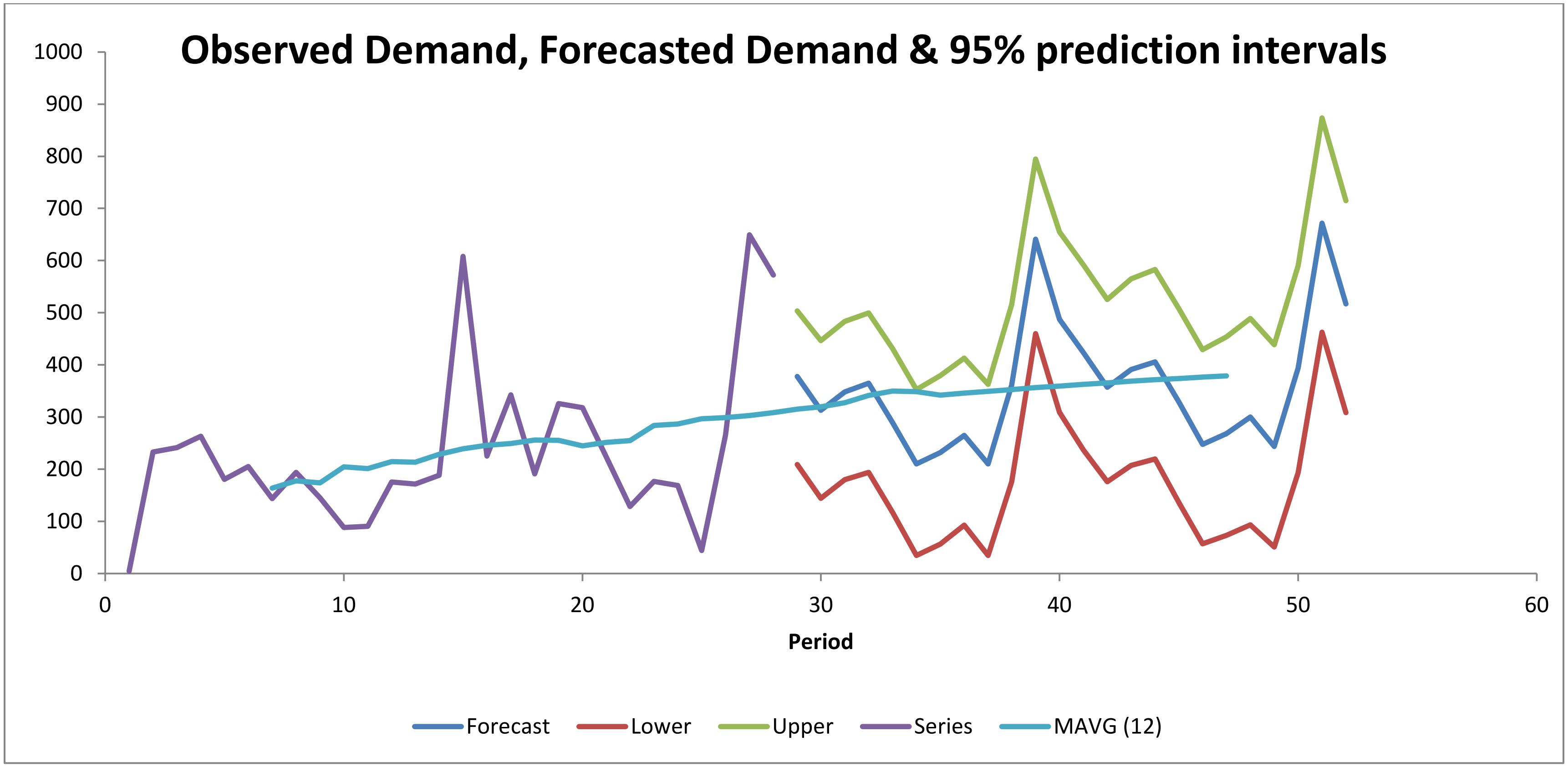
Period	*Forecast*	*Lower*	*Upper*
29	377.5492	208.9143	503.6505
30	312.9195	144.243	446.3915
31	348.3675	179.674	483.2738
32	364.9076	193.921	499.3503
33	289.4628	117.0521	431.5303
34	210.1769	34.83526	352.8703
35	232.1599	56.53523	379.5915
36	265.143	92.66469	413.0195
37	210.3104	34.51918	362.4622
38	361.773	175.8073	515.672
39	641.2112	459.6996	794.5702
40	487.4203	309.2874	654.9269
41	423.7669	237.1947	592.0703
42	357.2788	176.0469	525.3477
43	390.9432	207.077	565.0043
44	405.7714	219.38	582.6361
45	328.6835	135.9296	507.2165
46	247.8206	57.14199	429.4116
47	268.29	72.93859	453.6958
48	299.8204	93.11025	489.0959
49	243.5935	50.61135	438.8453
50	393.7178	193.2872	589.8981
51	671.8715	462.893	873.6794
52	516.8478	308.3061	714.5463

Series	***Series***
No. observations	28
No. forecasts	24
Seasonality	Monthly

Exponential Smoothing	
Model	Local trend, additive seasonal
Error	Additive
Growth	Damped
Seasonal	Additive

Summary Statistics	
Log-Likelihood	-161.7371552
AIC	331.4743104
RMSE	78.05302767
MAPE(%)	82.92808313
Sigma	78.05302767

Smoothing parameters	
alpha	0.1
beta	0.1
gamma	0.1
phi	0.959791377


Observed Demand, Forecasted Demand & 95% prediction intervals
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
Period
Forecast
Lower
Upper
Series
MAVG (12)

APPENDIX III

MODEL SYNTAX

MODEL 1: NO INVENTORY WITH VARIABLE PRODUCTION

```
Pellet_Opt

INDEX

! Index Residue
i := (1, 2);

! Index Pellet
j := (1, 2);

! Index Supplier
k := (1, 2);

! Index Customer
l := (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40);

! Index period
t := (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12);

DATA

!Fixed Overhead Cost
```

```
OC[t] := (5000, 5000, 5000, 5000, 5000, 5000, 5000, 5000, 5000, 5000, 5000, 5000);

! Manufacturing cost
D[j, t] := (65, 65, 65, 65, 65, 65, 65, 65, 65, 65, 65, 65,
            65, 65, 65, 65, 65, 65, 65, 65, 65, 65, 65, 65);

! Cost of shipping residue to plant ($/tonne)
C[i, k] :=

(6.08, 6.08, 16.7, 16.7);


! Cost of shipping pellets to customers ($/tonne)
A[j, l] =
  (40.26 , 20.08 , 14.37 , 18.48 , 23.84 , 0.05 , 27.91 , 6.04 , 12.03 , 23.65 , 10.43 , 14.87,
   13.4 , 32.03 , 21.23 , 48.59 , 28.04 , 26.76 , 18.25 , 15.01 , 10.66 , 46.48 , 31.52 , 37.7,
   39.35 , 34.86 , 25.53 , 26.72 , 26.99 , 36.6 , 41.95 , 27.91 , 39.12 , 24.98 , 25.03 , 12.26,
   25.3 , 29.92 , 23.38 , 11.94 , 40.26 , 20.08 , 14.37 , 18.48 , 23.84 , 0.05 , 27.91 , 6.04,
   12.03 , 23.65 , 10.43 , 14.87 , 13.4 , 32.03 , 21.23 , 48.59 , 28.04 , 26.76 , 18.25 , 15.01,
   10.66 , 46.48 , 31.52 , 37.7 , 39.35 , 34.86 , 25.53 , 26.72 , 26.99 , 36.6 , 41.95 , 27.91,
   39.12 , 24.98 , 25.03 , 12.26 , 25.3 , 29.92 , 23.38 , 11.94);


! Revenue from sale of pellets ($/tonne)
R[j, l] := (
  223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22
  223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22
  223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22 , 223.22
  223.22 , 223.22 , 223.22 , 223.22 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55
  264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55,
  264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55,
  264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 , 264.55 ;
```

```
! Cost of storing pellets ($/tonne)
E[j] := (1.82,1.82);

! Cost of storing residue ($/tonne)
F[i] := (1.86,1.86);



! Demand for pellets (tonnes)
G[j,l,t] := (
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  16 ,  0 ,  0 ,  0,
     0 ,  0 , 10 ,  0 ,  0 ,  0 ,  0 ,  0 ,  69 , 16 ,  0 ,  0,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   5 ,  0 ,  0 ,  0,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  5 ,   0 ,  0 ,  0 ,  0,
     0 ,  0 ,  6 ,  0 ,  0 ,  0 ,  0 ,  0 ,   8 ,  5 ,  0 ,  0,
     0 ,  0 ,  0 ,  0 , 48 ,  0 ,  0 ,  0 ,   0 ,  0 ,  0 ,  0,
     0 ,  4 ,  0 ,  0 ,  0 ,  0 ,  0 , 13 ,  28 ,  0 ,  0 ,  0,
    14 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 , 42 , 104 , 13 ,  8 , 13,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   0 , 31 ,  0 ,  0,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   1 ,  0 ,  0 ,  0,
     0 , 11 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   0 , 30 ,  3 ,  4,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   0 ,  0 ,  0 ,  0,
     5 ,  4 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  16 ,  0 ,  0 ,  0,
     0 , 17 ,  0 ,  0 ,  0 ,  0 , 10 ,  0 ,   0 ,  9 , 16 ,  0,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   0 , 15 ,  0 ,  0,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   0 ,  8 ,  0 ,  0,
     6 , 34 ,  0 ,  0 ,  0 ,  0 ,  0 , 46 ,   0 , 13 ,  0 ,  0,
     0 ,  0 ,  0 ,  0 ,  0 , 12 ,  0 ,  0 ,   0 , 38 ,  0 ,  0,
     0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  27 ,  0 ,  0 , 11,
     0 ,  1 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,   0 ,  0 ,  0 ,  0,
```

0	0	0	0	0	0	0	0	7	7	0	0
0	0	0	0	0	0	0	0	0	0	0	0
2	0	4	17	0	0	1	9	5	16	0	0
0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	12	0	0	12	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	37	34	31	0
0	0	0	0	0	0	0	16	0	0	0	0
55	38	0	0	0	0	0	101	49	31	31	29
0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	3	0	0
0	18	3	0	0	4	0	1	25	0	22	0
0	0	0	0	0	0	0	5	0	0	0	0
23	8	0	26	0	0	25	0	5	36	37	0
9	5	0	0	0	0	9	0	21	11	7	0
3	1	2	0	0	0	0	17	69	9	7	16
0	0	0	0	0	0	0	0	33	0	0	71
0	28	0	2	0	0	0	16	18	11	26	0
195	258	130	268	135	107	84	171	123	165	176	191
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

```
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0,
0 , 6 , 2 , 4 , 1 , 3 , 1 , 2 , 5 , 8 , 2 , 0,
1 , 0 , 6 , 4 , 0 , 3 , 1 , 0 , 0 , 3 , 0 , 5,
4 , 4 , 4 , 0 , 6 , 0 , 0 , 3 , 2 , 2 , 6 , 1,
4 , 1 , 1 , 4 , 4 , 4 , 0 , 2 , 1 , 1 , 0 , 1,
0 , 2 , 3 , 4 , 3 , 3 , 2 , 3 , 8 , 0 , 3 , 7,
1 , 2 , 0 , 5 , 2 , 1 , 3 , 2 , 2 , 0 , 4 , 1,
1 , 3 , 6 , 4 , 1 , 7 , 0 , 0 , 3 , 4 , 4 , 3,
5 , 1 , 0 , 5 , 0 , 5 , 1 , 2 , 2 , 6 , 5 , 0,
5 , 7 , 0 , 2 , 1 , 1 , 2 , 4 , 2 , 1 , 6 , 1,
1 , 3 , 3 , 2 , 1 , 2 , 1 , 6 , 4 , 0 , 2 , 5,
6 , 3 , 1 , 1 , 1 , 4 , 0 , 1 , 3 , 3 , 6 , 2,
0 , 0 , 4 , 2 , 4 , 3 , 1 , 1 , 3 , 1 , 6 , 1,
1 , 0 , 1 , 2 , 8 , 1 , 5 , 7 , 2 , 1 , 4 , 2,
1 , 0 , 2 , 6 , 1 , 0 , 6 , 1 , 4 , 5 , 0 , 5,
2 , 0 , 7 , 0 , 0 , 2 , 2 , 4 , 0 , 6 , 1 , 1,
1 , 5 , 2 , 2 , 1 , 3 , 6 , 0 , 3 , 4 , 6 , 0,
4 , 3 , 1 , 5 , 3 , 0 , 0 , 0 , 4 , 0 , 0 , 1,
4 , 4 , 1 , 1 , 7 , 6 , 5 , 1 , 6 , 2 , 0 , 3,
0 , 2 , 0 , 1 , 1 , 0 , 0 , 0 , 4 , 5 , 2 , 0);
```

```
! Supply of Residue (tonnes)
H[i, k, t] := (
183.6, 183.6, 183.6, 183.6, 183.6, 183.6, 183.6, 183.6, 183.6, 183.6, 183.6, 183.6,
122.4, 122.4, 122.4, 122.4, 122.4, 122.4, 122.4, 122.4, 122.4, 122.4, 122.4, 122.4,
```

122.4,	122.4,	122.4,	122.4,	122.4,	122.4,	122.4,	122.4,	122.4,	122.4,	122.4,	122.4,
81.6,	81.6,	81.6,	81.6,	81.6,	81.6,	81.6,	81.6,	81.6,	81.6,	81.6,	81.6);

```
!Penalty for unfulfilled demand
N[j] := (13.39, 15.87);

VARIABLES

          ! Amount of residue used
          X[i, j, t];

          ! Residue Stored
          U[i, k, t];

          ! Residue purchased
          V[i, k, t];

          ! Amount of Pellets built
          Y[j, t];

          ! Amount of pellets stored
          Z[j, t];

          ! Penalty
          UFD[j, l, t];

          !Amount of pellets sold and shipped
          W[j, l, t];

MACROS
          Penalty := SUM(j, l, t: UFD * N);
          Revenue := SUM(j, l, t: W * R);
          Cost := SUM(t: OC) + SUM(j, t: Z * E) + SUM(i, k, t: U * F) + SUM(j, t: Y * D) + Penalty +SUM(j,l,t: W * A)

MODEL

          MAX Revenue - Cost

SUBJECT TO

           ! [1]
           InventoryConstraintPellets[j, t= 1]:
                      Y[j, t] - sum(l: W) -Z[j, t] = 0;

           InventoryConstraintPellets[j, t= 2]:
                      Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

           InventoryConstraintPellets[j, t= 3]:
                      Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;
```

```
InventoryConstraintPellets[j, t= 4]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 5]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 6]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 7]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 8]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 9]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 10]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 11]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

InventoryConstraintPellets[j, t= 12]:
        Y[j, t] + Z[j, t - 1] - sum(l: W) -Z[j, t] = 0;

! [2]
InventoryConstraintResidue[i, k, t=1]:
        SUM(j: X) + U[i, k, t] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=2]:
        SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=3]:
        SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t])= 0;

InventoryConstraintResidue[i, k, t=4]:
        SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=5]:
        SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=6]:
        SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;


InventoryConstraintResidue[i, k, t=7]:
        SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;
```

```
InventoryConstraintResidue[i, k, t=8]:
            SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=9]:
            SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=10]:
            SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=11]:
            SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

InventoryConstraintResidue[i, k, t=12]:
            SUM(j: X) + U[i, k, t] - U[i, k, t - 1] - SUM(k: V[i, k, t]) = 0;

! [3]
ProductionEquation[j, t]:
            SUM(i: X)  = 1.02Y;

! [4]
DemandConstraint[j, l, t]:
            W + UFD  = G;

! [5]
SupplyConstraint[i, k, t]:
            V <= H;

! [6]
 Mixture[i, j, t] WHERE i=2:
X[i = 2]  = 1.02Y[j = 2];

! [7]
ProdLimits[t]:
Sum(j: Y) <= 720;
BOUNDS

![8] - [13]

U[i, k, t] = 0;
V[i, k, t] >= 0;
W[j, t, l] >= 0;
X[i, j, t] >= 0;
Y[j, t] >= 0;
Z[j, t] = 0;

END
```

MODEL 2: DEMAND FLOW INVENTORY WITH VARIABLE PRODUCTION

BOUNDS

```
![8] - [13]

U[i, k, t] >= 0;
V[i, k, t] >= 0;
W[j, t, l] >= 0;
X[i, j, t] >= 0;
Y[j, t] >= 0;
Z[j, t] >=0;
```

MODEL 3: DEMAND FLOW INVENTORY WITH CONSTANT PRODUCTION

```
! [7] ProdLimits[t]:

Sum(j: Y) = 500;
```

BOUNDS

```
![8] - [13]

U[i, k, t] >= 0;
V[i, k, t] >= 0;
W[j, t, l] >= 0;
X[i, j, t] >= 0;
Y[j, t] >= 0;
Z[j, t] >= 0;
```

The rate of constant production was set to the maximum amount possible given the consistent monthly supply of residue. The monthly supply of residue is 510 tonnes and there is a yield of 98% of pellets per tonne of residue; therefore for 510 tonnes of residue, 500 tonnes of pellets are produced.