Feedstock Supply Chain Models for the Frontier Renewable Resources Biofuel Facility in Kinross, Michigan

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Executive Summary

This project develops a biomass feedstock supply chain strategic planning model for the planned Frontier Renewable Resources, Inc., facility in Kinross, Michigan. The overarching goal is to support planning decisions that enable delivery of biomass in a low cost, reliable, and time effective manner. It is anticipated that the model will be exercised to identify: i) best harvesting schedules, ii) superior transportation methods, iii) storage size requirements, and iv) areas where effort should be directed to improve the supply chain. For modeling purposes the feedstock units are in short tons of green wood.

Several inter-related tasks were undertaken to realize the goals and objectives of the project. First, an in-depth literature review of biofuels supply chains was completed, and current policies, regulations, and laws directly affecting the supply chain were catalogued. Next, a conceptual model of the supply chain was constructed, including all phases of the wood supply chain from the roadside landing to the processing plant. This conceptual model was then transformed into a suite of optimization and simulation models in order to improve accuracy and expand the number of alternatives that can be examined. Using data acquired from all COEE Project teams, the models were applied to illustrate their use in evaluating strategic decisions and trade-offs in supply chain performance. In addition, the models can identify key parts of the supply chain where improved knowledge or changes in systems would have the largest effects on delivered feedstock volumes, reliability, and costs.

In exercising the suite of models, a long-term optimization model (20-year horizon with an annual time step) is run first to determine the minimum cost harvesting pattern and transportation methods, given constraints in availability due to growth and land owner participation. The resulting annual decisions are then disaggregated to a weekly time scale using either a pre-specified seasonal pattern or a short-term optimization model (1-year horizon with a weekly time step). Finally, the resulting weekly harvesting and transportation plans are used as input to the simulation model, which operates on a daily time step for a 1-year horizon, accounting for uncertainty in spring break up timing and weather conditions.

Model results can help to confirm strategic planning decisions based on experience, aid in the evaluation of trade-offs, and potentially provide insights for decision making under unforeseen contingencies. As an example of confirming strategic planning decisions, results from the long-term optimization model indicate that feedstock can be reliably supplied to the processing facility for a period of at least 20 years, with the majority of the feedstock harvested within 100 miles of the facility. Although the results of the optimization model should be recognized as "optimistic" (i.e., perhaps not achievable in practice), the simulation model confirms under realistic spring break up conditions that facility demand can be met at least 94 percent of the time, even without the purchase of so-called "emergency wood," purchased under a one-time contract, or shipping by rail from farther than 150 miles.

Output from the long-term optimization model illustrates how harvesting locations can be expected to shift farther from the facility during the course of a 20-year planning period, with a corresponding increase in transportation costs. Due to current wood fiber availability near the

facility, the model does not indicate a significant shift occurring until after 8-10 years. By years 16-20, however, transportation costs may be expected to increase by 25-30 percent.

Several trade-off and sensitivity analyses are illustrated with the simulation model. Scenarios with reduced truck availability, reduced rail use, and reduced storage yard capacities are simulated to predict potential impacts on feedstock reliability and cost. In general, cost impacts could not be fully analyzed because no assumptions are made regarding the cost of "emergency wood" or the cost of an unplanned facility shutdown. However, the reliability of meeting facility demand is shown to be quite sensitive to each of these three factors, with the probability of a feedstock shortage roughly doubling due to either a 5% reduction in harvest volume, a 90 percent reduction in rail use, or a 40 percent reduction in storage yard capacity. Simulation results also illustrate the trade-off between reliability and log age, e.g., increasing reliability from 94 to 97 percent, requires larger inventories, with average log age increasing by about 10-15 days (to ages of 50-55 days) just prior to spring breakup.

Project deliverables include a conceptual description of the supply chain model, software-based supply chain models (along with user and developer documentation), and recommendations for ensuring reliable and low-cost system performance.

Introduction

Motivation

Much of the petroleum use in the United States (U.S.) supports transportation needs, and 60 percent of this comes from imports. The U.S. Department of Energy (DOE) estimates that enough biomass is sustainably available to replace 20 percent of current transportation-related U.S. petroleum consumption. The National Academy of Sciences identified the utilization of renewable biomass feedstocks for production of bio-chemicals and biofuels as a grand sustainability challenge (NAS, 2005). The use of biofuels (including ethanol) in transportation applications can produce such benefits as improved national security, more favorable trade balance, rural U.S. job creation, decreased demand for petroleum, and lower emission of fossil-derived CO_2. The development of a profitable industry for the conversion of woody materials to ethanol requires efficient processes at every step of the value chain (e.g., biomass harvesting/gathering, loading, transport, processing, and distribution). The development of efficient processes calls for the support of systems-level, integrative analysis methods and tools to support technological, policy, and financial decisions.

Mascoma and JM Longyear, through collaboration, formed Frontier Renewable Resources (Frontier). Frontier is establishing a commercial-scale processing facility in Chippewa County's Kinross Township in Michigan's Upper Peninsula. The facility will create cellulosic fuels from a range of non-food biomass feedstocks, e.g., hardwood chips. At steady state, the production facility is expected to produce 40 million gallons of ethanol and other bio-products per year. The Feedstock Supply Chain Center of Energy Excellence (Feedstock COEE) was established to support the technical needs of Frontier.

In considering the development of a profitable company that can sustainably produce ethanol and other bio-products there are two principal questions: i) is there sufficient biomass to sustainably support the needs of a Kinross-based facility, and ii) what is the best system to gather, handle, and transport the biomass to the Kinross facility? Project #2 in the Feedstock COEE addresses the first of these two questions. The answer to the second question is critical since the gathering, handling, and transportation costs represent the overwhelming majority of the costs associated with the production of ethanol. This proposed project associated with the Feedstock COEE seeks to answer this question – the project focus is on developing a feedstock supply chain model (or suite of models) that can optimize and simulate the delivery of biomass to the production facility in a low cost, reliable, and time-effective manner. The model will be capable of addressing such issues as: i) spatial and temporal harvesting plans, ii) transportation methods, iii) storage size requirements, and iv) areas where effort should be directed to improve the supply chain – all aimed at the overarching objective of achieving a robust, cost-optimal supply chain (Figure 1).

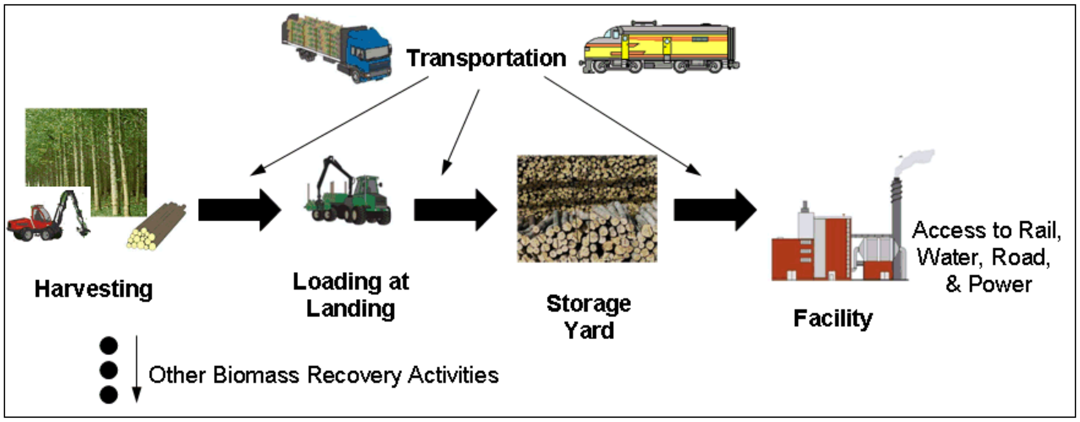


Figure 1: Components of the Feedstock Supply Chain

Objectives

The goals of this project are to i) develop a feedstock supply chain model, ii) utilize the model to provide guidance on where improvement opportunities exist, and iii) make recommendations regarding the establishment of the actual supply chain. To achieve these goals, the model must answer questions posed by the Frontier management team and other key stakeholders. And, of course, the overarching objective of the proposed modeling effort is to design a supply chain that minimizes the cost of supplying the facility while meeting necessary delivery requirements.

Developing the feedstock supply chain model required integration of many different types of information from many different sources. Frontier provided information regarding specific details of the plant's operation, the cost and difficulties of harvesting and shipping large quantities of wood, and other data as needed. Additional information was provided by the Michigan Technological University/Michigan State University research collaborations associated with the other COEE projects:

- Project 2: Increasing Availability of Feedstocks and Ensuring Sustainability
- Project 3: Improving Feedstock Harvesting, Processing, and Hauling Efficiencies
- Project 4: Outreach, Extension, and Technology Transfer

The primary goal of the supply chain team is to bring this diverse information together to develop comprehensive models that will successfully characterize the process of supplying the Frontier facility, with the goal of minimizing the cost of supplying the required biomass.

The spatial dispersion and change in availability of the resources over time makes the supply chain system complex. Therefore, the model(s) must be both flexible and comprehensive in order to evaluate a wide range of planning scenarios. The development of a detailed, time-dynamic operations scheduling model is beyond the scope of this project.

Background

Literature Summary

Based on the current literature, there are a number of research gaps filled by the biomass feedstock supply chain research for the Frontier project. The literature from existing cellulosic ethanol supply chains served as a basis for the development of supply chain management decision support tools and a unique supply chain model was developed that is tailored to the specific needs of Frontier. Table 1 provides a comparison of related research found in the literature to the current CoEE project. A full literature summary can be found in Appendix B.

National Biofuels Plan

The National Biofuels Plan developed by the Biomass R&D Board (2008) includes sustainability as an action area for successful development of the supply chain. This is similar to the Frontier facility because sustainability issues are one of the key drivers behind why the facility will be built. The Biomass R&D Board (2008) includes environment, health, and safety into an action area of its biofuels plan. The addition of these elements ensures that the supply chain can operate in a manner that is safe and compliant with energy policies, procedures, laws, and regulations. The Frontier facility relates to this part of the plan from an environmental and sustainability policy prospective.

The Biomass R&D Board (2008) also focuses on feedstock logistics because of its effect on the finished cost of cellulosic ethanol. These same feedstock logistics costs will be considered when developing the supply chain for the Frontier facility. The areas of focus for feedstock logistics in the biofuels plan that relate to the Frontier project are harvesting process, storage facilities, and transportation of the feedstock.

Table 1: Comparison of projects and current literature related to CoEE Project

	Idaho National Laboratory Hess, et al. (2007); Hess, et al. (2009); Idaho National Laboratory (2006)	**Sandia National Laboratory** Sandia National Laboratories (2009); West, et al. (2009)	**National Biofuels Plan** Biomass Research and Development Board (2008)	**Oak Ridge National Laboratory** Reynolds (2002)	**Simulation and Optimization** De Mol et al. (1997)
Feedstock Type	Wheat Straw	Corn-based/agricultural and forest residues	Corn, crop residues, woody residues	Corn stover, forest residues/thinnings, agricultural residue, urban waste	Thinnings, prunings, waste wood, sewage sludge, waste paper
Harvesting Procedures	Industrial harvesting (Crop harvesting, residue collection)	Not Identified	Industrial harvesting (Feller-buncher, skidder, crop harvesting, residue collection)	Not Identified	Not Identified
Transportation Methods	Truck/Rail/Water	Truck/Rail	Truck/Rail/Water	Truck/Rail/Water	Truck/Rail/Water
Locations and Facilities	Harvesting and collection sites, storage facilities, preprocessing locations, ethanol plant	Source locations, storage sites, conversion plants, blending locations, distribution facilities	Harvesting and collection sites, storage facilities, preprocessing locations, ethanol plant	Source locations, terminals, ethanol plant	Source locations, collection sites, transshipment sites, pre-treatment sites, the energy plant
Preprocessing Facilities	Reports suggest moving preprocessing of the biomass to early on in the supply chain	Not Identified	Various locations along the supply chain specific in each case	Not Identified	Optimization and simulation found preprocessing can best be done at the plant
Biorefinery or Energy Operations	Numerous ethanol plants	Numerous ethanol plants	Numerous ethanol plants	Single plant destinations	One central location
Output	Cellulosic Ethanol	Cellulosic Ethanol	Cellulosic Ethanol	Cellulosic Ethanol	Some type of fuel from Biomass

	Forest fuel network design Gronalt and Rauch (2007)	**Supply chain Optimization in the Forest Industry** Gunnarsson (2007)	**Jefferson County Biomass Facility Feasibility Study** McNeil Technologies, Inc. (2005)	**Integrated biomass supply analysis and logistics model (IBSAL)** Sokhansanj et al. (2006)	**CoEE Project 1**
Feedstock Type	Forest Fuel	Forest fuel, pulp products	Urban wood waste, forest biomass	Corn stover	Woody biomass
Harvesting Procedures	Industrial harvesting (Feller-buncher, skidder)	Not Identified	Industrial Harvesting (chainsaw, feller-buncher, harvester, skid steer, masticator)	Shredding, Baling, Stacking	Industrial harvesting (Feller-buncher, skidder)
Transportation Methods	Truck	Truck/Rail/Vessels/Barges	Truck	Truck (flatbed trailers)	Truck/Rail
Locations and Facilities	Harvesting site, regional terminals, industrial terminals, energy plant	Storage terminals, saw mill, pulp mill, paper mill, heating plant	Harvesting site, landing, energy plant	Harvesting site, satellite storage, biorefinery	Harvesting site, roadside landings, rail spurs, storage at the mill
Preprocessing Facilities	A central terminal where all the chipping can occur and mobile chipping options were analyzed	Chipping occurs at the forest or at the mill prior to transport to the heating plant	Chipping occurs at the landing	Grinding occurs at the biorefinery	Chipping occurs at the mill
Biorefinery or Energy Operations	Numerous energy plants	Numerous CHP facilities	Central facility, semi-mobile plant, existing facility, heating and cooling system	Biorefinery	One cellulosic ethanol plant
Output	Fuel for heating and bioenergy plants	Saw wood, paper, forest fuels	Fuel for heating and power plants	Biorefinery	Cellulosic ethanol

The supply chain model for the Frontier facility differs from the National Biofuels Plan in that it only uses logs for its feedstock. The National Biofuels Plan considered many sources of potential feedstock, such as agricultural residues and energy crops. Also, the Frontier facility supply chain will be tailored to meet the local criteria and demands of operating in Michigan, as opposed to a nationwide scale supply chain like the National Biofuels Plan. The Biomass R&D Board (2008) also focuses on conversion science and technology, distribution technology for the ethanol, and blending of the ethanol, which are all out of the scope of the project for the supply chain team.

Idaho National Laboratory

Idaho National Laboratory (INL) also developed a biomass supply chain for ethanol. Hess, et al. (2007) proposed a uniform-format feedstock supply chain that can be implemented at a nationwide level. This is different from the scope of the supply chain team for the Frontier facility. The main goal of the Frontier supply chain system is to develop a supply chain specific for the Frontier facility. Also, unlike the supply chain model that uses logs, the Idaho National Laboratory mainly uses wheat straw and agricultural residues as primary feedstocks. One of the variables identified by Hess, et al. (2007) is the different demands for different products that compete for biomass for energy production. This is similar to the Frontier facility. Some of the forest products will also be used by mills in the pulp and paper industry. Another recent source of demand for wood resources are the increasing number of combined heat and power (CHP) operations using co-firing of coal and woody biomass or completely operating with woody biomass. There will be a limited amount available for conversion to ethanol. Preprocessing of the biomass is moved prior to the transportation and handling in the INL report. This is so the transportation and handling procedures can be uniform no matter what type of feedstock is used. This is different from the Frontier facility supply chain since all of the preprocessing and chipping will occur at the dacility. Because of this unique feature, it will be not included in the supply chain model for Frontier. Hess et al. (2007) also highlight that transportation and handling costs account for nearly 30% of the annual cost for feedstock. The supply chain team will work to minimize transportation costs to the Frontier facility to ensure the system is cost effective.

INL (2009) study included some critical success factors for a supply chain feedstock model using wheat and barley straw. One of the critical success factors for the feedstock models includes the ability to contract straw from a specified distance. Even though the feedstock type is different from that of the Frontier facility, the issue outlined is very relevant. Logs need to be harvested from specific forest within a 150-mile radius of the facility. INL (2009) highlighted areas of concern for the feedstock supply chain system. The areas that relate to the Frontier facility include:(1) the cost of feedstock will vary with demand;(2) the logistics of moving the feedstock are complicated;(3) storage of feedstock may be subject to fire codes;(4) unloading the feedstock after transportation will vary with each case; and (5) the amount of field energy used while handling and transporting the feedstock.

Sandia National Laboratory

Sandia National Laboratories (SNL) performed a study assessing the feasibility of achieving national goals of producing 90 billion gallons of biofuels by 2030 (SNL, 2009; West et al., 2008). The study considered corn-based ethanol, and cellulosic ethanol from energy crops and agricultural and forest residues, to support the national goal. This is different from the Frontier facility since the supply chain will not incorporate any type of feedstock other than logs supplied from the forest. Energy crops will also not be in the scope of the supply system. SNL developed a model with inputs such as conversion yield, capital investment/annual capacity per cellulosic plant, energy prices, and feedstock yield improvements. This is very different from the supply chain model developed for Frontier which includes supply chain inputs such as feedstock inventory and availability, harvesting/processing, storage at landings, transportation, and policy.

Oak Ridge National Laboratory

The Oak Ridge National Laboratory (ORNL) investigated the feasibility of expanding the ethanol industry. Reynolds (2002) studied two different cases for this expansion scenario. Costs associated with additional infrastructure being built were estimated. This is beyond the scope of the Frontier supply chain system. The ORNL also calculated transportation costs. The transportation costs are also important to the supply chain team for the Frontier facility. However, these costs will be different from what is observed by the supply system for Frontier. This is because the Frontier facility only includes logs primarily in Michigan within a 150 mile radius of the ethanol plant. The supply chain team will fill the research gap of producing a log supply system for an ethanol plant in the Upper Peninsula of Michigan.

Mathematical Models

The issue of chipping is very relevant to the Frontier facility's supply chain since it is assumed that chipping will occur at the biofuel facility. Gronalt and Rauch (2007) investigated the issue of centralized and decentralized chipping when designing a forest fuel network. Availability issues affect the design of a supply network since not every tree in a forest can be reached to harvest. This is very similar to the Frontier facility since a large portion of the eastern Upper Peninsula is wetlands, which poses availability issues with harvesting the forests. The work described by Gronalt and Rauch (2007) solved the supply system problem for several plants at once using numerous storage facilities and terminals to meet the varying demands of each plant. This differs from the work being done with the Frontier facility. The Frontier facility will attempt to receive supply from a number of harvest sites (direct) or storage areas (indirect)and also have some on-site storage. The similarity involves materials coming from multiple locations.

Gunnarsson et al. (2004) proposed a solution to the supply chain problem involved with a forest fuel network structure through a large mixed integer linear programming (MLP) model. The main product used is forest fuel, which are mainly forest residues in harvest areas or from byproducts from sawmills. The destination for the forest fuel is a heat plant. This is different from the Frontier facility because the demand of the heat plant will rise based on the weather and particular season. The study also raised the issues of forests that are owned by the heat plant as opposed to contracted forests. Feedstock coming from forests owned by the plant would not have to be purchased while contracted forests would have to be purchased. This is partially similar to the Frontier facility since some of the land harvested may be owned by J.M. Longyear.

De Mol et al. (1997) created both simulation and optimization models for the logistics of biomass fuel collection. The network structure associated with the models includes nodes that correspond to source locations, collection sites, transshipment sites, pre-treatment sites, and the energy plant itself. Arcs connect the nodes that represent road, water, or rail transportation. This network structure is similar to the Frontier facility structure; but water transportation is not included in the Frontier study. The simulation model created by De Mol et al. (1997) is similar to the simulation model being developed for the Frontier facility. Both simulation models include the same network structure and one biomass type. However, the model for the Frontier facility has a fixed end destination while the De Mol et al.'s (1997) simulation model investigated a variety of different ending destinations. The optimization model created by De Mol et al. (1997) combines different types of biomass, different nodes, and pre-treatments situations to develop the optimal network structure. The fact that the optimization model includes different biomass types and pre-treatment situations differentiates it from the Frontier optimization model. The overall goal of supplying an ethanol plant with biomass is the same for both.

McNeil Technologies, Inc. (2005) investigated the feasibility of building a biomass plant in Jefferson County, Colorado. Several different scenarios were considered including centralized and decentralized facilities, various conversion techniques, and different harvesting processes. Urban wood waste and forest biomass travels through the supply chain from procurement to storage and finally to the energy plant. Woody biomass is used to fuel heating and power plants throughout Jefferson and nearby counties. While this study considers the feasibility of a biomass facility, an optimum facility or process is not chosen. This decision remains in the hands of Jefferson county officials. The Frontier model has a definite location in Kinross, MI and known harvesting and processing techniques.

Sokhansanj et al. (2006) examined an integrated biomass supply analysis and logistics model (IBSAL). This model examines the supply chain of corn stover through harvesting, storage, and transportation to the biorefinery. The IBSAL model examines costs and optimum conditions for harvesting and transportation logistics of biomass material. Weather conditions and routine equipment maintenance are entered in the model to calculate moisture content of the stover and equipment performance. Similarly, the Frontier model will consider moisture content. A difference is that the equipment maintenance will not part of the feedstock supply chain model. The Frontier simulation model combines truck and rail transportation in an optimization model; whereas, the IBSAL model only considers flatbed trucks. This difference complicates the model and offers greater options when optimizing the cost and time used in the supply chain.

The Frontier supply chain is greatly affected by policy related constraints. This gap was reviewed and constraints addressed in the simulation model. The literature reviewed provides guidance expanding the body of knowledge and application to develop an efficient and cost effective biomass supply chain model.

Relevant Policies

The main laws, regulations, and policies that are relevant to the Project 1 model were reviewed and summarized. At the federal level these include the 1990 Amendments to the Clean Air Act for air pollution restrictions; the Clean Water Act; and the Coastal Zone Management Act (although the latter gives management authority to the state environmental agencies). The latter two laws limit non-point sources of water pollution, including impacts of logging activities. At the Michigan State level, the other most pertinent policies are those from the Michigan Department of Transportation – the maximum legal truck loadings and dimensions based on Act 300 P.A. (1949), as amended, and the maximum allowable vehicle weight for the Mackinac Bridge.

Different land owners have very different tendencies when deciding whether or not to harvest timber. We were able to identify four distinct ownership classes in the supply zone: federal, state, private industrial and private non-industrial. The ownerships were divided into federal, state, and private in the Forest Inventory and Analysis (FIA) data provided by MSU Project 2. We were able to divide the private ownerships into industrial and non-industrial groups be using GIS information on industrial ownerships provided by Art Abramson.

The non-industrial private owners have a very broad set of goals reflected in their land management decisions, and it is hard to predict harvesting behavior. Furthermore, there are thousands of owners, most with relatively small areas. One subgroup that is both important and may be more likely to harvest timber is owners with larger tracts of land. Many of the individuals in that group practice active forest management, and might be willing to form long-term relationships with the Frontier facility. Bill Knudson of MSU Project 1 did a preliminary review to identify these owners, which was subsequently refined by MTU Project 1. Maps identifying these owners, along with a GIS layer and spreadsheet, are being delivered to Frontier. The information on larger private landholders is important to efficient operation of the cellulosic ethanol facility for two primary reasons. First, these owners represent an opportunity to establish long-term relationships with larger potential suppliers. This is particularly important in the northern Lower Peninsula, where there are no longer large private corporate land holdings. Second, ongoing relations with these owners may provide an opportunity to secure "emergency wood," purchased under a one-time agreement, to help the facility when breakup occurs unexpectedly early and additional fiber is needed on short notice.

Land Use Restrictions

The State Forest Management Plan and the plans of Ottawa National Forest, Hiawatha National Forest, and the Huron/Manistee National Forests were reviewed. A synopsis of these plans has been prepared by the MSU Project 1 team.

Logging activity in the State of Michigan is not allowed in designated critical dune areas pursuant to Part 353, Sand Dune Protection and Management and in designated environmental areas pursuant to Part 323, Shorelands Protection and Management, of the Natural Resources and Environmental Protection Act of 1994, PA 451 as amended (NREPA), without a permit from the Department of Natural Resources and Environment (DNRE). In the COEE Project # 1 study area, this includes several coastal townships in five UP and five LP counties:

Counties (Townships) Containing Designated Critical Dune and Environmental Areas in the Upper Peninsula:

- Alger (Burt)
- Chippewa (Bay Mills, Bruce, DeTour, Drummond, Pickford, Raber, Soo, Sugar Island, Tahquamenon)
- Luce (McMillan)
- Mackinac (Bois Blanc, Brevort Moran, Clark, Garfield, Hendricks, Marquette, Moran, Newton, St. Ignace)
- Schoolcraft (Doyle, Mueller)

Counties (Townships) containing Designated Critical Dune and Environmental Areas in the

Lower Peninsula:

- Antrim (Torch Lake)
- Benzie (Crystal Lake, Gilmore Blaine, Lake)
- Charlevoix (Charlevoix, Norwood, Peaine, St. James)
- Emmet (Bear Creek Little Traverse, Bliss, Cross Village, Wawatam)
- Leelanau (Centerville, Cleveland, Empire, Glen Arbor, Leelanau, Leland).

Restrictions that limit harvesting fiber on some lands have been integrated into the model via the timber volume, growth and historical harvest data. This data was provided by MSU Project 2 and excluded forest inventory and analysis plots (and the acres they represent) from the inventory available for harvest if there were restrictions on harvesting.

Load Restrictions

The current prototype simulation and optimization models include the Michigan Department of Transportation's maximum legal truck loadings and maximum allowable vehicle weight for the Mackinac Bridge. The simulation model will also include spring breakup road restrictions at the county level, and historical data on the timing of these restrictions was collected by the Michigan State and Michigan Tech Project 1 Teams.

Truck weight laws in Michigan limit the maximum weight of logging trucks through a restriction on the maximum weight per axle, since research has shown that pavement damage is directly related to axle loading, not gross vehicle weight (GVW). The COEE Project 1 models will only consider the weight of each truck. The framework for these restrictions, which are implemented by the Michigan Department of Transportation (MDOT), is based on State Act 300 P.A. 1949 as amended. GVW is defined to include the weight of the truck, logging cargo, fuel, and driver. Michigan's truck weight system allows greater maximum GVW than found in most other states, or on a "federal-weight- law truck", the latter of which is limited to 80,000 pounds per trip.

The maximum GVW allowed on the heaviest "Michigan-weight-law truck" is 164,000 pounds per trip, which can only be achieved by using 11 properly spaced axles (Michigan Department of Transportation, 2010a). The maximum allowable gross loading per axle is 18,000 pounds (and 20,000 pounds for vehicles that total 80,000 pounds or less in gross weight). When seasonal load limitations are in effect, the allowable gross axle loading for a rigid route is 15,000 pounds on a single axle and 12,750 pounds per axle on a tandem axle assembly, and for a flexible route is 13,000 pounds on a single axle and 11,050 pounds per axle on a tandem axle assembly. Finally, when traveling north or south on the Mackinac Bridge between St. Ignace and Mackinaw City, logging trucks are limited to a GVW of 144,000 pounds per trip (Michigan Department of Transportation, 2010b).

A list of seasonal road restrictions for state roads was obtained from MDOT, and lists of local and county roads were obtained from the county road commission office. Maps of the roads that are Class A and roads with load limits may be provided to Frontier upon request. An example is shown in Figure 2.

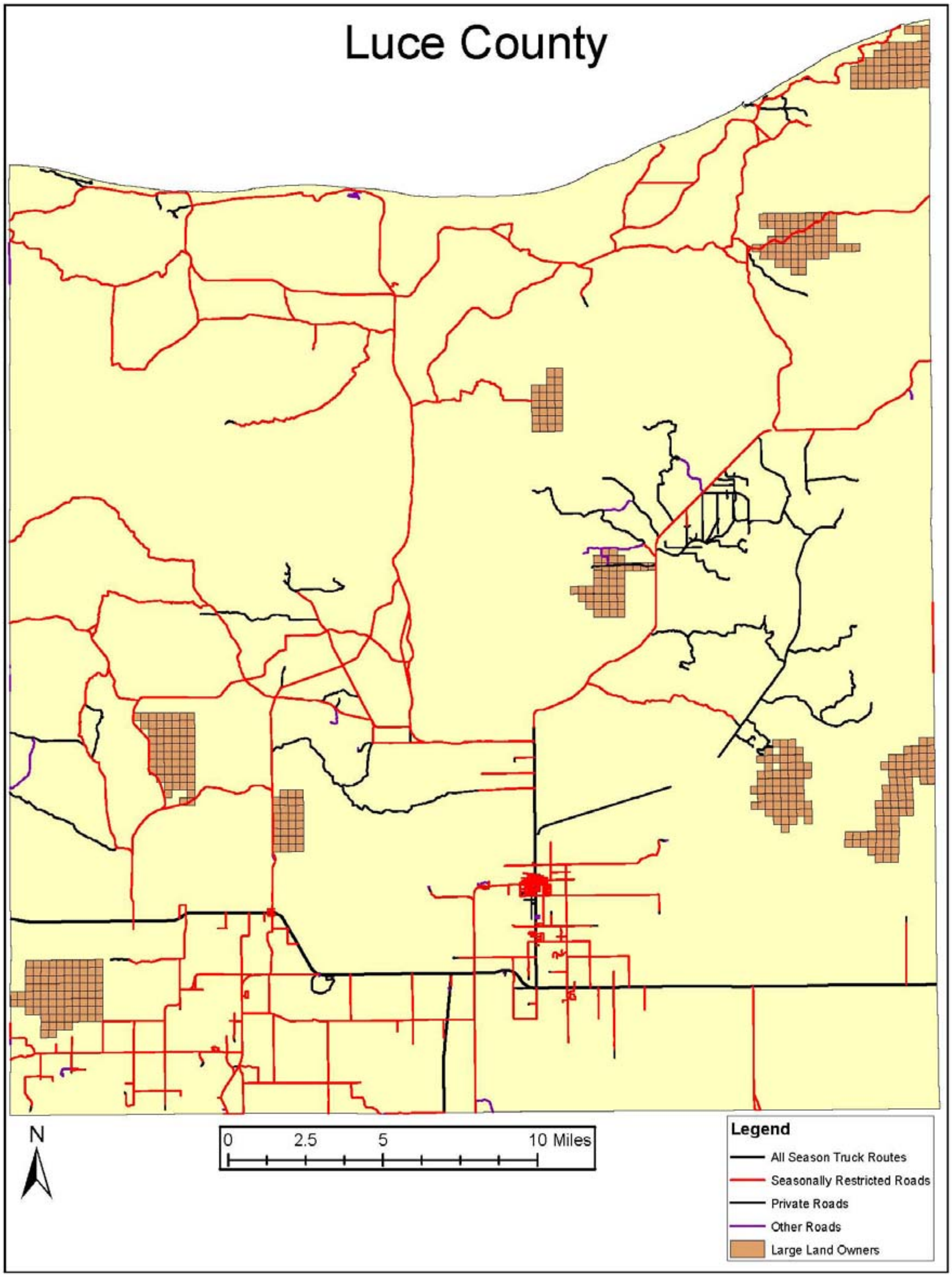


Figure 2: Class A (all season) roads and roads with seasonal load restrictions in Luce County.

Air Pollution

At the federal level the relevant policies and acts include the 1990 Amendments to the Clean Air Act, for air pollution restrictions; the Clean Water Act; and the Coastal Zone Management Act (although the latter gives the management authority to the state environmental agencies).These policies are accounted for in the harvest area availabilities and the unit costs of harvesting within the models.

Under the Clean Air Act Amendments of 1990 (CAA), there are several air pollution emission standards for heavy-duty diesel truck engines (Delphi, 2009). Strict new standards have been set for particulate matter (PM), nitrogen oxides (NO_x), non-methane hydrocarbons (NMHC), and carbon monoxide (CO). These standards have been phased in since 2007, and are expressed in grams per brake horsepower per hour (g/bhp-hr):

Air Pollutant	Standard
PM	0.01
NO_x	0.20
NMHC	0.14
CO	14.4

These emission constraints need to be reflected in the models and if the trucks are not meeting them in 2010 the technical requirements and costs need to be considered for future years.

There are no national requirements in place for carbon dioxide (CO_2) emissions control. However, based on a Presidential Memorandum of May 21, 2010 and authority under the CAA, such standards are expected to be proposed by the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration for commercial (heavy-duty) trucks in fall 2010, which would affect model year 2014 and later trucks (The White House, 2010). Consequently, it would be prudent to consider scenarios wherein annual baseline CO_2 emissions of the logging trucks are reduced by 10 percent, 20 percent, and 30 percent, starting in 2014.

No air quality issues are anticipated with current regulations. However, the U.S. Environmental Protection Agency is considering stricter standards for ozone and PM 2.5 air pollution, which could result in nonattainment problems when the Kinross ethanol plant is fully operational (as of May 2011, there were no air quality non-attainment areas in Michigan except for the Detroit Metropolitan Area, designated as non-attainment for PM 2.5; however, the Michigan DEQ has requested that the EPA change this designation).

Water Pollution and Runoff

Nonpoint water pollution control requirements are largely met by the best management practices (BMPs) employed by J.M. Longyear under the Sustainable Forestry Initiative (SFI), which the government does not regulate, although indirectly this program helps to ensure that the permitting requirements of Part 91 of the NREPA for logging, Soil Erosion and Sedimentation Control, are met. These requirements are implemented by each Michigan County Enforcing Agency, which require a Soil Erosion and Sedimentation Control Plan. While the active logging area does not technically require a permit (though ancillary activities such as building of a road, rail spur, and the establishment of a log landing would if they are greater or equal to 1 acre or within 500 feet of a lake or stream), the Michigan DNRE requires the logging company to conform to the same erosion and sedimentation control standards as if it had a permit. For the most part, these standards are similar to the BMPs normally used under the SFI.

Information Sharing

A report on the topic of the value of information in the Frontier supply chain can be found in Appendix C. The purpose of the report is to identify the activities that influence successful supply-chain information sharing and identify those that are particularly relevant to the Frontier biomass supply chain. Topics include the role of information in a supply chain, components of information decisions, and the major supply chain process in supplier relationship management. The processes discussed are information coordination capability, contracts and risk sharing, visibility in the procurement process, sourcing planning, and risk management is sourcing. Implementation and change management issues are also discussed. The approach to the topic has been more descriptive rather than prescriptive since the supply chain is currently being modeled and specific issues are difficult to identify and address directly.

Conceptual Model Development

Model Scope and Objectives

Developing the supply chain model required integration of many different types of information from different sources. To properly develop the conceptual feedstock supply chain model, the first step was to identify the required components and activities, the primary supply chain drivers (determinants of supply chain performance), and key trade-offs to be evaluated.

The feedstock supply chain for the Frontier facility in Kinross Township has a complicating factor that is quite unusual. There is generally a high degree of feedstock supply chain control by some entity, but there is no organization that will control the Frontier feedstock supply chain. Instead, Frontier intends to offer a price per unit volume for logs delivered from certain distances, and adjust the price until feedstock supply delivered just satisfies their requirement for current use and a safety reserve that varies over the year. The logs will be delivered by a large number of truckers cooperating with one or more harvesting crews. Furthermore, the fiber delivered may come from a range of landowners from small non-industrial private forest landowners to large corporate landowners or publicly owned forests. This situation has many implications for designing the feedstock supply chain. One of the most difficult to address is the precise location where the logs will originate after harvest but before entering the shipping component of the feedstock supply chain.

If the woodlands were all under central control, a harvest scheduling model could be developed to select the timing and location of harvests to supply the biofuel facility. In this case we would know precise locations where the logs would originate, and could optimize their delivery to the facility over the transportation network. The information might even be available to optimally plan the delivery directly from log landings where the fiber is stored at the harvest site; in the Frontier case this level of information would not be available under the current land ownership. For modeling purposes, the timber lands in Michigan within the specified 150 mile haul distance were grouped into mutually exclusive and exhaustive "harvesting regions." The harvest regions were defined as the overlay of the counties in the supply zone with the harvest zones defined in the Michigan State Project 2 fiber availability report mentioned above. The harvest zones in the Upper Peninsula were concentric circles at 30-mile intervals, while those in the Northern Lower Peninsula were centered on the south end of the Mackinac Bridge and adjusted for the distance from the facility site to the end of the bridge.

Feedstock Supply Chain Components

The fundamental framework of the feedstock supply chain model is shown in Figure 3, which is a conceptual diagram of the supply chain network distribution system. Logs will be transported by logging trucks from landing sites (the starting point of this supply chain network) to the facility gate, roadside, or log yards (with or without railroad spurs). Logs that are temporarily stored at roadsides are transported to the facility gate or to log yards as dictated by demand. Log yards provide critical storage capacity for the inventory of the whole supply chain. Rail is one possible way to transport large quantities of logs to the gate, according to the demand of the facility and the inventory of the log yard at the facility.

Figure 4 shows an activity framework for the feedstock supply chain. Forests, factors, and infrastructure are three "inputs" to the supply chain. This is based on the supply chain transport of logs. Verbs are used to describe the activities across the supply chain processes, to the facility for chipping and processing on demand.

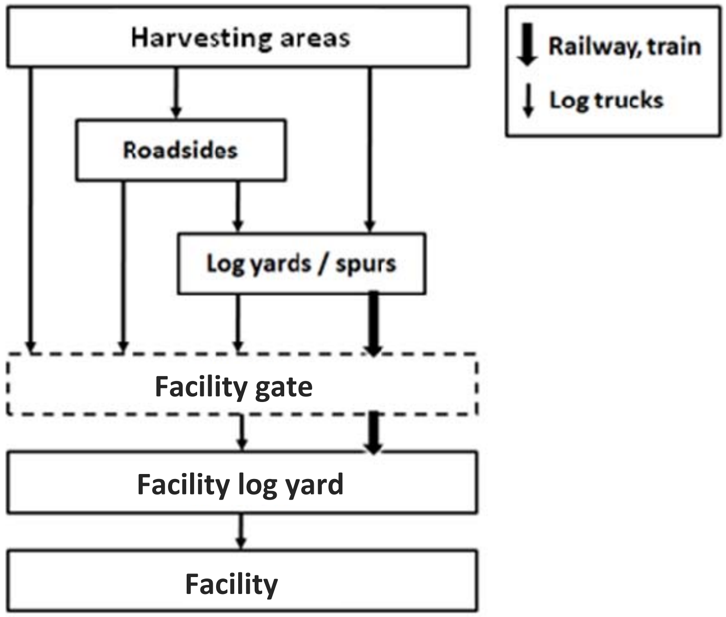


Figure 3: Conceptual diagram of supply chain network distribution system

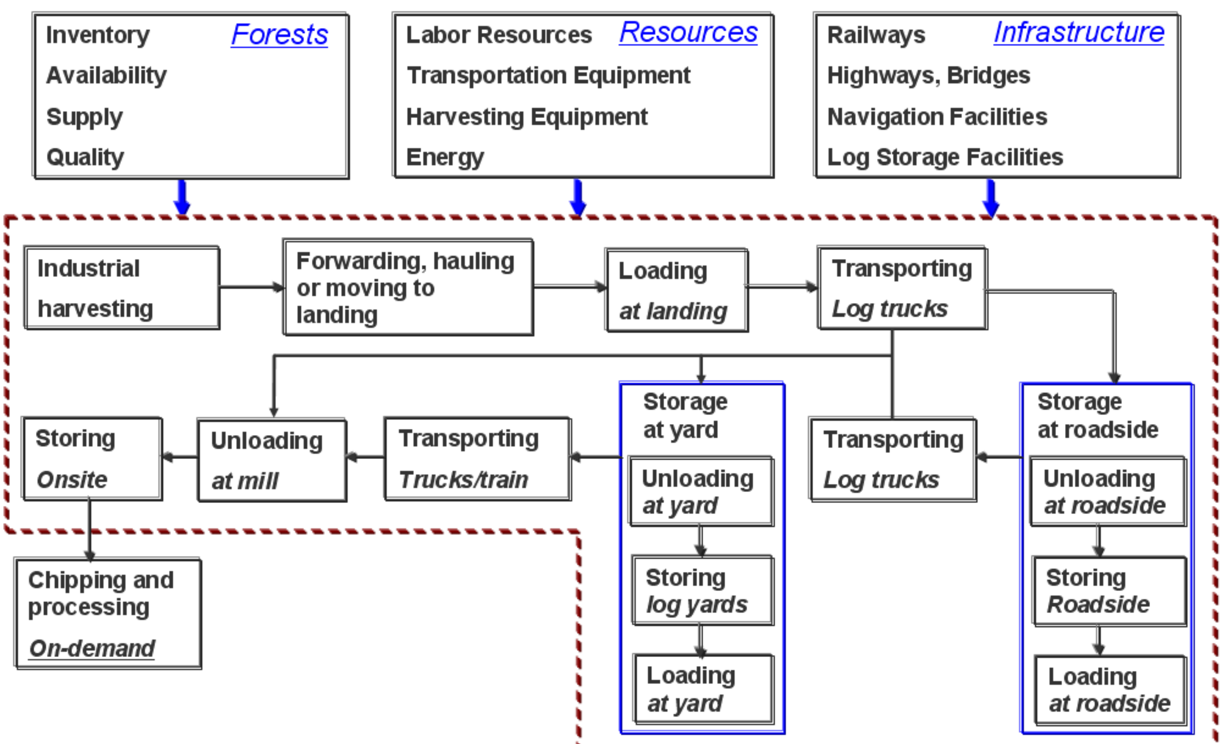


Figure 4: Activity framework of the feedstock supply chain

Feedstock Supply Chain Drivers

In addition to the network distribution system and activity framework, it is helpful to consider the main "drivers" (enablers) of supply chain performance. The main supply chain drivers to be considered in the model are facilities, inventory, transportation, information, and regulations/policies. Each of these is described briefly.

Facilities

The term facilities is used somewhat loosely to include forest and roadside landings, roadside storage yards, storage yards at rail spurs, and storage at the facility. Each facility has characteristics of location, capacity, and fixed and variable (unit) storage costs. To limit the scope of the feedstock supply chain model, industrial harvesting activities will not be modeled explicitly, but feedstock supply (log availability) will be considered an attribute of roadside landings (to be estimated by Project 2). In turn, feedstock supply may be characterized by quantity, tree species, and size of logs. The following facilities metrics are proposed and include:

- Number of harvesting areas and storage sites
- Log market/supply allocation
- Capacity allocation/utilization
- Storage costs (fixed and variable)

Inventory

Inventory is the mechanism used to address the mismatch between feedstock supply and demand. There are two type of inventory considered here: cycle and safety. Cycle inventory is estimated by the average demand, simultaneously considering the predictable seasonal effects such as winter climate and spring breakup. Safety inventory is evaluated under risks such as demand uncertainty, weather, and variable timing of spring breakup. Inventory performance may be measured by:

- Average inventory
- Days supply / inventory turns
- Quality
    - Moisture content
    - Age/freshness
    - Species
- Fill rate, i.e., proportion of demand met directly from inventory
- Fraction of time stocked out (shortages)
- Storage costs (fixed and variable)
- Amount of safety stock

Transportation

The transportation system includes infrastructure and equipment for two delivery modes: logging trucks and rail. Subject to network capacity constraints, the model will determine the best single mode or multimodal routes to the facility from the various origin nodes. The following proposed indicators are used to quantify the performance of transportation:

- Distance traveled and time

- Inbound/outbound costs
- Inbound/outbound shipment size
- Fraction transported by different modes

Information

Effective communication among the loggers, truckers, storage yards, and facility may dramatically reduce supply chain costs and improve responsiveness. The information exchanged may consist of demand (at the facility), log availability (location and quantity), storage inventory, transportation costs, road conditions and load restriction information, seasonal factors (e.g., spring breakup), and backhaul information. The following metrics are proposed to quantify the performance of information infrastructure:

- Cost for information infrastructure (fixed and variable)
- Forecast lead time and forecast error
- Variance from plan
- Response time

Regulations and Policies

Regulations and policies are considered drivers in that they represent constraints in supply chain operation and affect each of the other four supply chain drivers. For facilities and inventory, at least two types of regulations and policies should be considered: i) Nonpoint Water Pollution Control and Best Management Practices under the federal Clean Water Act (administered by the Michigan Department of Environmental Quality, or MDEQ), and ii) federal Coastal Zone Act Reauthorization Amendments requirements for tree clearing (administered by MDEQ with guidance from the U.S. Environmental Protection Agency (EPA) and the National Oceanographic and Atmospheric Administration). For the transportation sector, at least four regulations/policies will be considered: i) Air Emission Standards for Locomotives (EPA), ii) Air Emissions Standards Heavy Trucks (EPA), iii) Truck Weight and Travel Safety (U.S. Department of Transportation and Michigan Department of Transportation), and iv) Railroad Travel Safety (Federal Railroad Administration).

Supply Chain Trade-offs

A successful supply chain must address the trade-offs between responsiveness, cost efficiency, and social and environmental issues. The preliminary feedstock supply chain model developed in this project may be applied to address multiple tradeoffs inherent to these drivers, including the following:

1. An increase in the number and/or capacity of storage facilities will decrease transportation costs, reduce lead-time (improve responsiveness), and improve reliability, but it will also increase facility and inventory costs. Generally, locating many facilities close to the facility increases responsiveness, but at a high cost, while having only one centralized facility minimizes cost but decreases responsiveness.
2. Inventory cost may be reduced through inventory aggregation, but this may adversely impact responsiveness and quality. At the same time, storage of

biomass can result in weight losses that may be either detrimental (dry weight loss) or beneficial (moisture loss).

3. Higher speed transportation may increase costs, yet allow the supply chain to be more responsive. Proper strategy and choice of transportation mode(s) can improve responsiveness, but increase costs, energy use, and CO_2 emissions. Managing this trade-off depends on choice of transportation mode(s) and the network design and route selection.
4. Improved information infrastructure and effective information management can help decrease inventory and transportation costs, and improve responsiveness by a better match of supply and demand, but will likely result in increased information costs.

Model Inputs, Outputs, and Decision Variables

The preliminary required inputs (data), associated decision variables, and model outputs were identified for the feedstock supply chain drivers, with the exception of regulations and policies. Regulations and policies are treated as model constraints. Decision variables are the parameters in the model which are adjusted according to decisions made to improve supply chain performance. Outputs are selected in order to quantify specific metrics of supply chain performance.

Supply chain facilities include roadside landings and storage yards. As origin nodes in the supply chain network, roadside landings are considered the destination point for harvesting activities (not explicitly considered in the model) and have attributes associated with feedstock availability. Inputs, outputs, and decision variables are based on the requirements and definition of the feedstock supply chain. For information systems, decision variables are not computed by the model at this time, although different assumptions corresponding to various levels of information system investment may be incorporated into the model.

Model Assumptions

Developing strategic decision support tools for a hypothetical supply chain required a number of assumptions. These are outlined here to provide background to the model formulation and application. The validity of certain key assumptions is discussed in later sections.

General Assumptions

Several assumptions were made in both the simulation and optimization modeling, including the following:

- Various levels of decision-making are to be supported in this study, including long-term strategic planning (20 years) and annual operational planning (1 year).
- The various decisions to be made over different time horizons can best be represented by a suite of optimization and simulation models.
- It is appropriate for long-term planning models to include less detail than short-term operational models.
- The models should be structured so that the short-term decisions are constrained by long-term strategic decisions.
- Conversely, results from the shorter-term operational model can inform long-term decisions, thus encouraging iterative use of the models.
- The quantity of logs required by the facility will change over time because of varying requirements as the facility becomes fully operational.
- Effective communication with and management of suppliers must occur in order to develop and maintain supplier relationships since Frontier will rely primarily, or solely, on independent suppliers.
- Other transportation factors, including truck availability and rail capacity, can constrain supply chain performance.

Optimization Model Assumptions

- The user input for harvesting choices by ownership are adequate representations of actual harvesting behavior.
- The rail sidings included in the model will be available when the model chooses to use them.
- Average growth rates for the four timber types are the same across the supply zone.

Simulation Model Assumptions

Assumptions were made for each step of the supply chain simulation model: harvesting, transportation, storage, and delivery to the facility. The most important assumptions are as follows:

- Simulation is driven by both daily demand and daily log production (combined "Pull" and "Make-to-order" method).

- Simulation runs for one year in time units of one day. The facility operates 24 hours/day, 7 days/week, 52 weeks/year, although demands for feedstock can be reduced or set to zero for specific time periods (weeks).
- Optimization models inform the simulation model by providing weekly harvesting and transportation plans
- Simulation will be useful for uncertainty analysis. The most important uncertainty on an annual basis is the timing of spring breakup.
- During spring breakup, the only access to logs for the facility will from its own storage yard, logs stored on a Class A highway, logs stored in a truckyard along a Class A highway, logs stored with railway access, or logging jobs that are taking place on a Class A highway.
- The supply area is split into 43 harvest areas within a 150-mile radius of the plant, along with 3 harvest areas farther than 150 miles.
- Rail transportation is only available in the Upper Peninsula.
- Spring breakup timing is a stationary process, i.e., simulations will be based on historical data for the period 2000-2009.
- The occurrence of bad weather (e.g., a wet spring) was not statistically analyzed. However, the user can specify the probability and range of duration of a wet spring, which essentially extends the spring breakup period.

Data Requirements

A "metadata" matrix was developed to fully describe informational/data needs for the Project 1 supply chain model. The matrix was designed to be a central point to allow each team to know what documents and data are available. As a working document, it was generally reviewed and updated on a quarterly basis. This data matrix is provided in Appendix E.

A related issue was establishment of a central depository for all the data from each project. In the end, it was decided that a data depository was not required; rather Project 1 would be responsible for compiling the information and data required by the models.

Information on existing supply chains and forwarding systems in the study area was developed primarily by Project 3. In general, the data required from Project 3 for the supply chain model included the road and rail systems and availability, and cost, fuel efficiency and emissions factors for road and rail transportation.

Information about spring breakup timing (road restrictions at the county level) was compiled by Project 1, with assistance from the Michigan State Project 1 team.

Shipping Distance Estimation

The information collected by the Michigan Tech Project 3 team describing the available road and rail network was integrated into a GIS system to provide optimal routes between specified harvest areas and the facility yard or available rail sidings. The road network was used to calculate distances from points in the study area to the Frontier facility site via the road network. Furthermore, distances to a subset of the available rail sidings were also calculated.

An important component of distance is the type of road used. Class A highways are all-season roads, and therefore can be used during breakup. Interstates are Class A roads with higher speed limits. Other public roads can be either gravel or paved, and generally reduce the speed of travel. Woods roads tend to be small, are often poorly designed and maintained, and must be travelled at a much slower speed. Traveling a mile on a woods road can easily take 5 or 10 times as long as on a Class A road.

As a first approximation we calculated one distance from each county to the Frontier facility site. This effort used the centroid of the county to represent the county's location. The first part of the distance calculation was to calculate distance via the road network to the point nearest the county centroid, and then the straight-line distance from the centroid to the road network was added. This was not a particularly good estimate of the distance the fiber would need to be transported, for two reasons. First, counties are generally quite large, and representing the entire county with just the centroid involves a significant lack of precision. Second, the distance a truck would need to travel to reach the public road is always longer than the straight-line distance.

To help us understand the potential error introduced by using the initial mileage estimation methodology, we conducted a sensitivity analysis. We selected two counties, Luce and Montmorency, and laid a 3x3 grid over them to create 9 "sub-counties." We then calculated the distances from each of the sub-counties to the facility site. To address the concern that the straight line distances from the road to the point would underestimate the actual distances that the trucks will need to travel on woods roads, we used a combination of USGS quad maps and air photos to estimate the woods roads distances. Table 3 summarizes the results of this case study.

Table 3: Sensitivity analysis (ranges) of haul distances by road type from Luce and Montmorency counties.

County	I-75 Miles	Class A Highway	Other Public Road Miles	Woods Road Miles	Total Miles
Luce	6.7	68.9	31.0	0.5	107.0
Luce	6.7	52.6	40.7	1.1	101.1
Luce	6.7	52.6	19.7	0.6	79.6
Luce	6.7	70.7	16.7	1.8	95.9
Luce	6.7	68.9	9.0	3.7	88.2
Luce	6.7	68.9	16.4	0.3	92.3
Luce	6.7	68.2	8.2	0.0	83.1
Luce	6.7	61.8	2.7	0.0	71.2
Luce	6.7	48.9	0.8	2.3	58.7
Average	6.7	62.4	16.1	1.1	86.3
Montmorency	39.6	63.9	11.5	0.1	115.1
Montmorency	39.6	61.1	8.6	0.0	109.3
Montmorency	39.6	61.1	18.9	0.0	119.6
Montmorency	39.6	77.3	6.4	0.8	124.0
Montmorency	39.6	70.0	7.0	0.1	116.6
Montmorency	39.6	77.6	12.7	0.3	130.2
Montmorency	95.4	25.5	7.7	0.0	128.6
Montmorency	39.6	72.7	11.8	0.0	124.1
Montmorency	39.6	81.5	11.1	0.6	132.7
Average	45.8	65.6	10.6	0.2	122.3

These data show that using the centroid to calculate miles traveled could be quite misleading. Logically, the centroid would give fairly accurate estimates of the total miles traveled; since it is in the middle, it would be expected to be somewhat close to the average, which was true in these tests. However, what would be lost is the variability between the different road types. Woods road distances are particularly important because of the low haul speed, and woods roads display the highest coefficient of variation across points of any road type.

It was decided to use four to seven points to represent each county, and the woods road distances were calculated using the actual likely path of travel rather than the straight line distance. The same points were used to estimate the distance to a set of five suitable candidate rail sidings (see map in Figure 5 and Appendix F for details). Although the map only shows the route to the nearest rail yard, the data generated includes distances to all likely sidings.

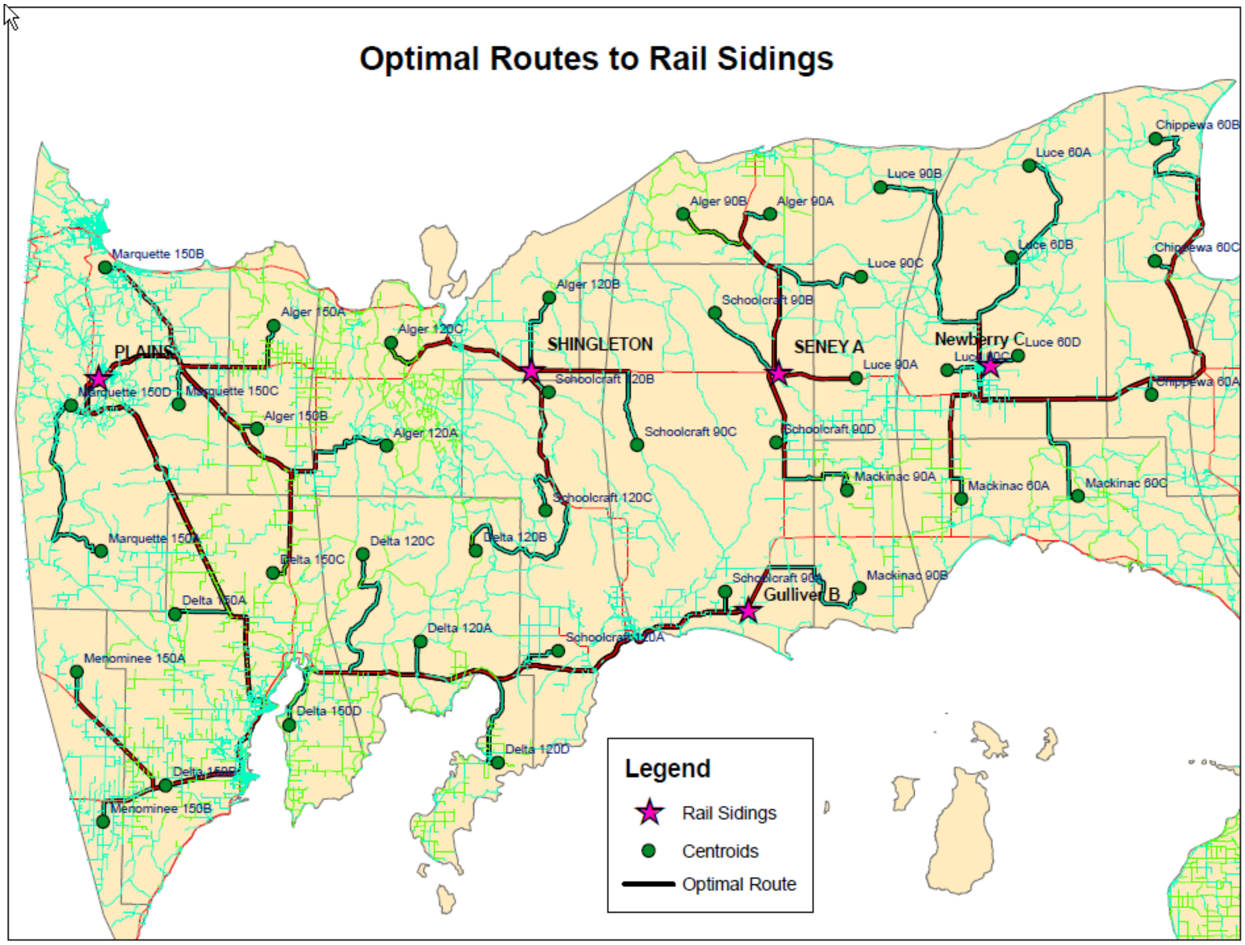


Figure 5: Optimal routes to rail sidings from selected locations (4-7 in each county).

Harvestable Volume Estimation

The Michigan State Project 2 team provided a comprehensive report titled "Timber Resources and Factors Affecting Timber Availability and Sustainability for Kinross, Michigan" dated December 2010. In addition, the team provided the data used to develop timber volume estimates in a flexible format. These data have been integrated into a database to support optimization model generation.

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service provides the only set of information about timber standing stock, growth, and removals that is consistent across the range of landowners and geographic areas in the U.S. This data source provides a time series of forest inventory information because it involves the re-measurement of permanent plots on a set interval (currently five years). The re-measurement of the same plots allows a far more statistically powerful information source.

The FIA data does have some serious limitations. The most damaging for this study is that the actual locations of the sample plots are "fuzzed," which means that they do not generally let anyone know where the actual plots are; the reported locations are generally moved less than two miles. The "fuzzing" process causes problems when an effort is made to match other spatial data with the FIA data. For example, several other spatial data sets have information about current vegetation (forest, fields, open, etc.), topography, soils, wetland classifications, habitat types, etc. It would be very useful to match the other spatial data with the FIA information to get a more accurate picture of the resource situation.

The FIA dataset used to construct our GIS system was the same data that was used in the Michigan State Project 2 Tessa Systems report. This data set has already had lands removed where timber harvesting is not allowed.

Harvest Difficulty and Cost Estimation

The difficulty of harvest, and therefore the cost to harvest a unit of volume, can be quite different on different sites and using different silvicultural systems. The optimization model groups the potential harvest systems into four groups:

1. Clearcutting, which is the conventional regeneration technique for the aspen cover type.
2. Shelterwood, which involves removing the majority, but not nearly all, of the stand during a regeneration harvest. This system is widely and successfully used for oak stands.
3. Uneven-aged selection harvests on routine terrain. This is the most widely accepted approach for harvesting northern hardwoods, and involves leaving the majority of the volume in the stand after harvest. This approach focuses on tending the stand to remove defective trees and thinning to assure adequate growing space for retained trees and removal of financially mature crop trees.
4. Uneven-aged selection harvest on difficult terrain. This is the same management approach as (3), but the cost of harvesting is increased because of either wet or steep conditions. The rough terrain may also decrease the intensity of the harvest. The optimization user interface (see Appendix H) allows the user to restrict the proportion of the land in a difficult to harvest class that can be harvested.

Separating case 3 from case 4 was made difficult because of the fuzziness of the FIA data. We evaluated a wide range of spatial data available, but were not able to match information well enough to be comfortable with the precision of classification. The current working solution is to classify the FIA plot as high cost if it is either hydric or has a slope greater than 20 percent.

Spring Breakup Data

Historical spring breakup data was obtained by Michigan State and Michigan Tech from the Michigan Department of Transportation (MDOT) and several county road commissions. The data was compiled in spreadsheet format, and a preliminary statistical analysis was completed. The key findings from this analysis were that the spring breakup start dates and durations in neighboring counties are highly correlated. According to the MDOT, the starting and ending dates of the spring breakup are determined by considering the soil types and conditions as well as the weather conditions. In other words, various sources of uncertainties are involved in spring breakup timing, making it difficult to predict even a short time in advance. Despite the large variability in the data, limited record length, and suspected changes in practices and possibly climate, the historical spring breakup data was fit to theoretical probability distributions, as described in Appendix I. The user will have the option to sample either from these distributions or directly from the historical data.

Supply Chain Models

Optimization Model

Purpose

The role of the optimization model is identifying what combination of options is the most efficient approach to supply the Kinross facility under a given scenario. One very important measure of efficiency is to minimize the cost, measured as a present value, of supplying the facility, but other measures may be of interest. An example of a different criterion to be optimized might be to minimize the emission of greenhouse gasses needed to supply the facility.

The optimization model developed evaluates a 20-year planning horizon, with the decision variables being the harvest each year from each harvest area. The harvest areas were defined as the overlay of the haul zones (the nine zones identified in the Michigan State Project 2 TESSA Systems report on supply availability within 150 miles of the Kinross site) and the counties in Michigan within the haul zones. The timber volume in each haul zone-county combination was further subdivided into four cost categories (see above) and four ownerships. The ownerships included are federal (predominately Forest Service), state (predominantly Michigan Department of Natural Resources (MDNR)), industrial (lands owned by TIMOs, timberland investment management organizations, and REITs, real estate investment trusts), and small non-industrial private ownership.

A key decision when constructing the optimization model was to develop a tool with flexibility to address a wide range of key policy issues over time. Examples of issues that might be of interest are:

- What supply can be produced with a given set of harvesting limitations? This generates the supply curve for hardwood pulp to supply the facility. This supply curve includes the cost of harvesting and transportation to the facility, but does not include the price of stumpage; stumpage prices will be negotiated between the organizations doing the harvesting and the land owners.
- What are the implications for overall price and energy efficiency associated with harvesting decisions by large landowners? This is most important for public agencies since the eastern Upper Peninsula has large tracts of public land, and future harvest levels are currently unclear for these owners. Much of the land closest to the facility is owned by the USDA Forest Service, while the MDNR has large tracts a little farther away.
- What are the implications from different zone pricing decisions for energy and economic efficiency?

The optimization model is a relatively simple concept which requires straight-forward data. The required data can be divided into two categories, the available supply of fiber and the costs associated with harvesting and transporting the fiber to the Kinross facility site. Unfortunately, this conceptually simple situation becomes quite complex when the actual model is formulated. Much of the complexity results because of the spatial nature of the data used to calculate the associated costs.

Harvests from lands more distant from the facility tend to have higher shipping costs. Straight line distance often diverges from the actual distance via existing roads, and the actual cost depends on how far the truck had to drive. Harvest costs are also affected by how well developed the road network is for a location. If there are few public roads, then the logs must be transported further on forest roads, and these roads are a much slower and more expensive situation for logging trucks to operate.

All hardwood species are acceptable fiber for the proposed Kinross facility. Harvest costs depend on silvicultural prescription, and the recommended silvicultural system is different for different species of hardwoods. To perpetuate aspen stands the use of clearcut harvesting is recommended. For oak dominated stands, which are very common in the northern LP, the proposed harvesting strategy is a shelterwood; in this silvicultural system, most, but not all, of the existing stand is removed. As the proportion of the stand removed increases, the cost per unit volume harvested decreases.

The optimization model had default data included, but most of the more interesting scenarios involve changes in the default data. An example will help clarify the types of sensitivity analysis that may be of interest. If the cost of diesel fuel increases dramatically, rail transport gains a competitive advantage. This would also be expected to shift the fiber supply away from the northern Lower Peninsula (NLP) and to the Upper Peninsula (UP) because of the lack of rail from the NLP to the UP. The optimization model has a graphical user interface that allows the user to adjust the various parameter values:

Two parameters can be used in unison to adjust the amount of fiber available over time:

- The proportion of growth that the various landowners can be expected to make available.
- The proportion of available annual growth that can be harvested in a year

The four different landowner classes would be expected to respond differently in their harvesting decisions. Timber industry would be expected to harvest their lands at a rate that nearly completely removes annual growth over time, while federal land managers have only harvested a small fraction of growth over the last two decades. State and private non-industrial managers would be expected to harvest levels between the low federal and high industrial patterns.

Landowners do respond to changes in the price offered for their timber, and would be expected to make more of the annual growth available if a higher price is offered. It would be very useful if we knew how much each owner would increase timber sold with an increase in offered price; this is called the price elasticity of supply by economists. This information tends to be quite hard to estimate, and none of the projects in the COEE have addressed this question. The optimization model allows the user to analyze the impact of different proportion of growth sold, but being able to draw that proportion will require adjustments to stumpage prices. We can make some professional judgments based on the characteristics of the four land ownership classes. Industry would be expected to be quite responsive to changing prices, but may already be so close to harvesting 100 percent of growth that there is not a large amount of discretionary volume they could offer with increased price. Forest Service harvesting decisions are part of a long process, and changing the allowable sale quantity may be more a matter of political pressures rather than the offered price having an influence on decisions. The state lands and non-industrial private land owners would be expected to again be somewhere in the middle.

One thing that is worth noting is that having a market, even a market with a low price, provides an opportunity for landowners to have harvests that promote long-term improvements in timber quality and a range of multiple-use goals that would otherwise be too expensive to consider. The opening of the Kinross facility will provide a market for low quality fiber that otherwise would remain in the forest and occupy growing space with very little potential for return.

The second parameter, the proportion of annual growth that can be removed in a year, determines how quickly the available supply can be harvested in each harvest area; we will call this the *drain rate*. The optimization model minimizes the discounted present value of the harvest and transportation cost of supplying the facility. Since costs are discounted, the model will choose to supply the facility first from nearby sources of fiber, then switch later to sources further away. The drain rate limits how quickly nearby sources can be liquidated, and thus determines how wide of an area will be chosen at the different points in time. The default drain rate is set to two, which means that two times annual growth can be cut in any year. An implication of this choice is that the least expensive supplies will be harvested over the first 10 years, after which the 20 year growth has been harvested from those areas, and the model will choose to move out to more distant supply sources. This will cause disruptions in the supply chain when fiber from further away is selected and difficulties for the logger and trucker communities because their work is no longer where they live. Art Abramson mentioned that this happened when the paper mill in Quinnesec, MI was opened. The optimization model can be used to analyze different scenarios of draw rates, and may prove useful in designing zone premiums that balance harvesting the fiber close to the facility quickly to increase early net revenues, while retaining a supply of close fiber for continuous employment of loggers and truckers.

The Frontier facility does not have a dedicated supply source for any of their feedstock requirements; all fiber will have to be purchased either on the open market or via contractual relationships with suppliers. The amount of fiber available for harvest was calculated to assure that decisions were sustainable in the sense that harvest must be less than growth. Furthermore, the calculation recognized that different land owners would have different tendencies to harvest timber, and that some of that growth was already being used by other wood processing facilities. The landowner tendency to harvest is included in the optimization user interface in the block labeled proportion available for harvest. The amount available for the optimization model is what is grown times the tendency to harvest for the landowner less what other facilities are already using. Clearly, the tendency to harvest is not really a set value. Increasing stumpage prices or providing additional services for the landowners can change the harvesting decision. The past harvest information has been adjusted to reflect the closure of several large mills since the harvest data was collected.

The optimization model can be used to identify ownerships and harvest areas where the wood could be harvested most efficiently to create a base model. Next, the proportions available for harvest by owner and fiber type (e.g., aspen) could be adjusted to determine the sensitivity of the solutions to restricting harvest by the various landowners.

Conservative Biases in Fiber Supply Calculations

When the available supply of fiber was estimated there was a systematic effort to choose conservative rather than optimistic estimates of what would be available to supply this facility. These conservative biases build a safety buffer into the model. In reality, more fiber should be available than the model assumes. The most important sources of conservative bias were:

1. The available harvest was based on the standing crop of fiber when the FIA plots were last visited. Over time the standing crop of fiber has persistently increased in Michigan, as growth exceeds removals and mortality. This relationship is expected to continue. The optimization model was intentionally constrained to harvest less than all of the growth, and was further constrained to harvest not more than a percentage of the annual growth that occurred in the first year during each year of the planning horizon. Because growth exceeds removals and mortality, this is a conservative estimate of what will be available in the future.
2. Much of the fiber listed in the FIA data as cull is suitable for this facility. The amount of cull that would be suitable for this facility is estimated to be eight percent of total volume. It is also likely that much of this cull will be removed in early selection harvests, further increasing the observed harvest.
3. With improved harvesting equipment it is possible to recover more fiber than occurred in the past. For example, new equipment is nimble enough to harvest useable fiber from the tops of sawtimber trees, which were previously left in the woods. Simultaneously, the minimum size for pulp has decreased, allowing the removal of stems that would previously have been lost to mortality before they reached merchantable size.
4. Some mill residues, such as sawdust, will be usable in the Frontier facility. Much of this source has traditionally not been usable for pulp due to the small size of the particles.

Optimization Software Used

The optimization model uses the Xpress Optimization Suite (http://www.fico.com/en/Products/DMTools/Pages/FICO-Xpress-Optimization-Suite.aspx) to generate and solve mathematical programming models. These models are formulated as a travel cost minimization problem, although the metric used to measure "cost" is flexible and could include other measures of process efficiency such as energy use and carbon emissions. The model schedules harvests over multiple 1-year time periods to assess sustainability of the harvests. A menu-driven user interface allows the user to adjust input data and define scenarios for strategic decision making (see Figure 6 and Appendix H for details.)

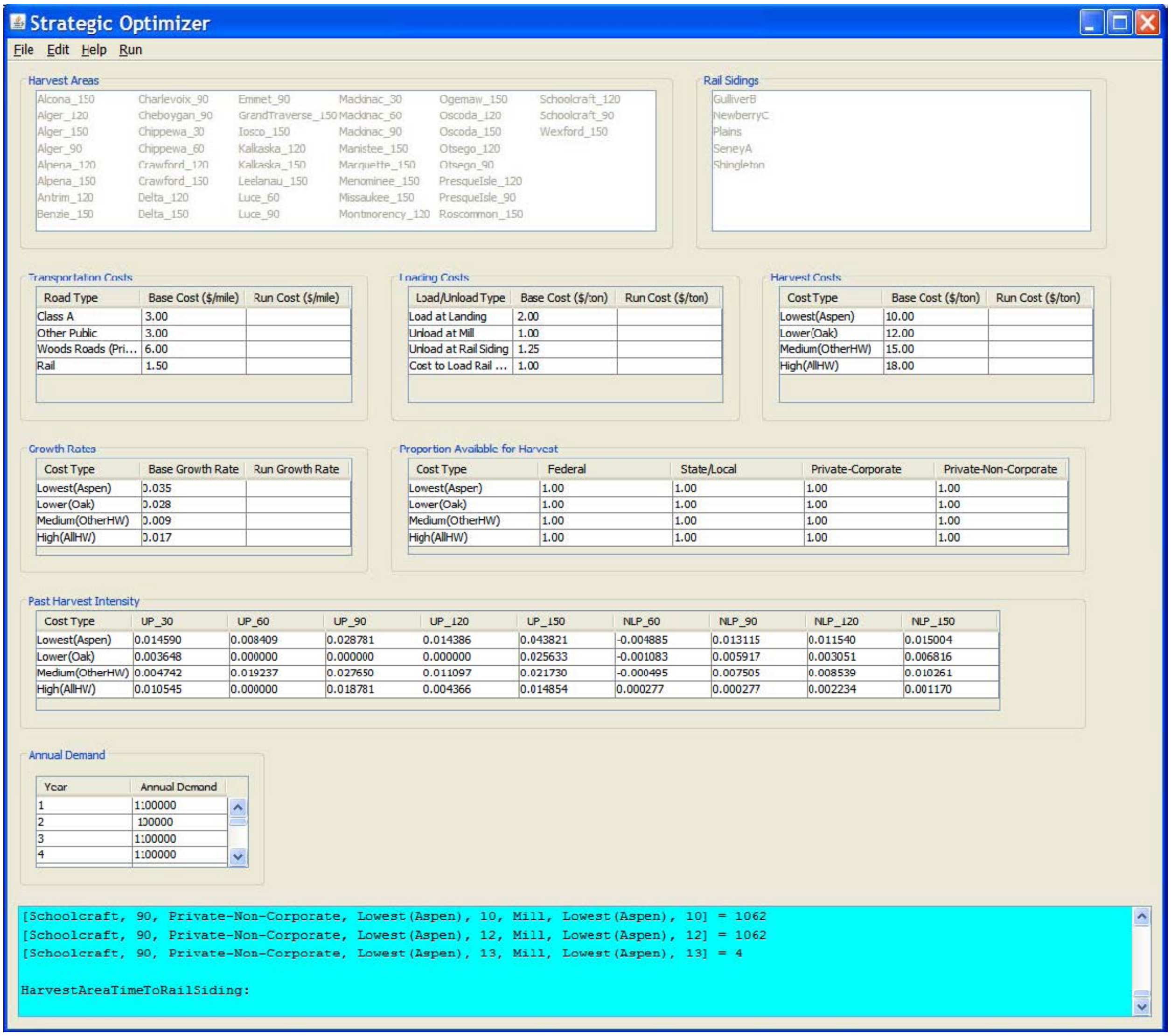


Figure 6: Optimization model interface for data input and scenario definition.

Simulation model

Purpose and Scope

The primary questions addressed with the simulation model are the following:

- What overall cost, energy use, and CO_2 emissions may be expected for the Frontier supply chain system?
- What are potential social costs (e.g., traffic congestion) associated with the supply chain system?
- What is a recommended operating plan for spring break-up, and how reliably can facility demand be satisfied under this plan?
- What is the impact of a given harvesting plan on the supply chain system? What are the impacts of the transportation plan and the numbers of available trucks and rail cars?

The simulation model will provide detailed outputs for specified (annual) scenarios, and could help to answer strategic questions, such as how many log yards should be used and when and where to acquire harvesting contracts, if run in an iterative approach. However, the complementary optimization can address these strategic decisions more directly.

The supply chain simulation model was developed in Arena software (Version 13). As an event-driven system, three component systems are defined in the model: harvesting areas, log yards and the ethanol facility. Roadside storage is also included in the model as one part of the harvesting area, with each harvest area having a specified storage capacity. The model tracks the logs' age, supply cost (including storage cost, transportation cost and harvesting cost), energy consumption (including harvesting fuel usage, machinery fuel usage in logs yards and transportation fuel usage) and emissions (equivalent CO_2 emissions).

<u>Model Description</u>

A conceptual model was first developed, primarily as a scoping exercise. As summarized in Figure 7, the supply chain models will begin at the landing and end at the facility. Beginning at landing sites after logs are harvested, all logs are assumed to be stored in roadside storage areas before being transported either directly to the facility by truck, or to the log yards for storage. From the storage yards, they will be transported by rail to the facility in the Upper Peninsula or by truck to the facility in the Lower Peninsula. The facility has a storage capacity as well in order to meet production demand during low harvesting periods.

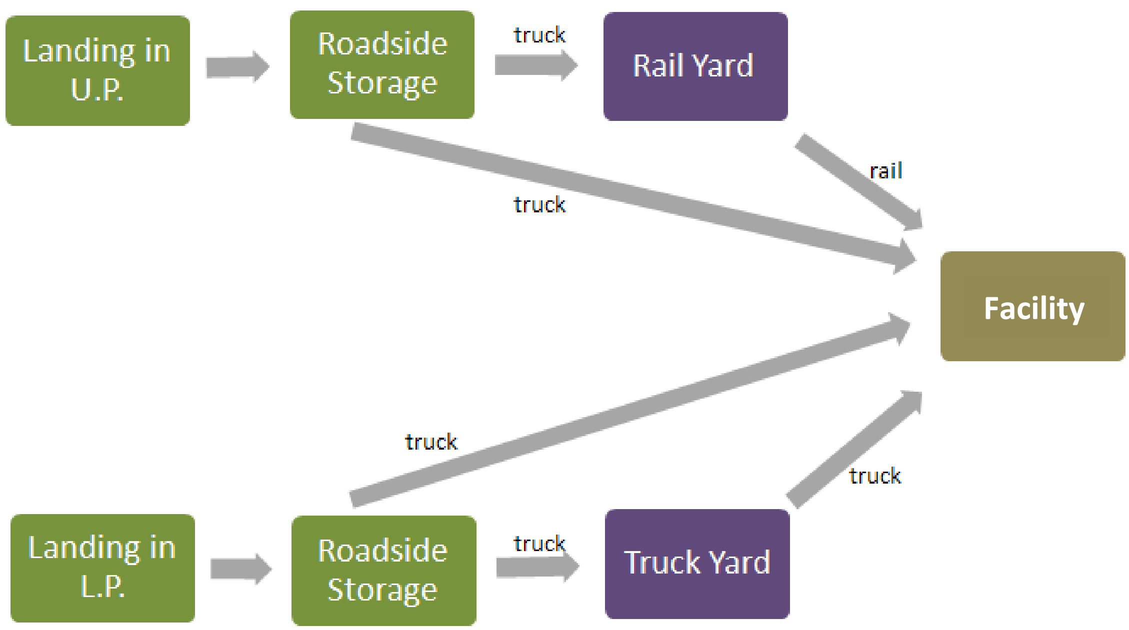


Figure 7: Schematic of the conceptual model. Arrows indicate log transportation activities.

Next, a prototype model of the supply chain system was developed based upon the conceptual model. It includes 15 harvesting areas, 5 log yards at rail spurs, and the ethanol production facility. The simulation is driven by the daily log production at each harvesting area, which is determined when the simulation runs. Each day, the facility requires some quantity of logs from log yards and harvesting areas, and trucks and railcars are appropriately "dispatched." The model tracks the logs' age, supply cost (transportation cost and harvesting cost), energy consumption (transportation fuel usage) and emissions (equivalent CO2 emission). The inventory of the facility and log yards is output by the simulation, as are the total system cost, fuel usage and emissions. The spring break-up time is specified as a scenario input to each harvest area in order to allow representation of the time dynamics of the system. The prototype model considers just three scenarios of spring break-up timing, i.e., normal start date, early, and very early.

We then extended the first working prototype of the simulation model to meet the real requirements of the supply chain system. To be consistent with the optimization model, the final simulation model includes a total of 46 harvesting areas, including 3 areas that may be specified by the user for harvests beyond the 150-mile radius considered in Project 2. These can be used to represent logs shipped by rail from outside the 150-mile harvesting zone. Other refinements were made to the statistical model for modeling spring breakup timing, and the inventory decision made prior to and during spring breakup. The new refined model allows up to 3 truck yards and 5 log yards located at rail spurs, but one truck yard and 3 log yards at the rail spurs are recommended for simulation.

As before, the simulation is driven by both the daily demand of the facility and the daily log production at all harvesting areas. As the inventory at the facility/log yards is impacted by the production requirements, a so-called (s, S) inventory strategy is adopted to simulate this supply chain (i.e., the inventory policy is defined by a reorder point, s, and a reorder level, S). In addition, the user specifies weekly harvesting and transportation plans to direct the "signals" sent by the facility, effectively specifying production schedules for the harvest areas and the percentage of logs transported to the facility and log yards. Thus, the system is a combined "pull" and "make-to-order" supply chain system.

Model simulations are driven by demand at the facility and a specified harvesting plan based on three distinct periods, or "seasons": (1) Regular plan to meet the daily product requirement without building up inventory; (2) Three months before Spring Breakup to prepare inventory for Spring Breakup; and (3) Plan for Spring Breakup period that specifies little or no harvesting.

Initially, spatial variation in harvesting was assumed to be proportional to the forest cover in each county; the refined simulation model is able to use a harvesting plan based on output from the optimization model.

Other refinements made to the simulation model include the following: 1) specification of user-defined start date and initial inventory levels; 2) improved tracking of maximum log age; 3) inclusion of roadside storage; 4) option for simulation over multiple years to eliminate "end effects" and evaluate equilibrium (long-term) inventory levels; 5) option to include additional log concentration yards (see Figure I.2); and 6) improved representation of spring breakup uncertainty. For ease of use, there are now two ways to input spring breakup (road restriction) data. The first is to input the spring break up start day and end day for all 29 counties in Excel. The second way is to specify only the start day and end day of Alcona County's road restrictions, and the Arena model (through Visual Basic) will calculate the other counties' spring break up periods according to a statistical model developed from the historical data (see Appendix I). Alternatively, the probability distributions of Alcona County's start day and end day may be user-defined. For the second approach, all data are entered in a user form that appears at the beginning of the simulation to request inputs. All calculated spring breakup data are written back to an Excel file so that the user can check the calculations.

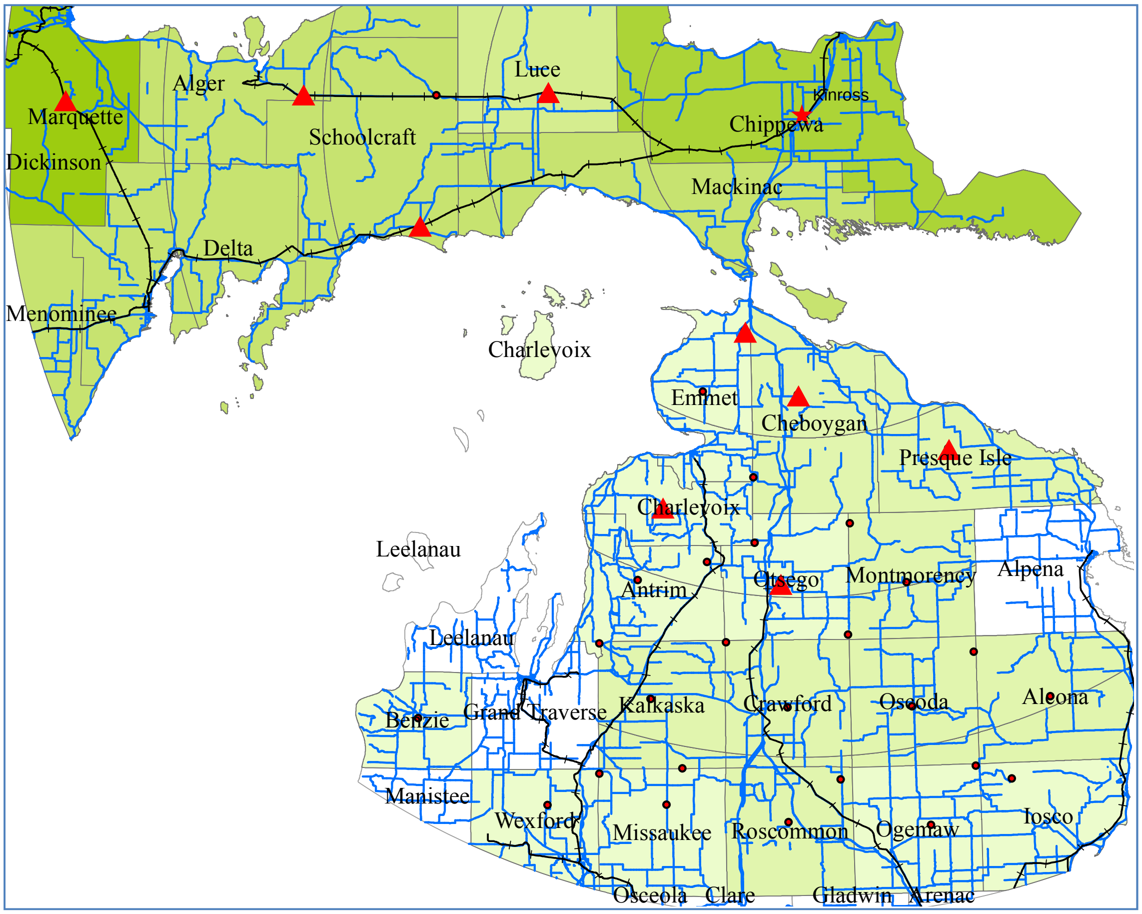


Figure 8: Map of potential (◦) and tentatively selected (#) storage yards. Potential yards in the Lower Peninsula are placeholders in the model and may not be feasible locations.

The model can be run for multiple replications of a single year, for several consecutive years, showing both time series of results and statistical outputs. Through an iterative process, the user may evaluate the sensitivity of model results (e.g., cost, reliability, energy consumption, log ages) to various assumptions and parameter values, or optimize the parameters of the supply chain. The model is expected to be useful in supporting strategic decisions for the supply chain system, such as the percentage of annual available logs harvested in each harvesting area, the number of truck yards and rail yards used for storage, and the proportion of transport by trucks and rail cars.

User Instructions

As shown in Figure 9, the simulation model first reads the parameter values and data from a spreadsheet file which can either be the outputs of the optimization model and the GIS system, or specified by the user using judgment. The model tracks the inventory status of every storage site (harvesting area, log yards, and the production facility), the logs' ages, and transportation routes in a real-time manner. It presents the inventory, overall cost, energy consumption, and emissions at the end of simulation. Multiple replications may be run automatically (i.e., with one click of the Start button).

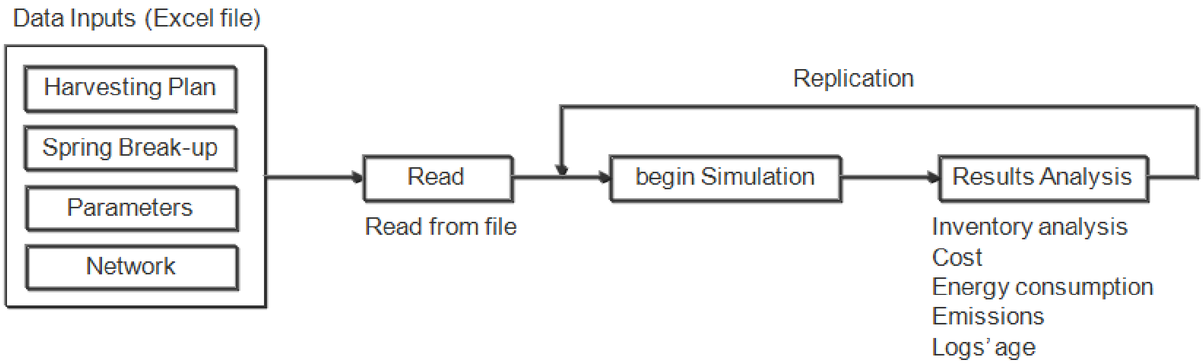


Figure 9: The structure of the refined simulation model

In order to improve the flexibility of the model, an Excel file is used to import data for the simulation. These data include a harvesting plan, a transportation plan, transportation availability, spring breakup data, storage yard characteristics, and cost and efficiency factors. Input to VBA forms is another way for the user to communicate with the simulation model. Before the simulation runs, there is a VBA form shown for the supply chain system parameters. Thus, the model can be used to check the impact of changing inputs on the supply chain system (overall cost, energy consumption, emissions, logs' age, etc.) either by changing the spreadsheet data or the VBA form entries.

Two manuals have been completed: a User Manual and a Developer Manual. The User Manual provides step-by-step instructions for a user seeking to understand key model assumptions, modify input data, and perform analysis based on the current model structure. The Developer Manual provides additional details on model implementation and may be useful to someone seeking to modify the structure of the model (e.g., add harvesting areas, implement a new statistical model of spring breakup timing, or add other features). The manuals are provided in Appendices I and J.

Model Interaction

The optimization model is designed to support long-term planning decisions, such as leases of storage yards and multi-year options contracts, as well as to evaluate the potential impacts of (exogenous) policy decisions, such as increased harvesting on federal lands. The model has a planning horizon of 20 years and operates with an annual time step. In contrast, the simulation model is designed to focus on the uncertainties of the supply chain system, primarily the variability of spring break-up timing, although other uncertainties such as rail operation disruption may also be considered. The simulation model has a 1-year horizon with a daily time step, with harvesting and transportation plans specified for each week of the year.

Interaction between the optimization and simulation models is through the harvesting and transportation plans output from optimization and provided as input to the simulation model. Specifically, the optimization model generates an annual time series, for 20 years, of harvest volumes from each harvest area, land owner classification, and cost category. These annual volumes are aggregated for each harvest area and passed to a weekly version of the optimization model (or directly to the user) for determination of the weekly harvest and transportation plan that is input to the simulation model. The weekly transportation plan includes the proportion of logs to be shipped by truck and by rail, as well as the proportion going to a storage yard and directly to the facility. The simulation model then attempts to follow these plans to the extent possible, given the randomness in spring breakup timing. (Note that rather than run the weekly optimization model, the user may use their knowledge of the system or apply heuristics to develop the weekly harvesting and transportation plans.)

The simulation model may be run for any number of replications (or spring breakup scenarios). Upon completion, the model can show statistical results for the outputs. It is anticipated that the simulation outputs will provide feedback to the optimization model in the form of refined parameter values. The optimization model can then be run again to provide updated harvesting and transportation plans to the simulation model. This process can be repeated as necessary in order to develop a robust solution for the supply chain scenarios being considered.

Model Results

A broad range of scenarios can be analyzed using the optimization and simulation models. However, each model has different areas of strength. The optimization model selects the best harvest pattern over time to maximize profitability, while the simulation model helps the user understand the impact of randomness within the supply chain.

The optimization model is best suited to answer the following questions:

- What should are the potential contributions from the various landowner types under different policy assumptions?
- What regions (UP or LP) and haul zones should be the focus for providing the fiber supply over time?
- What share of the fiber should come from each species group?

We believe that the most important questions are associated with land ownership questions.

Conversely, simulation models are generally used to help decision makers anticipate problems that may occur because of processes that have a random component. We see the simulation as being the most useful for:

- Understanding the severity and likelihood of supply problems associated with spring breakup, and development of strategies to ameliorate potential supply problems.
- Understanding the potential problems with "wood freshness" over the year.
- Evaluating the adequacy of both on-site and remote (rail sidings in the UP and log concentration yards in the LP) storage capacities relative to breakup log supply.
- Evaluating the role of rail transportation.
- Understanding the need for roadside storage by third parties.

We believe that the most pressing issues that the simulation model can address are associated with the wood supply for spring breakup.

Scenarios

As an example of spring breakup scenario analysis, Figures 10 and 11 show the impact of early or late spring break-up on facility inventory and the logs' age leaving the facility for production, respectively. Results are from a simulation of 100 replications (hereafter referred to as "scenarios"), with spring breakup start and end dates generated randomly based on the spring breakup model. An assumption under these scenarios is that inventory grows at a nearly constant rate up until the time of spring breakup. Under this inventory plan, the early spring breakup scenario may cause a facility shutdown, as inventory is depleted between days 265-275 of simulation period (May 19-29). Other inventory plans may be tested to reduce this risk.

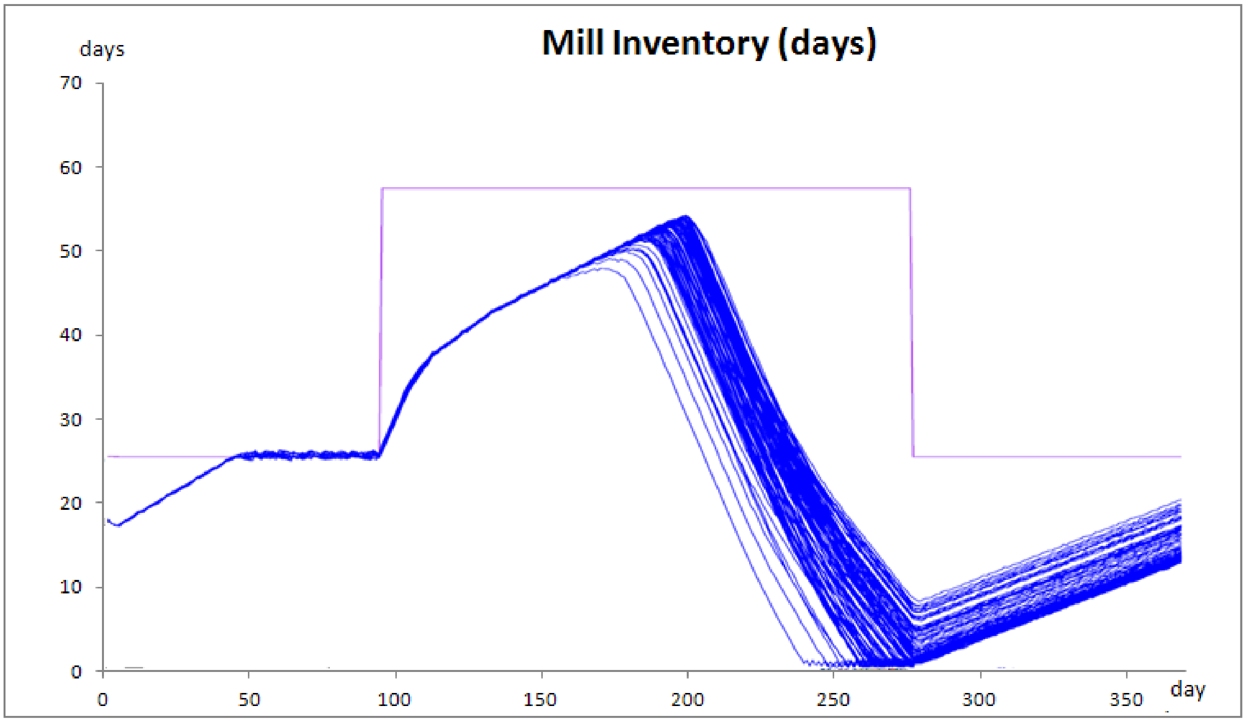


Figure 10: Facility inventory over 100 random spring breakup scenarios. The simulation period is September 1 through August 31.

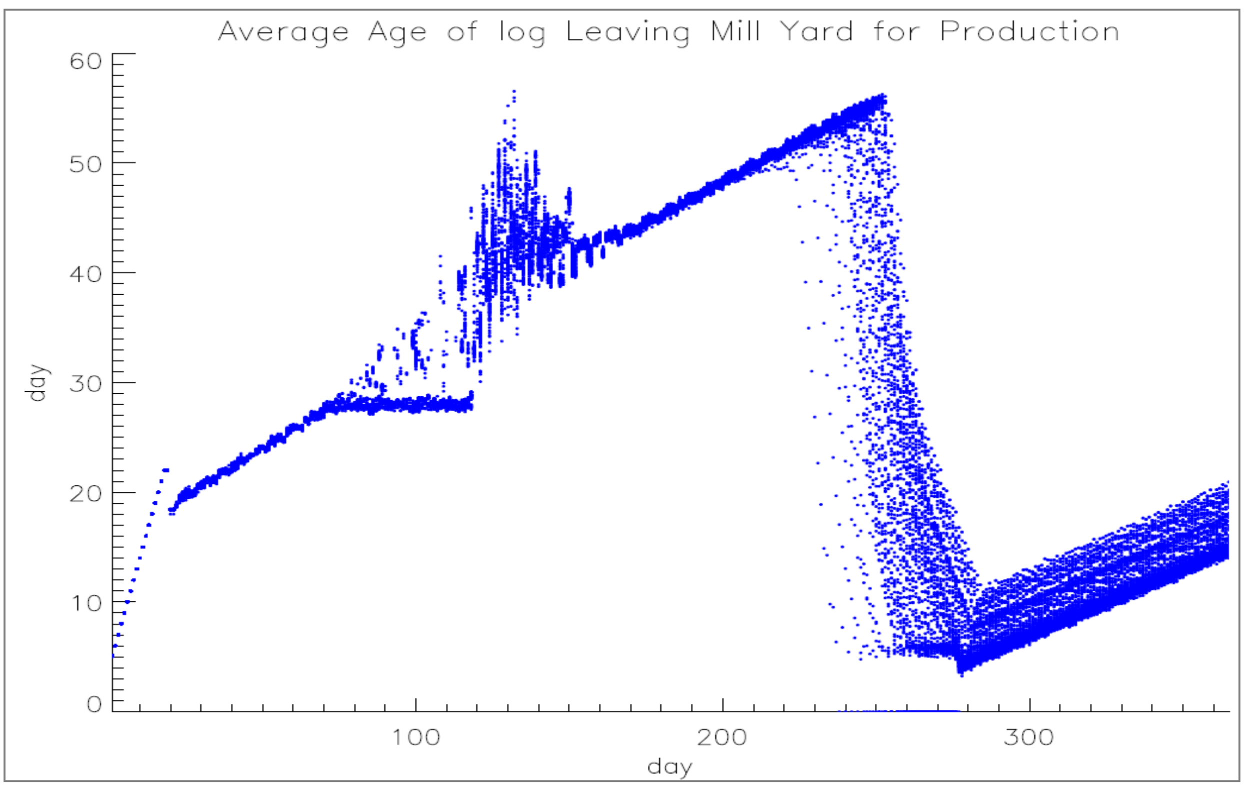


Figure 11: Average log age entering facility over 100 random spring breakup scenarios.

In addition to inventory levels and log age, the simulation model outputs total cost, fuel consumption, and CO_2-equivalent emissions, which may be used as metrics to compare the effects of different scenarios or the outcomes of various plans. Figure 12 shows the total (cumulative) cost for the three spring breakup scenarios. The early spring breakup has the lowest cost because there is less harvesting and transportation over the time period of the simulation, and currently (based on parameters used in the model, such as unit harvest cost, unit transportation cost), harvesting accounts for about 55-70 percent of the total cost, and transportation accounts for just 30-45 percent. Of course, early spring breakup would not be desired, due to the risk of a facility shutdown. In reality, it is likely that "emergency wood" would be purchased at a higher price than the regular supply. Such a decision may be considered outside the scope of the model, or the user may specify an additional wood supply from one of the harvest areas outside of the 150-mile radius to the emergency wood purchase.

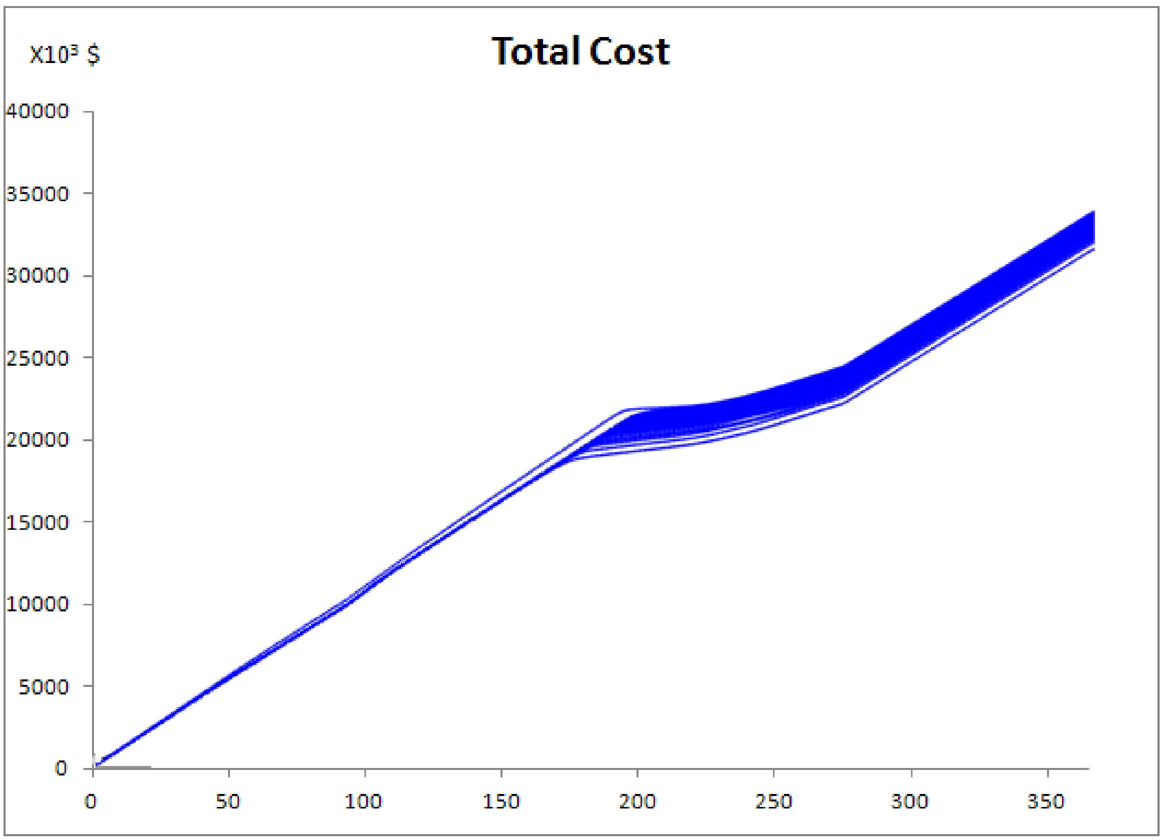


Figure 12: Total cost for a 1-year simulation period under 100 random spring breakup scenarios.

As an example of a "policy" scenario, assume that harvesting restrictions require 70 percent, 80 percent, 90 percent, and all the wood to come from harvesting areas farther than 90 miles from the facility, as compared to the base case shown in Figures 10-12, which called for 61 percent of the wood to come from areas farther than 90 miles. Figures 13 shows the impact facility inventory with the same transportation plan in each scenario, respectively. These impacts could be partially mitigated by greater reliance on rail transport.

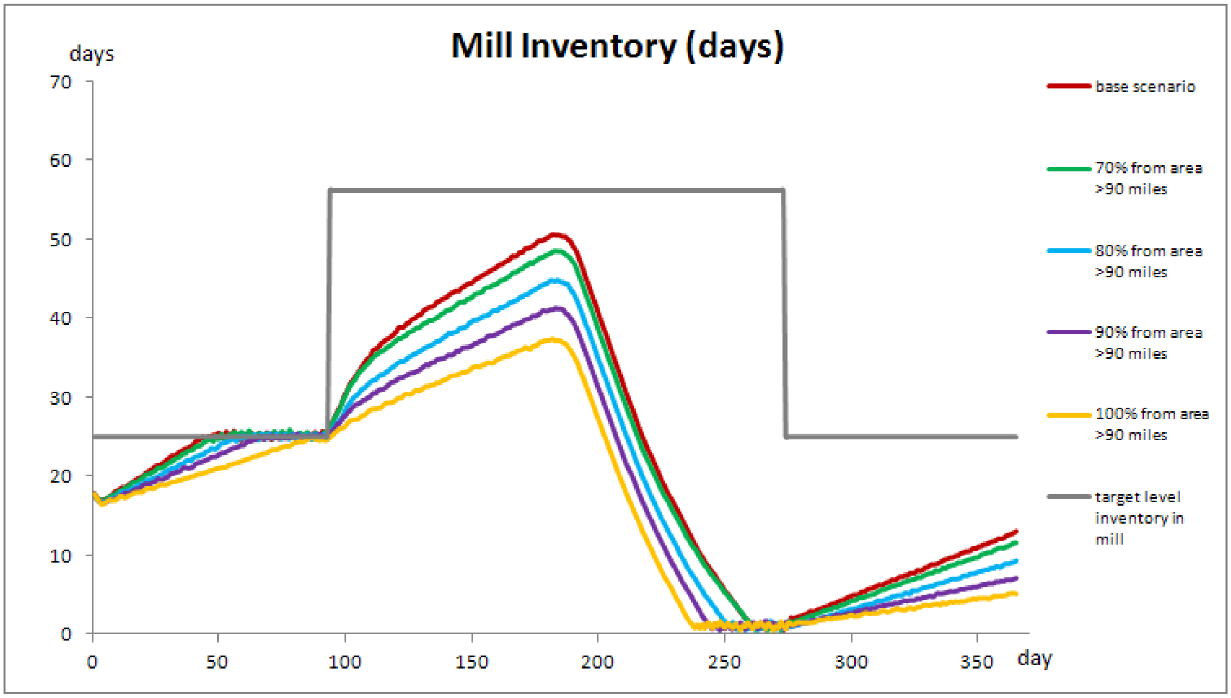


Figure 13: Facility inventory under the base scenario (red line) and other scenarios with 70 percent (green line), 80 percent (blue line), 90 percent (purple line), and 100 percent (orange line) harvesting shifted to areas greater than 90 miles from the facility. Transportation availability is not shifted.

Because the transportation plan is constant across these scenarios, truck availability is a constraint in areas beyond 90 miles from the facility, and logs accumulate in roadside storage areas or log yards. Increasing the transportation availability for areas greater than 90 miles from the facility, and decreasing for areas less than 90 miles, according to the harvesting shift can mitigate this shortage. This is shown in Figures 14-17, indicating the impact of coordinated harvesting and transportation planning on facility inventory, transportation cost, total cost and average age of logs arriving at the facility, respectively.

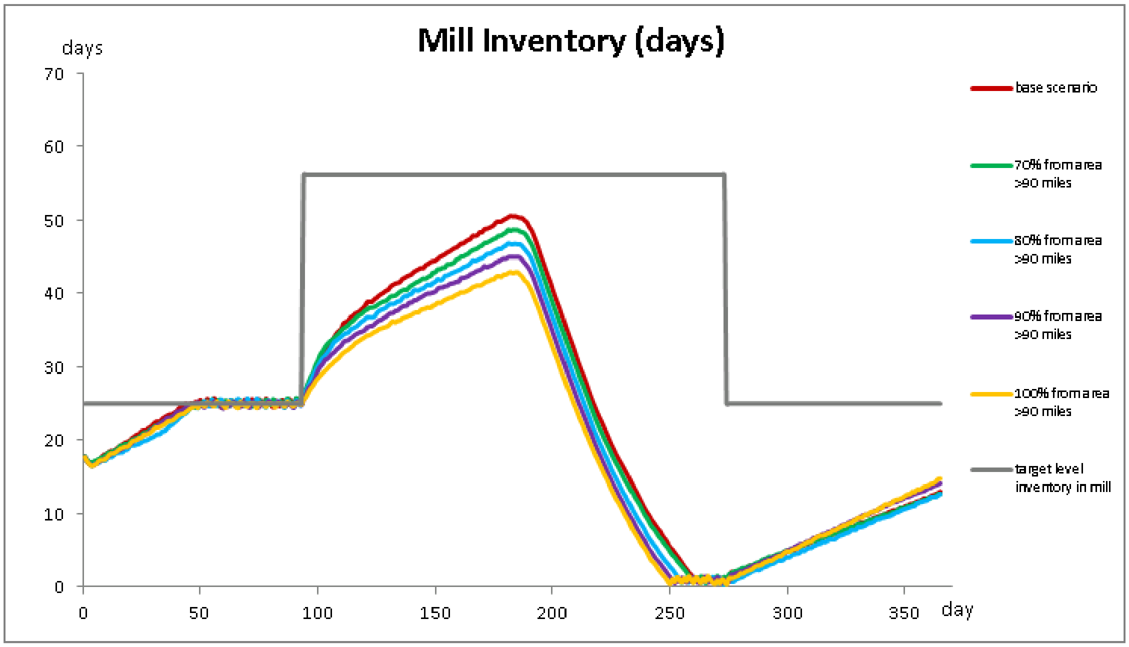


Figure 14: Facility inventory under the base scenario (red line) and other scenarios with 70 percent (green line), 80 percent (blue line), 90 percent (purple line), and 100 percent (orange line) harvesting shifted to areas greater than 90 miles from the facility. Transportation availability is also shifted.

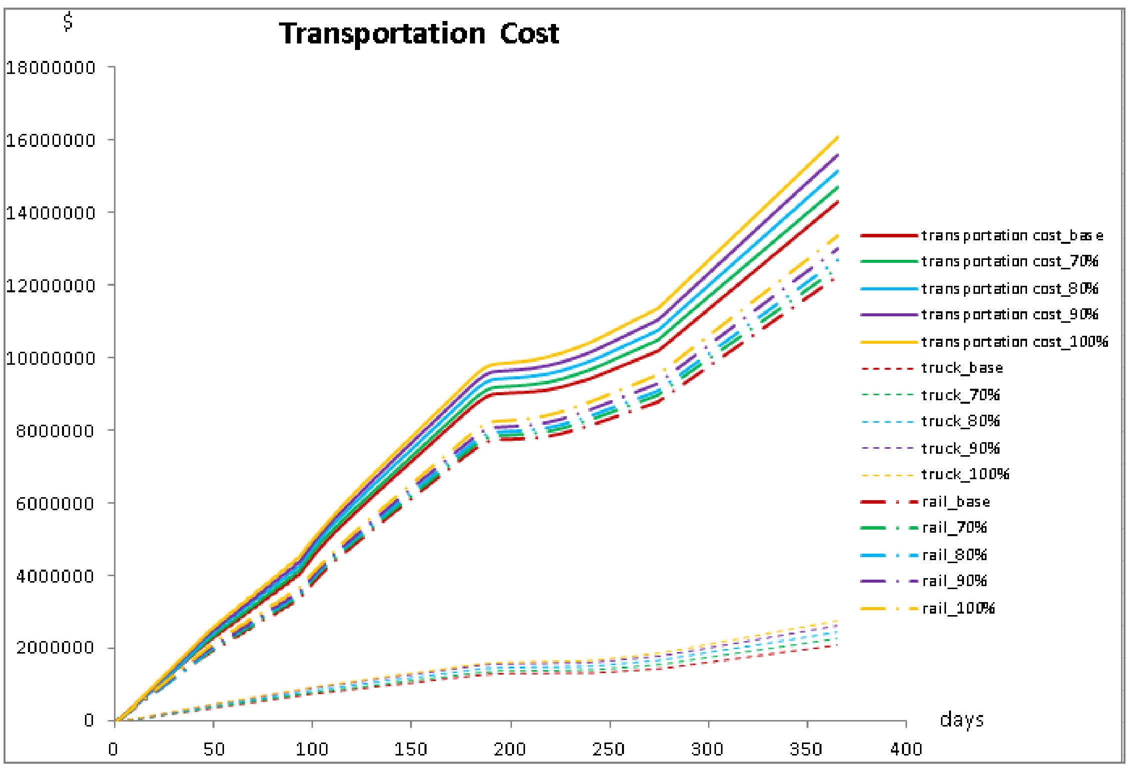


Figure 15: Total transportation cost, cost of truck, and cost of rail under the base scenario (red line) and other scenarios with 70 percent (green line), 80 percent (blue line), 90 percent (purple line), and 100 percent (orange line) harvesting shifted to areas greater than 90 miles from the facility. Results are shown with and without a corresponding shift in transportation availability.

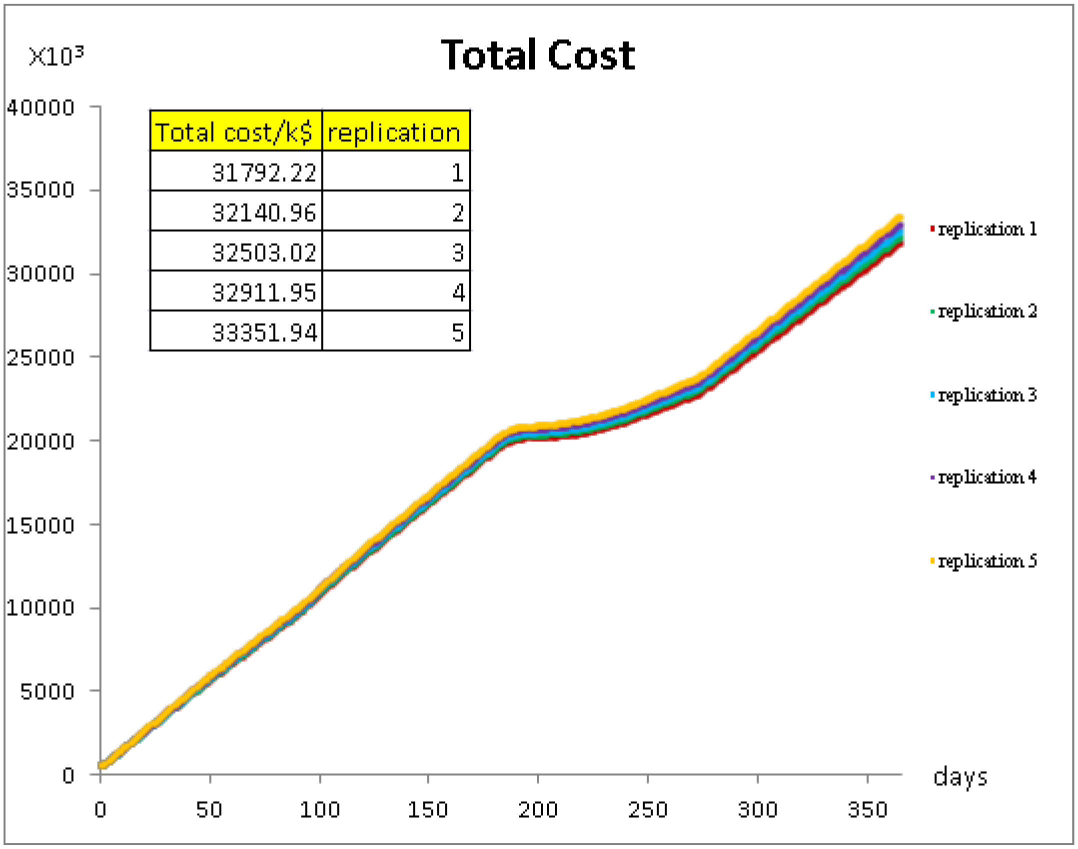


Figure 16: Total cost under the base scenario (red line) and other scenarios with 70 percent (green line), 80 percent (blue line), 90 percent (purple line), and 100 percent (orange line) harvesting shifted to areas greater than 90 miles from the facility.

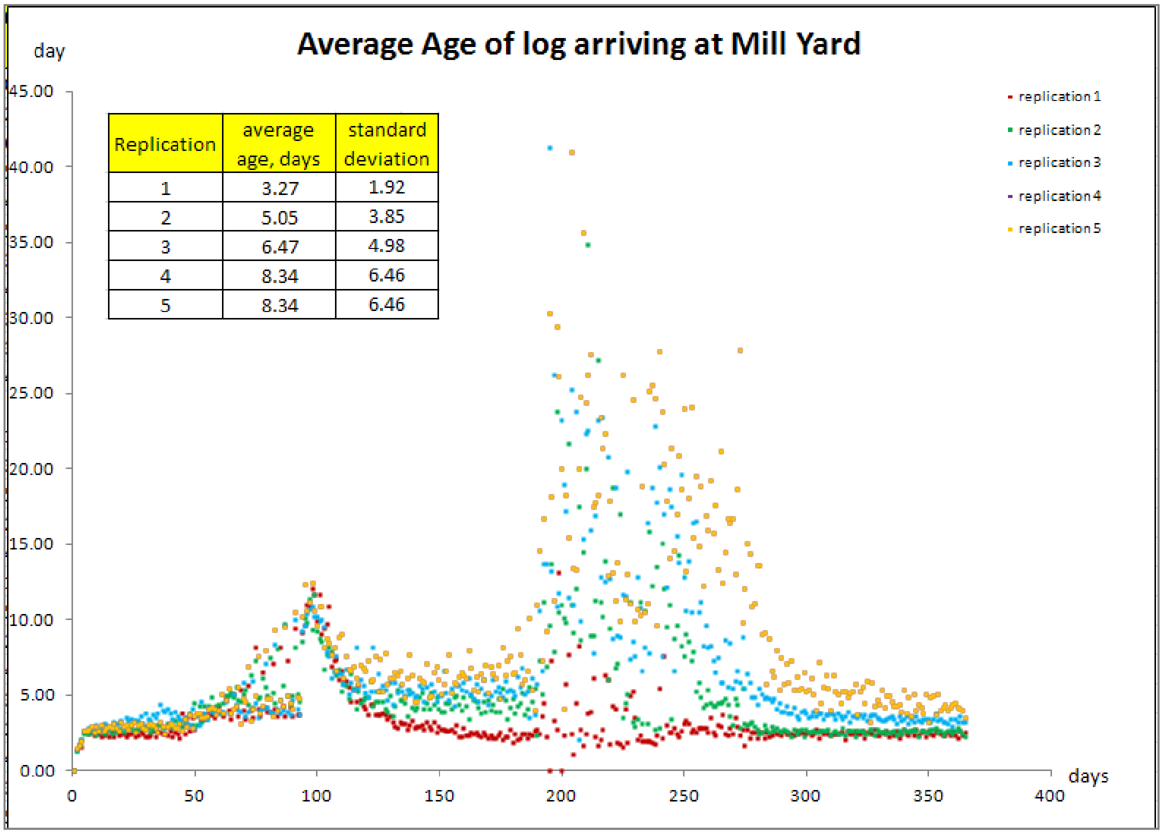
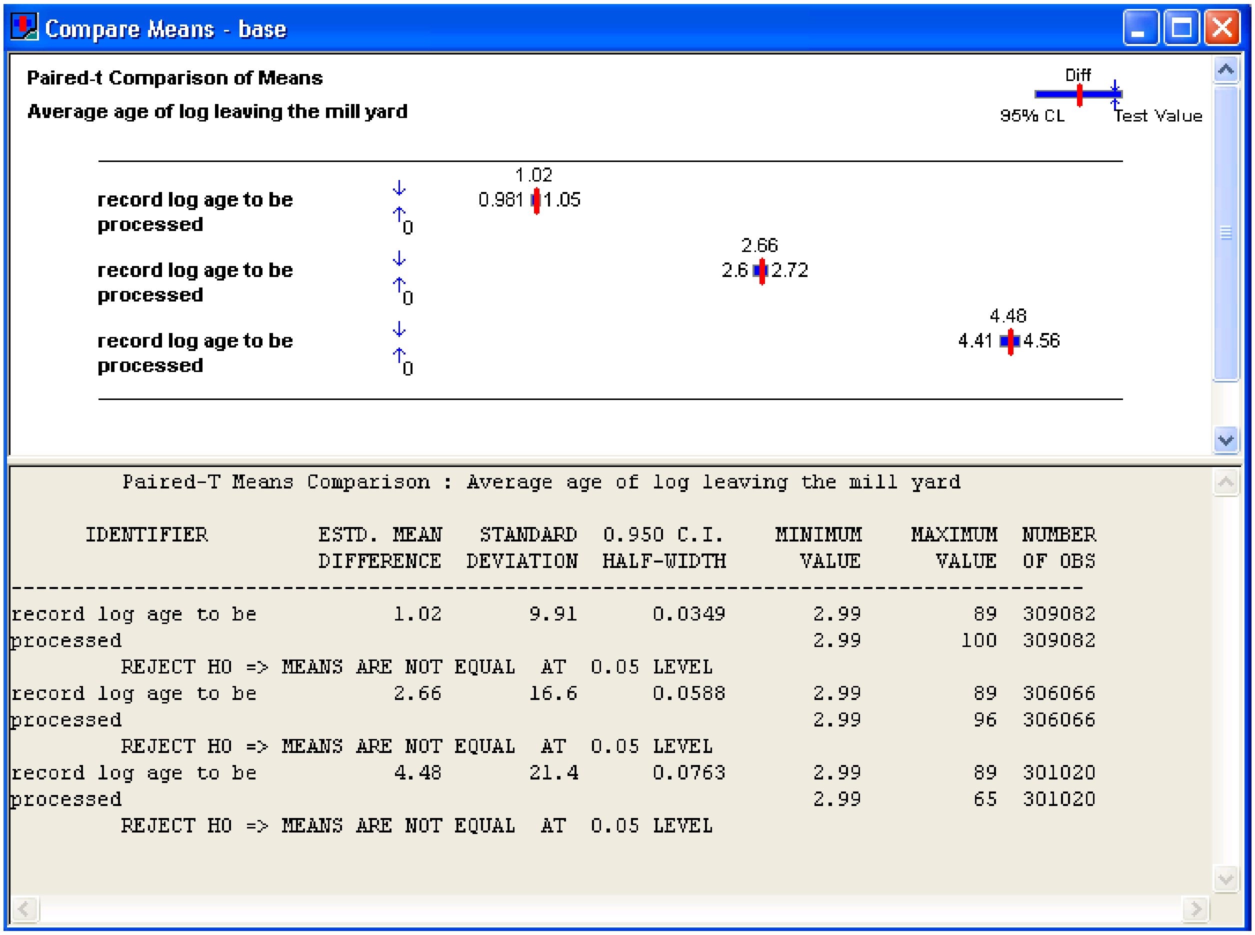


Figure 17: Average age of log arriving at the facility under the base scenario (red) and other scenarios with 70 percent (green), 80 percent (blue), 90 percent (purple), and 100 percent (orange) harvesting shifted to areas greater than 90 miles from the facility.

Sensitivity Analysis

As one example sensitivity analysis, the effects of reducing harvest volumes by 1 percent, 2.5 percent, and 5 percent are evaluated (compared to a baseline harvesting plan that leads to inventory buildup in the facility yard and other storage yards). The effects of the reduced harvest volumes on log age are summarized in the Arena software's statistical output analyzer, Figure 18 For reductions in harvest volumes of 1 percent, 2.5 percent, and 5 percent, average log age is reduced by an average of 1.0, 2.7, and 4.5 days, respectively. Figure 19 shows a plot of average log age throughout the 1-year simulation period for 15 replications of each harvest volume reduction scenario.



Paired-T Means Comparison : Average age of log leaving the mill yard

IDENTIFIER	ESTD. MEAN DIFFERENCE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS
record log age to be	1.02	9.91	0.0349	2.99	89	309082
processed				2.99	100	309082
REJECT H0 => MEANS ARE NOT EQUAL AT 0.05 LEVEL						
record log age to be	2.66	16.6	0.0588	2.99	89	306066
processed				2.99	96	306066
REJECT H0 => MEANS ARE NOT EQUAL AT 0.05 LEVEL						
record log age to be	4.48	21.4	0.0763	2.99	89	301020
processed				2.99	65	301020
REJECT H0 => MEANS ARE NOT EQUAL AT 0.05 LEVEL						

Figure 18: Arena's Output Analyzer, showing summary statistics for three reduced harvesting plans compared to a baseline plan that results in inventory buildup.

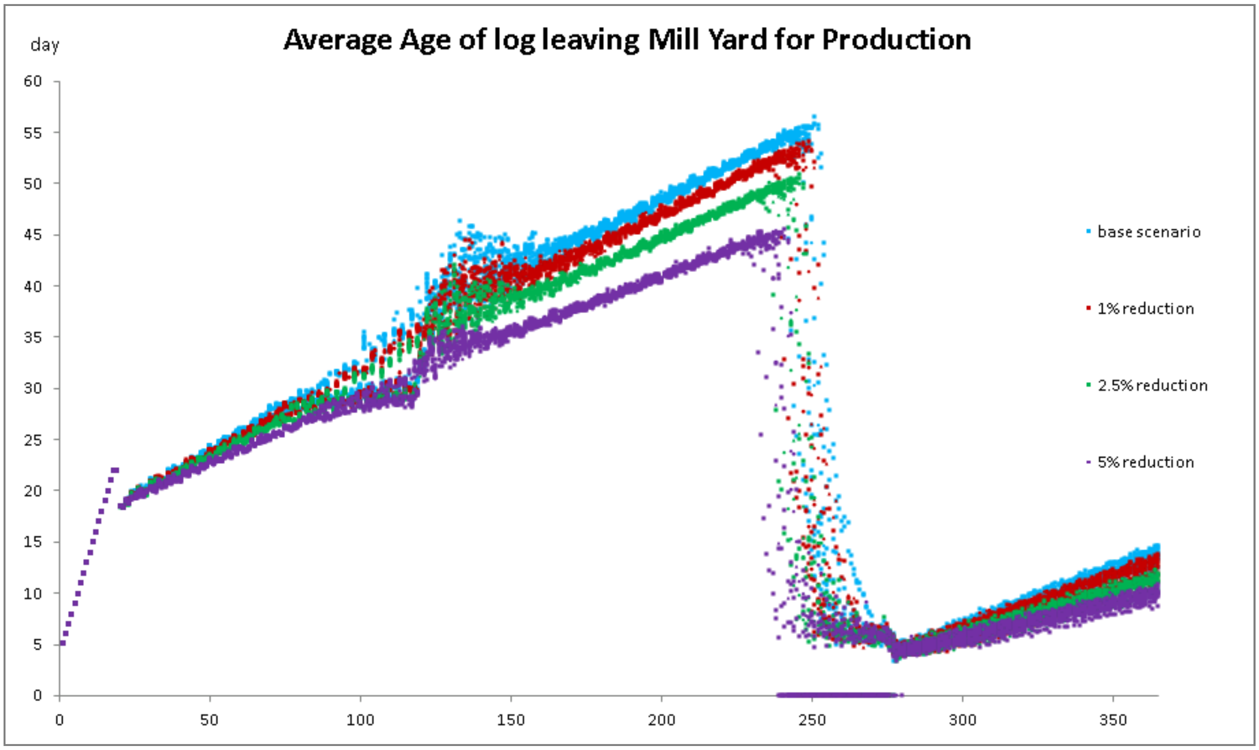


Figure 19: Average log age vs. Julian day for the baseline harvesting plan (blue) and three reduced volume harvesting plans with 1 percent (red), 2.5 percent (green), and 5 percent (purple) reduction in harvesting plan.

Figures 20-24 show the impact of the reduced harvest plans on total cost, total emissions, total fuel consumption, facility inventory and facility supply reliability, respectively. Reductions in total cost, emissions, and fuel consumption are all roughly proportional to the reduction in harvest volume.

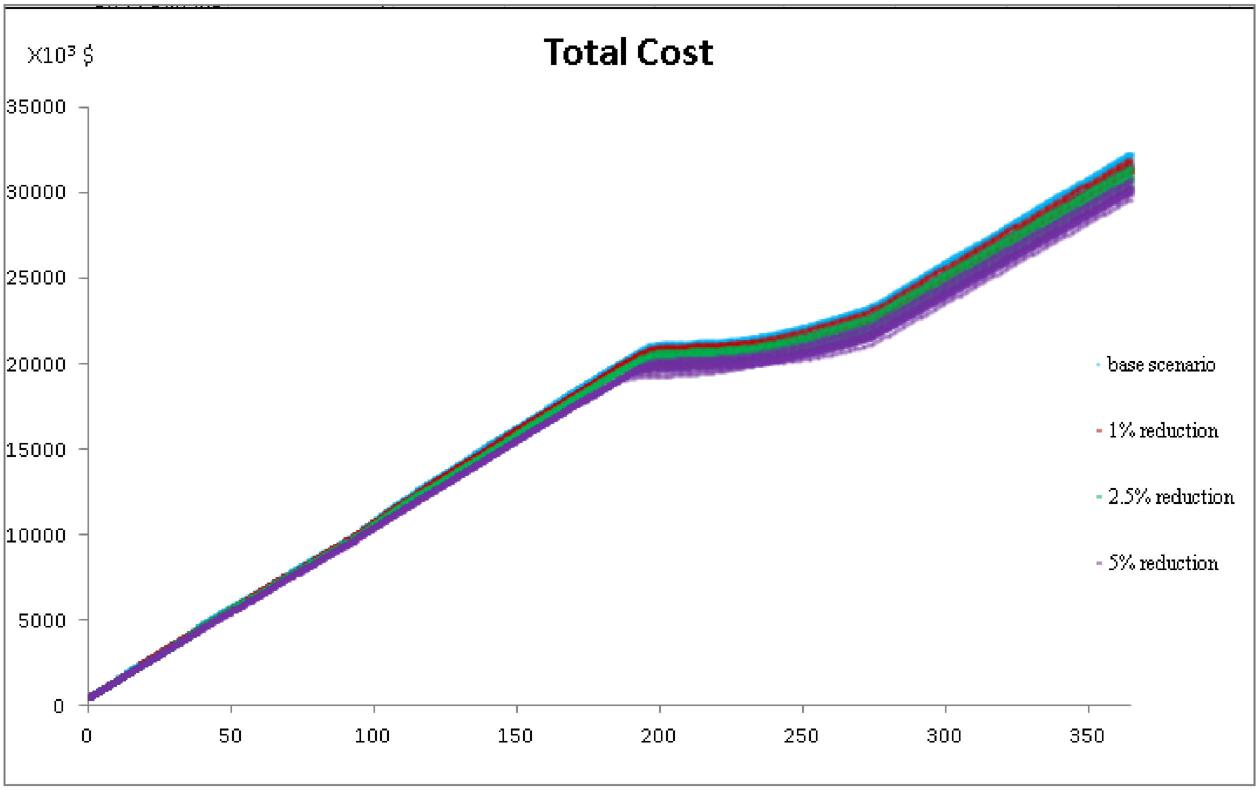


Figure 20: Total cumulative cost ($ millions) vs. Julian day for the baseline harvesting plan (blue) and three reduced volume harvesting plans: 1 percent(red), 2.5 percent(green), and 5 percent(purple) reduction in harvesting plan.. Total cost includes harvesting cost, transportation cost, and storage cost.

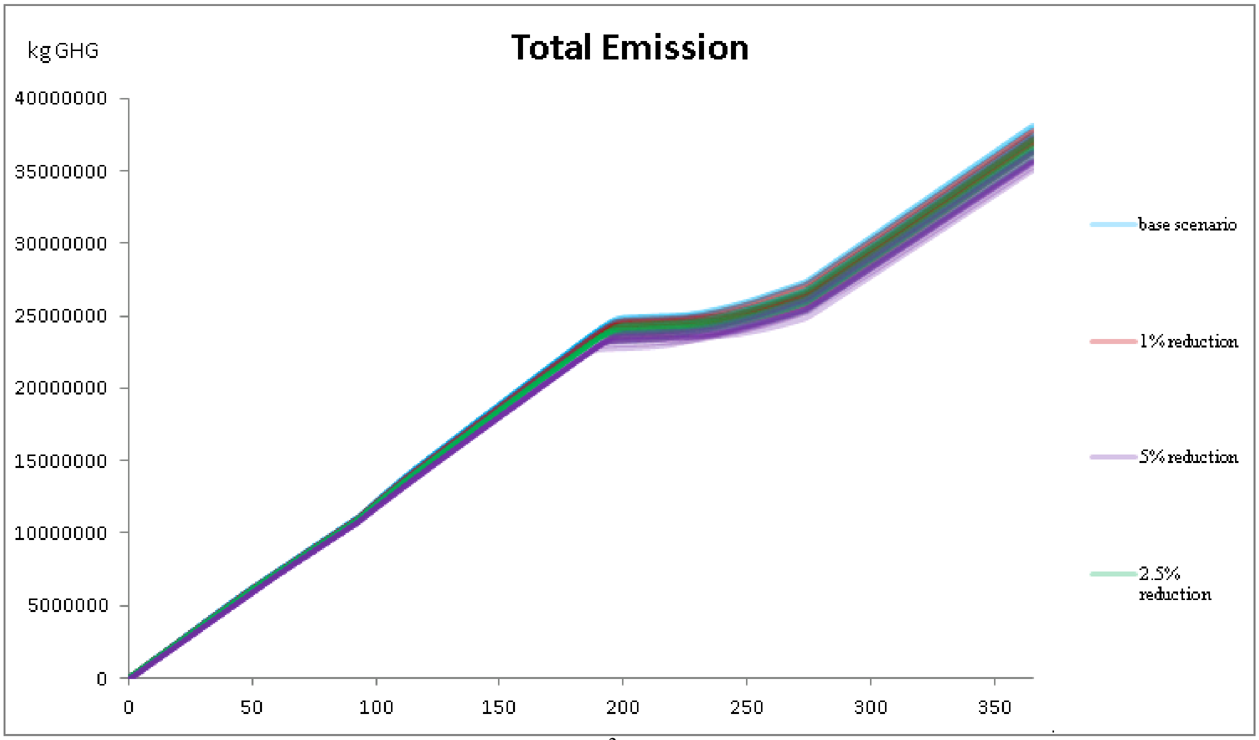


Figure 21: Total cumulative CO_2 emissions (10^3 kg) vs. Julian day for the baseline harvesting plan (blue) and three reduced volume harvesting plans with 1 percent(red), 2.5 percent(green), and 5 percent(purple) reduction in harvesting plan.

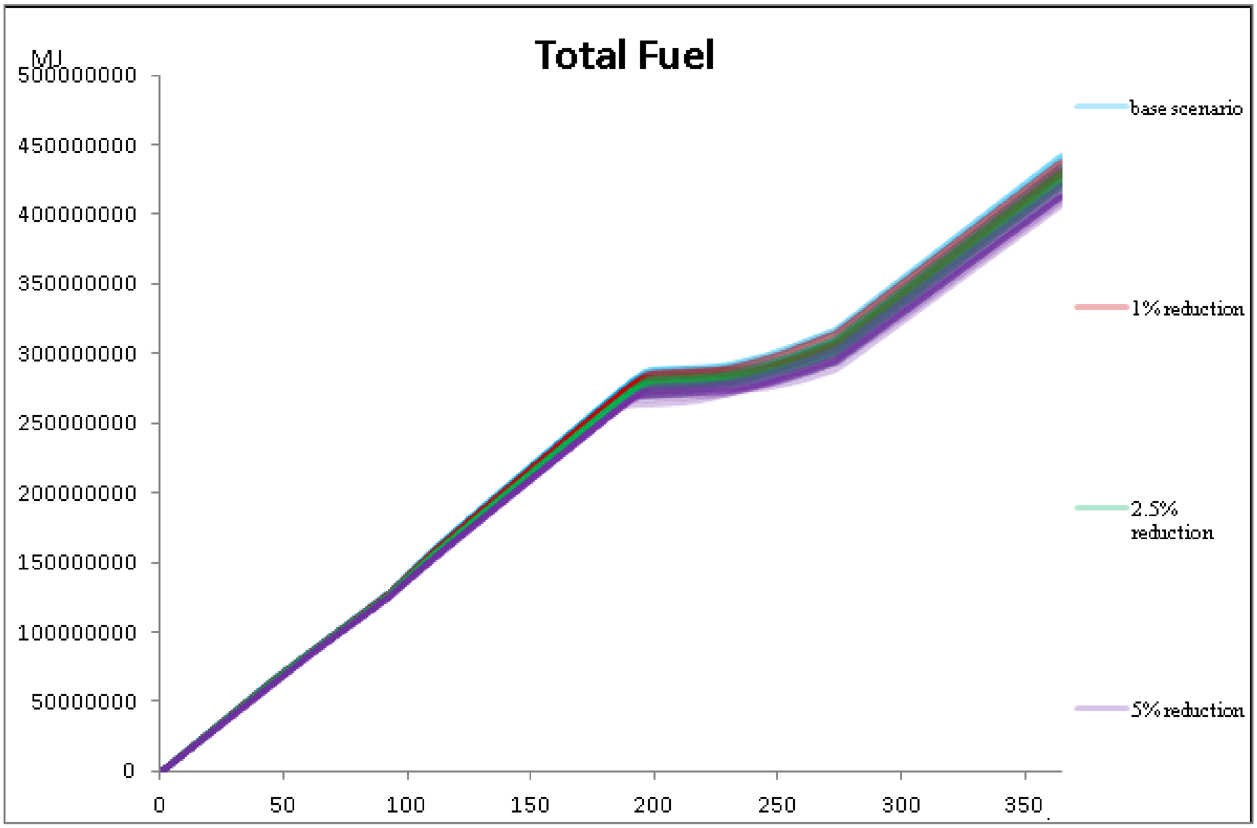


Figure 22: Total cumulative energy consumption (MJ) vs. Julian day for the baseline harvesting plan (blue) and three reduced volume harvesting plans: 1 percent(red), 2.5 percent(green), and 5 percent(purple) reduction in harvesting plan.

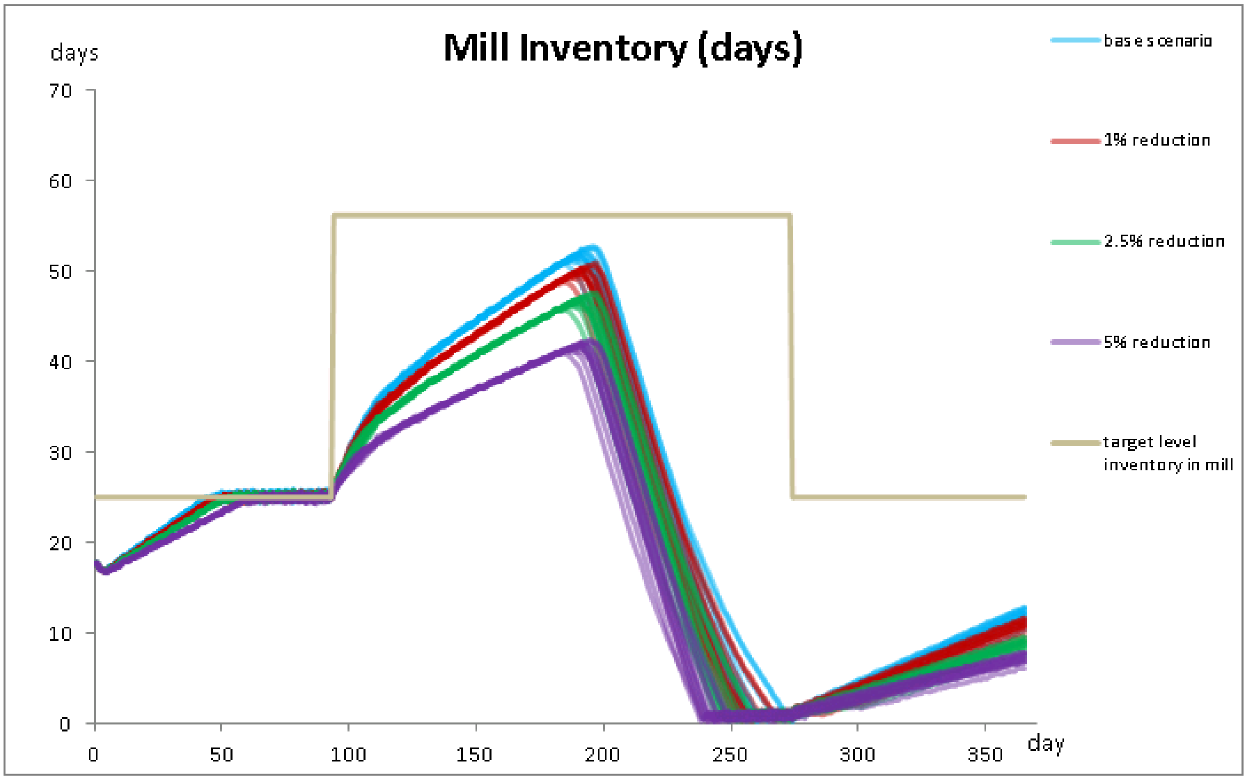


Figure 23: Inventory at the facility (in units of days of production demand) vs. Julian day for the baseline harvest plan (blue) and three reduced volume harvesting plan: 1 percent(red), 2.5 percent(green), and 5 percent(purple) reduction in harvesting plan. The facility inventory under the 5 percent reduction harvesting plan is depleted earlier and longer than the inventories under other scenarios.

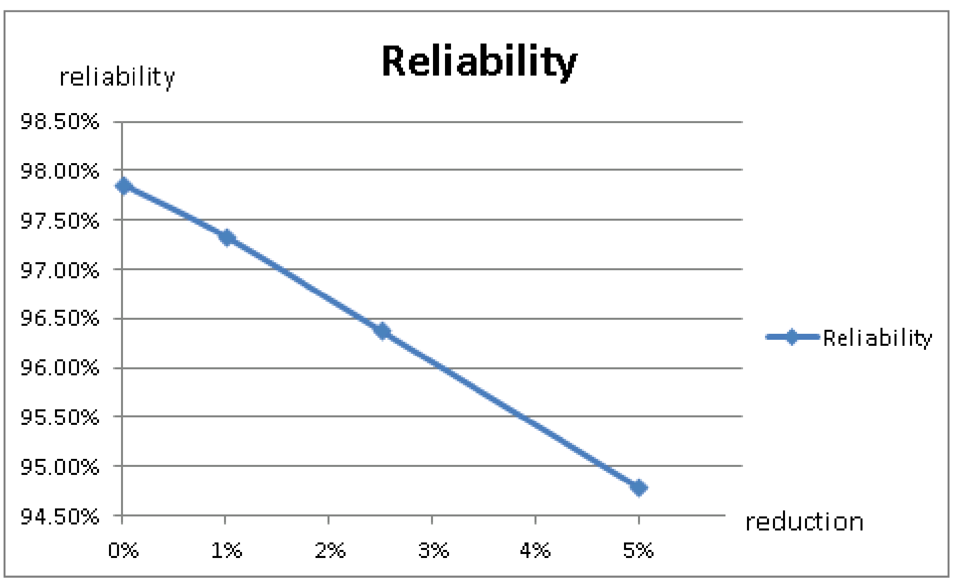


Figure 24: Facility supply reliability vs. harvesting reduction under each scenario. The reliability of the facility yard supply decreases with greater reduction in harvesting.

A second sensitivity analysis was done to evaluate the impacts of reduced transporter (truck and rail car) availability under the baseline harvesting plan. Reductions of 10 percent and 20 percent were simulated and compared to the baseline transportation plan. Figures 25 and 26 show the impacts on facility inventory and log age.

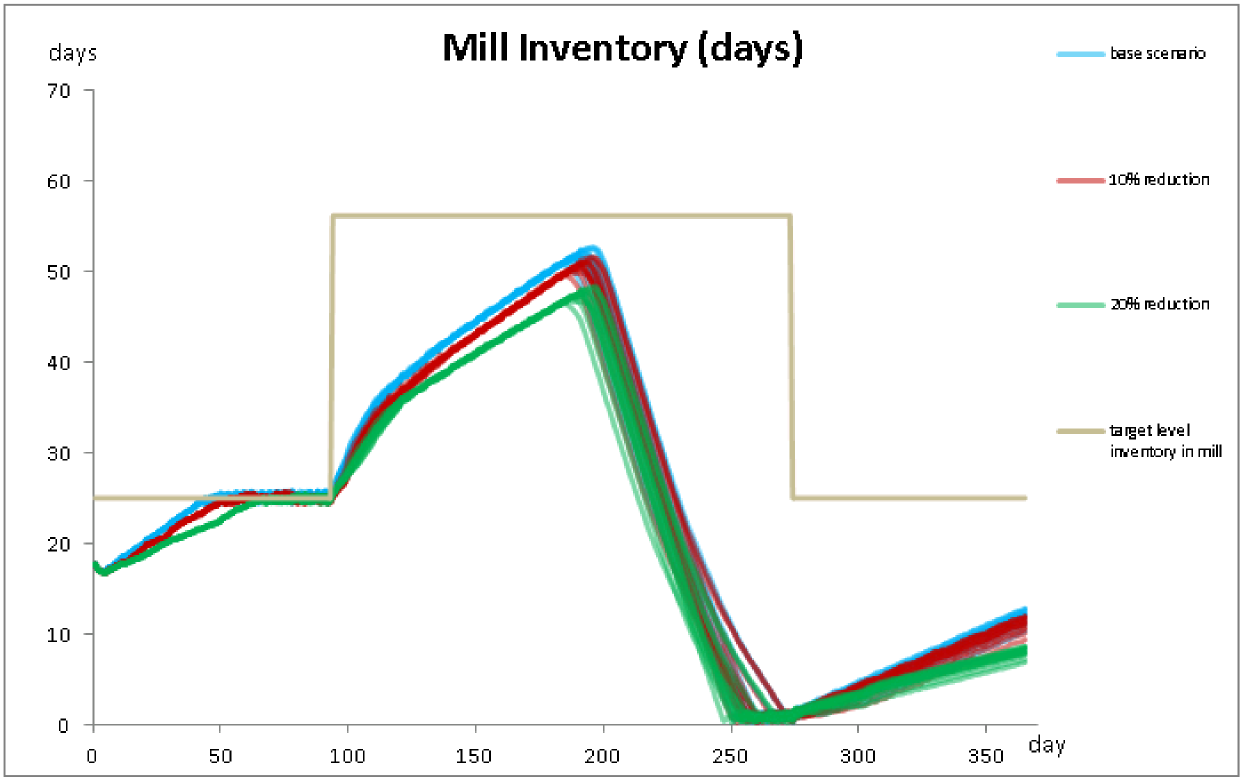


Figure 25: Inventory at the facility (in units of days of production demand) vs. Julian day for the baseline transportation plan (blue) and plans with 10 percent (red) and 20 percent (green) reductions in transporter availability.

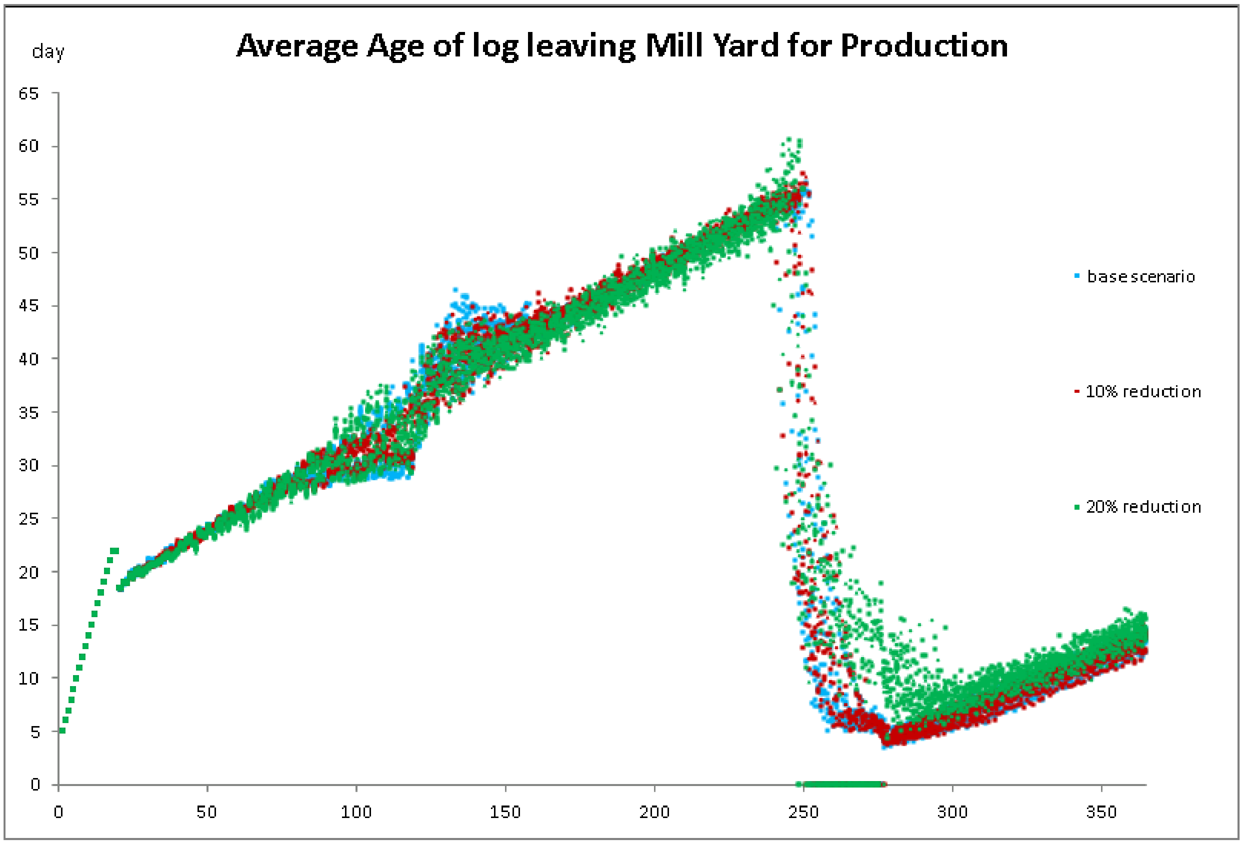


Figure 26: Average log age (days) vs. Julian day for the baseline transportation plan (blue) and plans with 10 percent (red) and 20 percent (green) reductions in transporter availability.

Trade-offs

A number of different trade-offs can be evaluated through multiple runs of the simulation model. As an example analysis of the trade-off between yards' storage capacity (both facility yard and rail yards) and reliability, 100 replications of spring break-up were simulated to track the reliability of meeting daily production demand at the facility. In this simulation, we assumed that the bad weather (wet spring) occurrence probability is 5 percent, with the duration of the bad weather following a uniform distribution of [15, 30] days. Figure 27 shows Alcona County's spring breakup start day and end day for each of the replications from the 1st simulation, with end day "outliers" due to bad weather. Figure 28 shows the relationship between yards' storage capacity and reliability, defined as the percentage of days that the facility demand is met. Figure 29 shows the relationship between rail use and reliability. Figure 30 shows the relationship between the bad weather occurrence probability and reliability. In general, reliability responds linearly to changes in these variables, over the ranges evaluated.

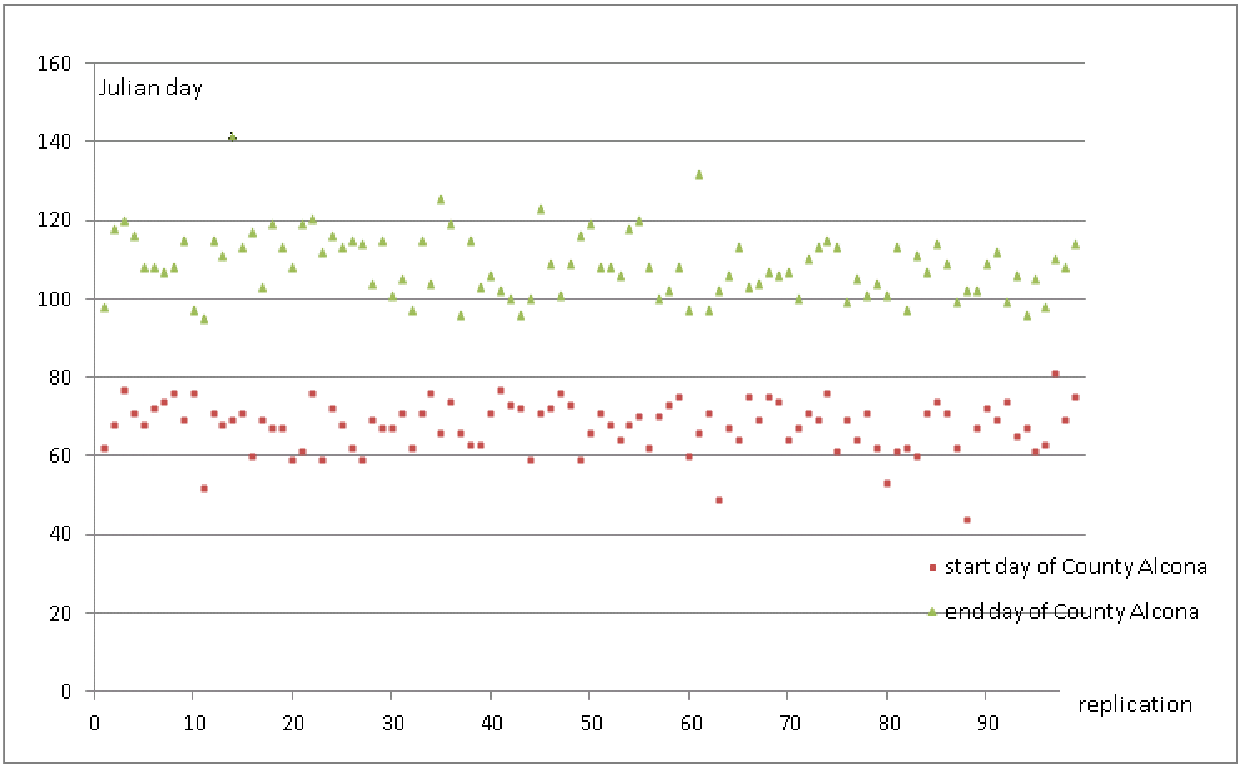


Figure 27: Start day (red) and end day (green) of Alcona County's spring breakup in 100 replications.

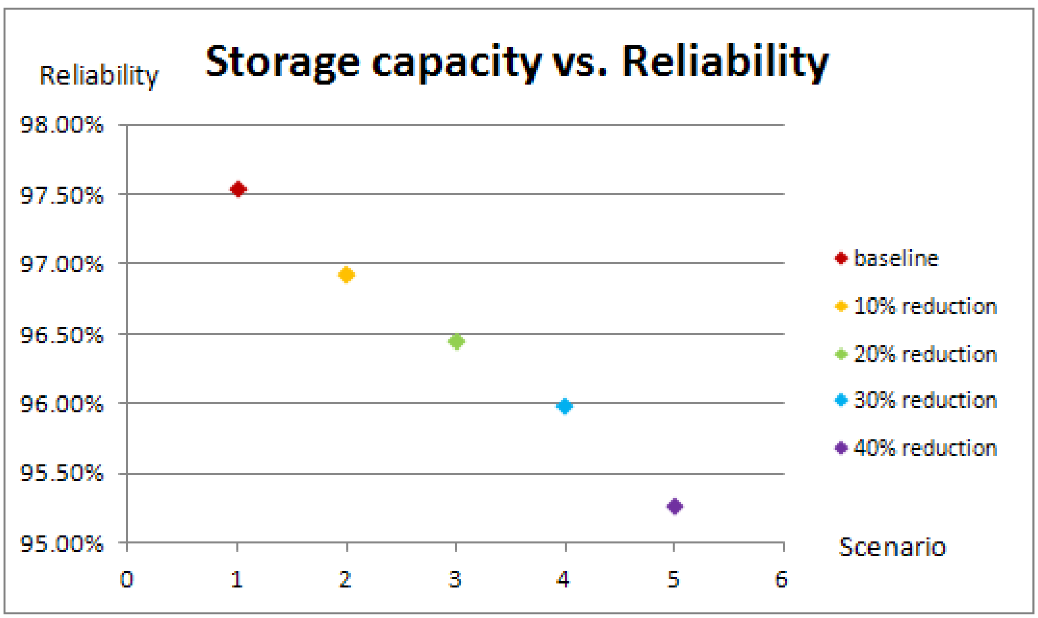


Figure 28: Yards storage capacity vs. Reliability. There are 5 scenarios in the plotting: base scenario (red), 10 percent reduced capacity from the base scenario (orange), 20 percent reduction (green), 30 percent reduction (blue), and 40 percent reduction (purple).

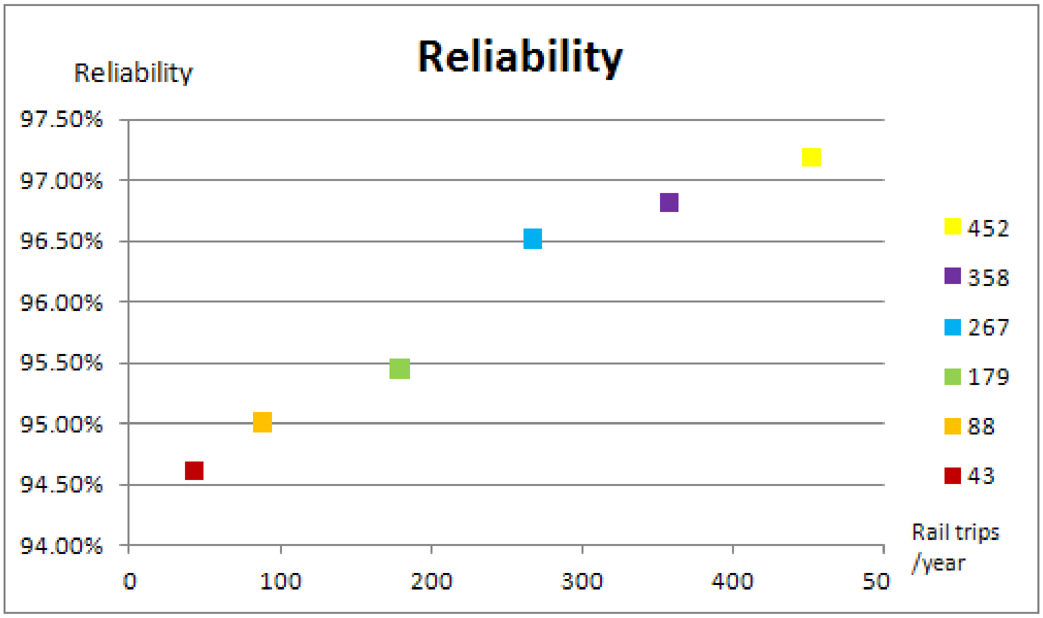


Figure 29: Rail use vs. Reliability. Assuming each rail trip has 4 railcars with 80 tons capacity per car, the first scenario has 452 rail trips available annually (yellow). Other scenarios have fewer annual available rail trips: 358 (purple), 267 (blue), 179 (green), 88 (orange), and 43 (red).

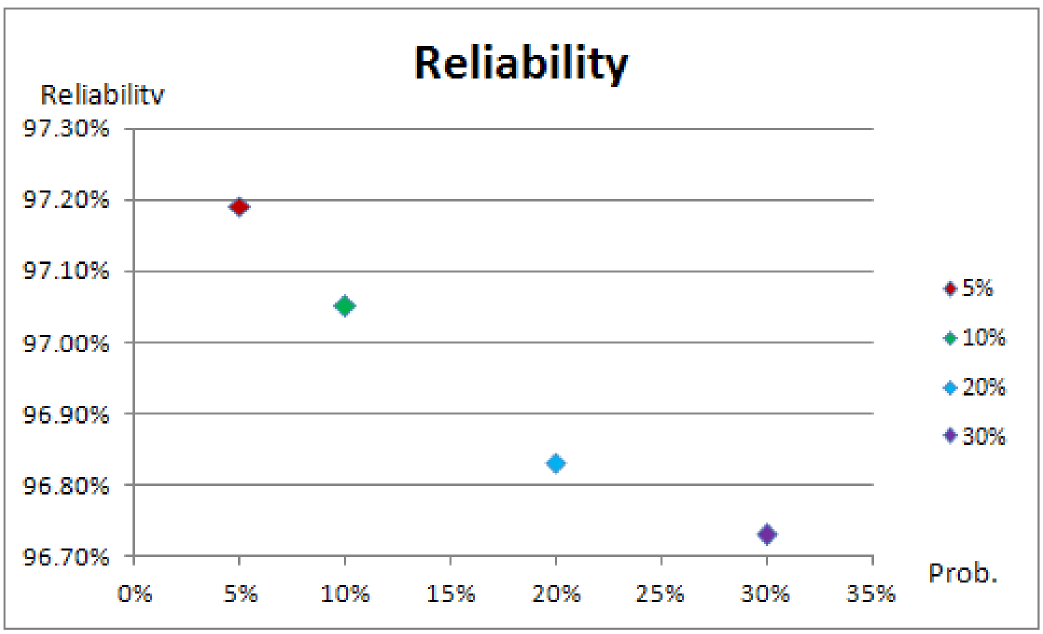


Figure 30: Bad weather occurrence probability vs. Reliability. The base scenario assumes an occurrence probability of 5 percent with a uniformly distributed duration of [15 days, 30 days] (red). Results are shown for higher occurrence probabilities: 10 percent (green), 20 percent (blue), and 30 percent (purple).

Discussion

The suite of optimization and simulation models developed in this project is primarily intended for strategic planning purposes (i.e., mid- to long-term planning decisions such as leasing of rail yards or signing of multi-year options contracts). To support such decisions, the models are intended to be used in concert--with optimization results serving as input to the more detailed simulation model--but the models may also be used individually to test different strategies or evaluate trade-offs under different scenarios. In fact, to respond to sudden and/or "limited" perturbations in the supply chain (e.g., a decrease in truck availability for one season), it may be reasonable to use only the simulation model to predict the expected impacts of the perturbation and evaluate strategies (e.g., increase use of rail transportation) to mitigate those impacts. For this reason, the simulation model is able to start at any time of year, with specified initial conditions (inventory levels in each yard).

Total feedstock cost mainly depends on transportation distance. Thus, greater participation by each landowner type, especially in harvest areas near the facility, will allow the supply chain to be optimized with respect to cost and reliability. However, opportunities exist to develop a supply chain that is robust with respect to uncertainties in land owner participation. These include strategic siting and sizing of railyards in the U.P. and truckyards in the L.P., the purchasing of options contracts for lands adjacent to Class A highways, and developing options for transporting wood (by rail) from more than 150 miles away. The models are capable of evaluating each of these strategic decisions.

The main uncertainty considered by the simulation model is the timing of spring break-up, but other uncertainties could be added, such as the reliability of rail shipments or harvest variability. The model provides flexibility for the user to run (automatically) multiple replications through random sampling (Monte Carlo), or to specify a small set of individual scenarios. In the case of Monte Carlo sampling, the user is cautioned against selecting a large number of random variables, as computational time may limit the fraction of possible cases that can be evaluated, and correlation among the variables may skew the results if not properly accounted for. In some cases, judicious selection of a small number of random variables, to be tested independently in sensitivity analyses, may provide more insightful results.

A host of other trade-offs could be evaluated in addition to the examples presented here focusing on total cost and reliability of supply to the facility. Trade-offs among cost, energy use, and emissions could be evaluated, for example, although the three have been found to be highly correlated with each other since they all depend primarily on fuel consumption. Nonetheless, some policy decisions are envisioned that may require analysis of these trade-offs. For instance, rail could be used for distance less than 100 miles in order to reduce energy use and emissions, although transportation costs would increase. Considering that the facility is expected to be in operation for 20 years, there may also be trade-offs associated with the timing of harvesting over the harvest area, with higher costs incurred early in the facility's lifetime in order to reduce costs or maintain high reliability in later years. As a (possibly extreme) example, consider the strategy to harvest feedstock only at locations nearest the facility in the first 5 years, and then move concentrically outward in each 5-year period thereafter. This could essentially prevent any long-term relationships with loggers, truckers, land owners, and storage yard owners, thereby jeopardizing the facility's operations in later years.

One of the most challenging issues that confront the Frontier facility is securing wood when unusually warm weather forces road weight restrictions to be imposed much earlier than expected. There are several possible solutions to this problem. The simplest response is to stop the facility when the available supply is processed, and the risk of facility shutdown under this management option can be directly computed using the simulation model. Clearly, a shut down involves the loss of potential revenue and the cost of restarting the facility (which are not part of the model). There are several ways that fiber can be secured to supply the facility during breakup, and successful management may employee a mix of the available strategies.

The simplest and least costly approach is notifying suppliers that you will be short and will be accepting deliveries through breakup; a premium price may also be involved. Since breakup usually moves north in the LP, then west in the UP, over time, loggers may be able to stockpile significant supplies even well after the start of breakup in other counties. Furthermore, the loggers may have some stands on class A highways and with well drained soils that they can continue processing through breakup. This is the least costly approach, with the only direct cost being any premium the facility decides to pay to attract supply. Unfortunately, it is also an approach that allows little control in assuring a sufficient supply. This is a management option that depends primarily on improved information flow, but it could be represented in the simulation model through increased feedstock availability during the spring breakup period.

Another approach that would give the Frontier facility more control over its emergency wood supply would be to establish long-term contracts with landowners who have direct access to Class A highways and would be flexible in the timing of their harvests. These stands could be prepared for harvest well ahead of time, but then reserved until emergency wood was needed. Larger landowners, including TIMOs and REITs, would be the most likely candidates for this type of relationship. A key partner in this activity would be individuals or groups that own relatively large tracts of land, but which are not TIMOs or REITs. A collaborative effort between MSU Project 1 and MTU Project 1 developed a relatively comprehensive list of these owners. (Maps showing the larger land owners identified are provided in Appendix G. Maps showing the road system with Class A highways, seasonally restricted roads, and several other road designations are available upon request.) This management option could also be represented in the simulation model through increased feedstock availability during the spring breakup period, but would not require as much coordination across the supply chain.

Another source of emergency wood could be bio-fuel plantations. This is the only category of fiber that can be where it is most useful rather than where they happen to have grown. Since these crops would be managed using a clearcut regeneration technique, there would be no concern about damaging the residual stand; concerns about equipment damage to the site is an issue. If coppice regeneration were used, a cut in the late winter would enhance the success of sprouting. The negative traits of this option are that it would be extremely expensive to grow due to planting and intense protection (from deer) efforts, and a strategy to encourage the landowners to initiate these crops would be needed. A final concern is that this fiber source would first be available sometime around 15 years after the decision was made to use this option.

The crop would need to be about 10 years old to reach utilization standards for the Frontier facility, while it would take time to convince land owners to pursue the option, generate enough of the chosen planting stock, and initiate and protect the stands. This option could be incorporated in the models through adjustments to timber availability in harvest areas with bio-fuel plantations.

Recommendations

Recommendations stemming from this study point to critical aspects of the feedstock supply chain, where attention should be focused to ensure efficient (low-cost), reliable, responsive, and socially responsible operations. Recommendations are also provided on future use of the models in strategic decision making, as well as further studies that may be conducted to test modeling assumptions and improve or update model parameters and input data.

A key assumption in the models is that restrictions that limit harvesting fiber on some lands can be represented via the timber volume, growth, and historic harvest data. Due to a host of uncertainties, a systematic effort was made to choose conservative rather than optimistic estimates of what would be available to supply the Kinross facility. In reality, we expect that more fiber will be available than the model assumes, but these conservative biases will have to be evaluated and revised over time. In particular, growth may continue to exceed removals and mortality, harvesting efficiencies are expected to continue to improve, and more cull and facility residues may be available than conservatively assumed.

Another critical uncertainty arises because different land owners have very different criteria when deciding whether or not to harvest timber. In the models, four distinct ownership classes were defined: federal, state, private industrial and private non-industrial. In addition to state and federal policies which can have large impacts on timber availability, non-industrial private owners have a very broad set of goals reflected in their land management decisions, and it is hard to predict harvesting behavior. One subgroup that is both important and may be more likely to harvest timber is owners with larger tracts of land. Many of the individuals in that group practice active forest management, and might be willing to form long-term relationships with the Frontier facility.

Many landowners would increase timber sold with an increase in the offered price, and thus it would also be very helpful to have information about price-supply relationships (i.e., the price elasticity of supply). The optimization model allows the user to analyze the impact of different proportions of growth sold, but being able to draw that proportion in practice will require adjustments to stumpage prices. In the long run, having a market also provides incentive for landowners to promote long-term improvements in timber quality and a range of multiple-use goals that would otherwise be too expensive to consider. In addition, the opening of the Kinross facility will provide a market for low quality fiber that otherwise would remain in the forest and occupy growing space with very little potential for return. Although the COEE Project (particularly the land owner surveys conducted by MSU Project 2) was an important first step in understanding potential impacts of landowner behavior, continued efforts should be made to educate and develop long-term relationships with landowners, as well as to ascertain price-supply relationships among the different land owner types.

For modeling purposes, the area in Michigan within the specified 150-mile haul distance was divided geographically into 43 mutually exclusive and exhaustive “harvesting regions.” The harvest regions were defined as the overlay of the counties in the supply zone with the harvest zones defined in the MSU Project 2 fiber availability report. In addition, three unspecified areas beyond the 150-mile haul distance were included in the models to add flexibility. Although revisions to timber availability in these areas could easily be made, changing geographic extents would be more involved. In particular, travel distances and associated costs would need to be revised, which would require detailed analysis of the road network in and connecting to the revised harvest area. Thus, the 46 total harvesting areas were selected to provide sufficient flexibility for any future analyses.

Since feedstock deliveries from areas more distant from the facility tend to have higher shipping costs, the specified “drain rate” (the proportion of annual growth that can be removed in a year) is critical to planning harvests over the 20-year horizon. Since the optimization model minimizes the discounted present value of the cost of supplying the facility, it will choose to supply the facility first from close sources of fiber, and then switch to sources farther away. The drain rate limits how quickly closer sources can be liquidated, and thus determines how wide of an area will be chosen at the different points in time. The default drain rate is set to two times annual growth, which results in the least expensive supplies being harvested over the first 10 years, and the model choosing to move out to more distant supply sources in the next 10 years. This may cause disruptions in the supply chain and difficulties for the logger and trucker communities. The optimization model can be used to analyze different scenarios of draw rates, and may prove useful in designing zone premiums that balance harvesting the close fiber quickly to increase early net revenues while retaining a supply of close fiber for continuous employment of loggers and truckers.

The Spring breakup statistics (start day and duration for each county) are based on a very small sample of only about 8-9 years of data. Historical knowledge may be used to augment this data (adjust distribution parameters), and new observations should be accounted for each year. New information will be particularly important if a climate change trend becomes apparent in the region.

Facility and supply chain activities are not expected to be in violation of any air quality or water quality regulations. Stricter standards for ozone and PM 2.5 air pollution, however, could result in nonattainment problems when the Kinross ethanol plant is fully operational. Potentially, this could either limit ethanol production or place additional constraints on fiber deliveries (e.g., increased use of rail, or more uniform arrival of trucks throughout a 24-hour delivery window). Any changes in truck weight laws in Michigan would also affect the supply chain. Some of these changes in regulations could be directly evaluated in the simulation model (e.g., changing transporter capacity), but others could not (e.g., sub-daily scheduling of deliveries).

Numerous other model assumptions and parameters may be subject to change, and most likely will need to be revised or updated once the supply chain begins functioning and new information is acquired. Examples include fuel prices, transporter (truck and rail car) availability, and possibly fuel efficiency and emissions factors.

The flow of information across the supply chain was not explicitly analyzed or modeled in this project. However, information processes which are critical to supply chain reliability are discussed qualitatively. These processes include information coordination capability, contracts and risk sharing, visibility in the procurement process, sourcing planning, and risk management in sourcing. Future research could investigate ways to quantitatively assess the importance of these processes, as well as ways to enhance the overall efficiency of the supply chain, such as maximizing the use of backhauls.

Conclusion

A suite of strategic planning models have been developed for the planned Frontier Renewable Resources, Inc., facility in Kinross, Michigan. The overarching goal is to support planning decisions that enable delivery of biomass in a low-cost, reliable, and time-effective manner. Using data acquired from all COEE Project teams, the models were applied to illustrate their use in evaluating strategic decisions (e.g., harvesting scheduling, transportation mode, and location and capacity of storage facilities) and trade-offs in supply chain performance. In addition, the models can identify key parts of the supply chain where improved knowledge or changes in systems would have the largest effects on delivered feedstock volumes, reliability, and costs.

In exercising the suite of models, a high-level optimization model (20-year horizon with an annual time step) was run first to determine the long-term, minimum present value cost harvesting pattern and transportation methods, given constraints in availability due to growth and land owner participation. The resulting annual decisions were then disaggregated temporally using a short-term optimization model (1-year horizon with a weekly time step). In practice, this step may be replaced with a pre-specified seasonal pattern based on analyst experience. Finally, the resulting weekly harvesting and transportation plans were used as inputs to the simulation model, which operates on a daily time step for a 1-year horizon, accounting for uncertainty in spring break up timing and weather conditions through stochastic (Monte Carlo) simulation.

Results from the long-term optimization model indicated that feedstock can be reliably supplied to the processing facility for a period of at least 20 years, with the majority of the feedstock harvested within 100 miles of the facility. However, harvesting locations can be expected to shift farther from the facility during the course of a 20-year planning period, particularly after the first 8-10 years, with transportation costs estimated to increase by 25-30 percent by years 16-20. Although the results of the optimization model should be recognized as "optimistic" (i.e., perhaps not achievable in practice), the simulation model confirmed under realistic spring break up conditions that facility demand can be met at least 94 percent of the time, even without the purchase of so-called "emergency wood," purchased under a one-time contract, or shipping by rail from farther than 150 miles.

Since many uncertainties exist in the data and modeling assumptions, particularly in predicting landowner behavior, a focus was placed on conducting trade-off and sensitivity analyses with the simulation model. Scenarios with reduced harvesting activity, truck availability, rail use, and storage yard capacity were simulated to evaluate potential impacts on feedstock reliability and cost. In general, cost impacts could not be fully analyzed because no assumptions have been made regarding the cost of "emergency wood" or the cost of an unplanned facility shutdown, but the reliability of meeting facility demand was shown to be sensitive to each of the factors analyzed.

Future research will be needed to test modeling assumptions and obtain new data as it becomes available. Accordingly, the planning models have been developed with flexibility in mind. Although some coding may be needed to adjust the geographic extents or spatial discretization of the models, all other model data and parameter values may be adjusted through spreadsheet inputs or user interface screens. The conceptual supply chain model; modeling assumptions and data requirements; user and developer documentation (Appendices H, I, and J); and examples of model use for sensitivity and trade-off analyses have been presented herein to facilitate model use to support strategic planning and decision making for feedstock supply chain sustainability.

Appendix A: Detailed Plan of Work – Project 1

Project Investigators:

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Executive Summary

This COEE project will create a model for the feedstock supply chain with the goal of delivering biomass to the Frontier facility in a low cost, reliable, and time-effective manner. The model will be able to be exercised to identify: i) best harvesting procedures, ii) superior transportation methods, iii) storage size requirements, and iv) areas where effort should be directed to improve the supply chain. The project has the following deliverables: a) supply chain model in conceptual form, b) software-based form of the supply chain model, c) listing of the policies, regulations, and laws that directly affect the supply chain, and d) recommendations for improving system performance. These deliverables will require the proposers to effectively integrate their actions with those of the other COEE researchers; in particular, the harvesting, forwarding, and processing system model from Project 3 will be integrated into the supply chain model.

Tasks

1. Construct Conceptual Supply Chain Model – Construct a basic model of all phases of the supply chain and populate it with the best available information
2. Build/Refine/Implement the Supply Chain Model – Transform the conceptual version of model into a computer-based simulation model.
3. Catalog Policies – Catalog all the current policies, regulations, and laws directly affecting the supply chain and refine the model as needed.
4. Identify Performance Improvement Opportunities – Apply the model to identify where changes in the supply chain can bring about the biggest improvements.
5. Integration – Interface with the other Project Teams to incorporate new data as it becomes available and disseminate the project results to support efforts of the other projects.

Approximate Timeline – Project Date: May 1, 2009 – April 30, 2011

• Construct Conceptual Supply Chain Model	5/09 – 9/09
• Build/Refine/Implement the Supply Chain Model	8/09 – 1/10
• Catalog Policies	5/09 – 9/10
• Identify Performance Improvement Opportunities	9/09 – 11/10
• Documentation	11/10 – 4/11
• Quarterly project updates	7/31, 10/31, 1/31, …

Motivation for Project

Background

Much of the petroleum used in the United States supports transportation needs, and 60 percent of this comes from imports. The United States Department of Energy (DOE) estimates that enough biomass is sustainably available to replace 20 percent of current transportation-related U.S. petroleum consumption, and the utilization of renewable biomass feedstocks for production of bio-chemicals and bio-fuels was identified as a grand sustainability challenge by the National Academy of Sciences (NAS 2005). The use of biofuels (including ethanol) in transportation applications can produce such benefits as improved national security, more favorable trade balance, rural U.S. job creation, decreased demand for petroleum, and lower emission of fossil-derived CO_2. The development of a profitable industry for the conversion of woody materials to ethanol requires efficient processes at every step of the value chain (e.g., biomass harvesting/gathering, loading, transport, processing, and distribution). The development of efficient processes calls for the support of systems-level, integrative analysis methods and tools to support the technological, policy, and financial decisions that are required.

Frontier Renewable Resources (Frontier) has been formed through a collaboration between Mascoma and JM Longyear. Frontier is establishing a commercial-scale processing facility in Chippewa County's Kinross Township in Michigan's Upper Peninsula. The facility will create cellulosic fuels from a range of non-food biomass feedstocks, e.g., hardwood chips. At steady-state, the production facility is expected to produce 40 million gallons of ethanol and other bio-products per year. To support the technical needs of Frontier, the Feedstock Supply Chain Center of Energy Excellence (Feedstock COEE) has been established.

In considering the development of a profitable company that can sustainably produce ethanol and other bio-products there are two principal questions: i) is there sufficient biomass to sustainably support the needs of a Kinross-based facility, and ii) what is the best system to gather, handle, and transport the biomass to the Kinross facility? The first of these questions will be addressed by Project #2 in the Feedstock COEE Request for Proposals (RFP). The answer to the second question is critical since **the gathering, handling, and transportation costs represent the overwhelming majority of the costs associated with the production of ethanol.** This proposed project associated with the Feedstock COEE seeks to answer this question – it is focused on developing a **model that can be used to establish a feedstock supply chain that can deliver biomass to the production facility in a low cost, reliable, and time-effective manner.** The proposed model will be capable of addressing such issues as: i) best harvesting procedures, ii) superior transportation methods, iii) storage size requirements, and (iv) areas where effort should be directed to improve the supply chain – all aimed at the overarching objective of achieving a robust, cost-optimal supply chain.

Knowledge Gaps

The model to be developed through this effort will have all the characteristics that constitute a supply chain, namely, the integration and coordination of the flows of materials and information between the various points of supply and demand along the chain with the objective of minimizing system-wide costs while satisfying service-level requirements. A successful supply chain must address the tradeoff between the responsiveness and cost efficiency with the goal of meeting the organization's goals. Supply chain performance is to a large extent determined by four drivers (enablers): inventory, transportation, facilities (network), and information (Chopra and Meindl, 2007; Marien, 2000). The supply chain model developed in this project will address the trade-offs inherent to these drivers and their impact on performance. A multi-criteria assessment methodology that integrates economic, social, and environmental factors to rank biomass collection and transportation alternatives was developed by Kumar et al. (2006).

Adding inventory increases costs and decreases cost efficiency, but makes the supply chain more responsive. However, storage of biomass can result in weight losses that may be either detrimental (dry weight loss) or beneficial (moisture loss). Combustion is also a concern. A preliminary review of the literature reveals attempts to describe these phenomena (DeMol et al., 1997).

Faster, higher speed transportation often increases costs, yet allows the supply chain to be more responsive. Managing this trade-off heavily depends on choice of transportation mode(s) and the network design and route selection. The degree of coordination and integration achieved is impacted by the timing of the various components of the transportation system. The use of multiple modes of transportation has been addressed in the literature. Mahmudi and Flynn (2006) evaluate the offloading of biomass from trucks to dedicated rail units and deal not only with economic issues but also social issues such as traffic congestion.

When making facilities/network design decisions the fundamental trade-off is between the cost (efficiency) and responsiveness (flexibility) of the system, as determined by the number, location, and type of facilities (storage or production). Locating facilities close to the point of demand increases the number of facilities, and thus the costs, but increasing the responsiveness. One centralized facility increases cost efficiency but comes at the expense of reduced responsiveness. The literature on network flows and site selection is extensive. Load balancing issues have also been examined. Gunnarsson et al. (2004) considered the material flows between sawmills and harbors and address the issue about which terminals to use. Their solution methodology consisted of a mixed integer linear program combined with a heuristic solution approach. Gronalt and Rauch (2007) proposed a stepwise heuristic approach to solve the biomass supply network design for a number of alternative configurations. Near optimal solutions can be found by including all relevant transportation costs. Of course, much literature on infrastructure also exists.

In addition to other issues, it is also important to also consider information management when constructing a supply chain. Effective information management can increase both responsiveness and reduce costs, with trade-offs occurring between the cost of the information and the responsiveness that the information creates. Information connects various stages of the supply chain, allowing coordination of actions; for example, providing inventory visibility. Much has been written about the value of information in supply chains (Cachon and Fisher, 2000; Simchi-Levi et al., 2008). However, this topic does not appear to have been addressed in the literature on woody biomass processing.

The nature of COEE Project #1 suggests simulation and optimization as possible methodological approaches. DeMol et al. (1997) developed a simulation model and employed optimization methods to gain insight into the costs and energy consumption of the logistic of biomass fuel collection. They note that the choice of model depends mostly on the objectives of the user.

In general, the literature provides little guidance on the modeling and optimization of supply chains for biomass resources; however, research that has been undertaken on other applications can be applied to the tasks associated with the project.

Project Description

Overview of Approach

The goals of this project are to i) develop a feedstock supply chain model, ii) utilize the model to provide guidance on where improvement opportunities exist, and iii) make recommendations regarding the establishment of the actual supply chain. To achieve these goals, the model must be developed in such a manner to answer questions posed by the Frontier management team and other key stakeholders. And, of course, the overarching objective of the proposed modeling effort is to design a supply chain that minimizes the cost of supplying the facility while meeting necessary delivery requirements.

Developing the feedstock supply chain model requires integration of many different types of information from many different sources. Much additional information needs to be secured from Frontier regarding specific details of the plant's operation, the cost and difficulties of harvesting and shipping large quantities of wood, and a variety of other topics. Still other information will be provided by the Michigan Technological University/Michigan State University research collaborations associated with the other COEE projects:

- Project 2: Increasing Availability of Feedstocks and Ensuring Sustainability
- Project 3: Improving Feedstock Harvesting, Processing and Hauling Efficiencies
- Project 4: Outreach, Extension, and Technology Transfer

The primary goal of the supply chain team is to bring this diverse information together to develop a comprehensive model that will successfully characterize the process of supplying the Frontier facility with the goal of minimizing the cost of supplying the required biomass.

This supply chain system is made complex by both the spatial dispersion and the availability and change in volume of the resource over time. The goal of this project is to provide a flexible and comprehensive model that can be used to evaluate a wide range of planning scenarios. The development of a detailed, time-dynamic operations scheduling model is beyond the scope of this project.

As stated in the Request for Proposals, development of this planning model will be an evolutionary/iterative process, with many of the details determined by the various challenges and opportunities that arise. The general approach is to develop a simulation modeling system which has various (potentially optimized) sub-models embedded within it. The overall simulation model will provide both necessary analysis tools and a framework to connect and analyze the various parts of the supply chain. Once established, the model can be utilized to provide supply chain design recommendations.

Research Plan

The following tasks will be undertaken to realize the goals and objectives of the project:

1. Construct Conceptual Supply Chain Model – Construct a basic model of all phases of the wood supply chain (from the soil to the processing plant) and populate it with the best immediately available information
2. Build/Refine/Implement the Supply Chain Model – Transform the conceptual version of model into a simulation model. Create elements of this model and add modules to improve accuracy and expand the number of alternatives that can be examined.
3. Catalog Policies – Catalog all the current policies, regulations, and laws directly affecting the supply chain and refine the model as needed.
4. Identify Performance Improvement Opportunities – Apply the model to identify key parts of the supply chain where improved knowledge or changes in systems would have the largest effects on delivered volumes and feedstock costs.
5. Integration – Interface with the other Project Teams to incorporate new data as it becomes available and disseminate the project results to support efforts of the other projects.

In considering these tasks, we envision that there will potentially be a wide variety of biomass resources (e.g., logs, forest residues, and mill waste) that are gathered, loaded, stored, and transported to the processing facility (Figure 1 shows this for harvested logs and suggests that other biomass sources will be planned for). The proposed project tasks are described in detail below.

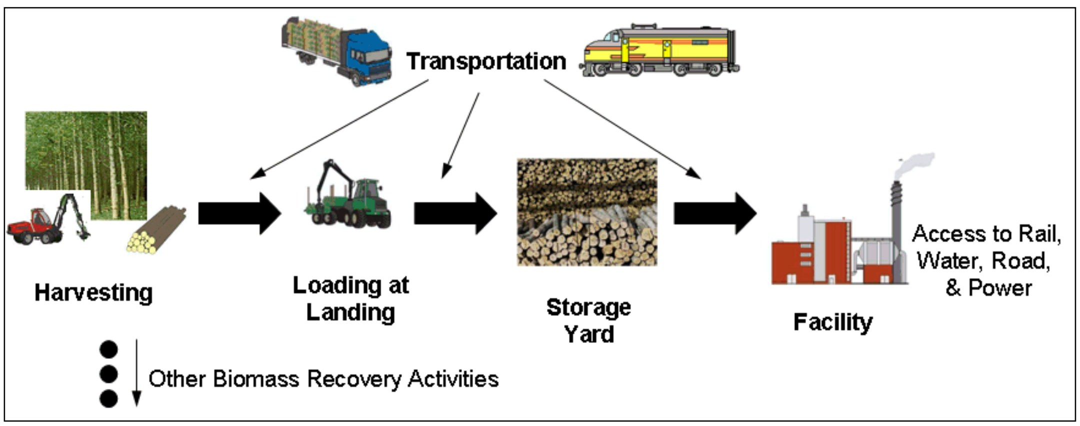

Figure 1: Components of the Feedstock Supply Chain

Task 1: Construct Conceptual Supply Chain Model

In this task, the fundamental structure or framework of the supply chain model will be established. This version of the model will contain large portions that are conceptual, as opposed to concrete; conceptual portions will be replaced with mathematical descriptions developed in Tasks 2, 3, and 4. This simple version of the model will identify important factors and their inter-relationships. Important components include:

- Biomass resource availability (resources ready to be harvested and transported):
  - Biomass ready for harvesting (by location, species, size, etc.)
  - Cost of feedstock
- Forest biomass harvesting, forwarding and processing

    - Cost, productivity, and other factors associated with harvesting, forwarding, and processing (we will work closely with Project #3 personnel on this issue)
- The log/biomass storage capability/capacity of the supply chain
    - Existing (and, if possible, future) storage availability at the Frontier facility site and elsewhere
    - Cost of storage by location and capability to organize stored material, by location
- Available transportation infrastructure
    - Road network information (Class A and other highways, including logging roads)
    - Railroad (including landing) locations
    - Distances on all connecting rail and road systems
    - Barge/ship access by water
    - Multimodal transportation costs
- Other infrastructure availability/capacity (e.g., power and water)
- Travel distances, times, and other cost factors between harvest sites, log/biomass storage sites, and the Frontier facility.
- Other factors such as road load restrictions, harvesting seasonal impacts, variability of feedstock availability

It is envisioned that the conceptual model will be represented in a standard form such as IDEF, Integration DEFinition (Hanrahan, 1995), or SADT, Structured Analysis and Design Technique (Marca and McGowan, 1988), that describes the relationship between functions/activities (e.g., gathering and transportation), and also indicates inputs, outputs, controls, and mechanisms. We will consider a variety of feedstock sources, for example, harvested logs, forest residues, mill waste, and biomass purchased from other multiple sources. The model will also include chipping, intermediate storage, material handling, transportation, and other activities as necessary that are envisioned to play key roles within the supply chain. The model structure will have sufficient flexibility to allow its overall structure to be modified based on inputs from other projects, key stakeholders, and knowledge gained as the project evolves.

Deliverable: Conceptual Model in a Standardized Form

Task 2: Build/Refine/Implement the Supply Chain Model

The second task will involve transforming the conceptual model of Task 1 into precise mathematical descriptions and then implementing these model components into software. The first step in the task will be to determine the nature of the quantitative relationships among the various components of the Task 1 model and using the information available at the time of development to parameterize the models. Clearly, our ability to accurately describe the system will be limited by both the short timeline of Task 2 of the project and by the availability and quality of data provided by other partners in this process. It is likely that final data will not be available from either Project 2 or 3 at this point in time. It is also possible that Frontier will not have finalized all of the requisite information.

The second task is to take the mathematical descriptions that have been developed above and use them to establish a software-based form of the model. If we consider the supply chain to be a system, it may be broken down into a number of processes (e.g., biomass gathering and transportation), and each process may be further broken down into activities (see Figure 2). Activities perform functions (e.g., load and move) on entities (e.g., logs or wood chips), and require resources (e.g., equipment and people) to achieve completion. An activity level description of the supply chain can then be represented by a general purpose simulation language such as ARENA [Rockwell Automation, 2008].

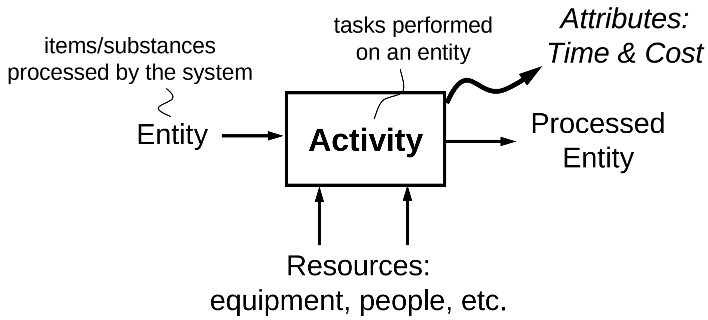

Figure 2: General Description of Relationship Among Activities, Entities (e.g., Biomass), and Resources

One of the fundamental benefits associated with establishing a simulation-based form of the model is that such a description will allow us to better describe those parameters and variables which are subject to uncertainty, assuming they may be characterized by statistical distributions. For example, the time required to load a logging truck is not a constant, but the time could be described with a probability distribution that has a mean and standard deviation. A weakness of the simulation-based model is that it requires nominal values for all the decision variables in the model (e.g., number of trucks and logging teams). To converge upon best values for these decision variables requires the conduct of a simulation experiment, with the results then used to identify how the variables should be modified to secure better performance (see Figure 3). This approach can often be time consuming, especially in light of the large number of variables that are expected to be associated with the supply chain model; with this in mind, to speed the convergence of the system optimization process, we may employ optimization tools (e.g., linear programming) to identify very good values for the decision variables associated with several of the activities/processes. The optimized values of these variables will serve as excellent starting points for more detailed simulation experiments.

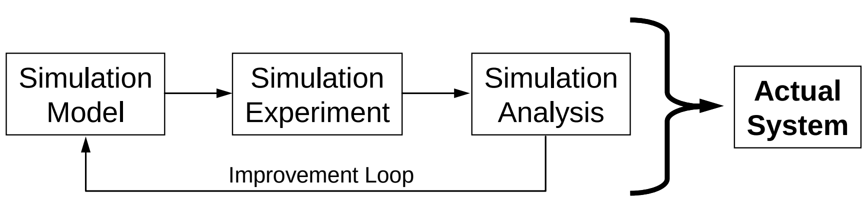

Figure 3: Using Simulation to Optimize a System

Model Guidance

It should be noted that considerable discussion with Frontier leadership is needed to craft a supply chain model that is responsive to their needs. Examples of the type of information needed include: i) more information on the amount and source of biomass to supply the Frontier plant, and ii) existing infrastructures. As noted above, discussions with Frontier will be on-going, and thus the model will be developed in an evolutionary process. Ultimately, it may be desirable to interface the supply chain model to GIS-based information that contains information on biomass resources and transportation networks.

Certainly, the model development activity will be responsive to and integrate the findings of the other COEE projects; in particular, the harvesting, forwarding, and processing data and model from Project 3 will be integrated into the supply chain model.

Complicating Issues

There are several issues that add complexity to the supply chain model. One complicating factor is associated with logging and log delivery (in general, biomass gathering and transport). In the Upper Peninsula there are restrictions placed on hauling heavy loads over many roads during the "spring breakup." Breakup is a period when heavy loads cannot be shipped on most public roads, and begins in early March and may last over 3 months. Full loads of logs can only be hauled on major roads designated as Class A highways during breakup. During this period, the only practical source of logs would be those stored at the Frontier facility, logs stored in remote log yards on either class A highways or with railroad access, or from logging jobs on class A highways. Existing practices in the U.P. generally suggest that hauls greater than 100 miles can be made in a more cost effective manner via rail; for example, the Quinnesec pulp mill is 93 miles from a log storage facility accessed via a railroad spur in L'Anse.

Deliverable: Software-based form of the Supply Chain Model

Task 3: Catalog Policies

An important activity of the project is to ensure that the supply chain model adequately describes the effects of pertinent current laws, regulations, and policies (LRP).
Task 3 will focus on two sub-tasks: i) identification of LRP that directly impact the supply chain, and ii) development of a model that is responsive to these identified LRP. The first of these sub-tasks will of course require interaction with the other COEE projects, essentially utilizing the information collected and developed by them regarding critical laws, regulations, and policies.

Task 3 will identify, catalog, and characterize such LRP issues as: a) transportation issues (including the paving of logging roads and road restrictions), b) land use concerns, and c) governmental laws/regulations. We will only catalog policies that will be relevant to the feedstock supply chain model (including sensitivity analyses), as opposed to a comprehensive review of policies. MTU will focus on policies in the energy, environmental, and health & safety areas; MSU will focus on policies in the forestry area, and the economic and technological areas. Based on these LRPs, the simulation model will be updated as required.

Deliverable: A listing of the laws, regulations, and policies that directly affect the supply chain and modify the model as needed

Task 4: Identify Performance Improvement Opportunities

The supply chain model developed in Tasks 1 and 2 will provide support for Frontier's strategic planning decisions related to harvesting, transportation, and storage. As has been noted, the model will undergo refinement throughout the project, and as indicated will be revised based on the laws, policies, and regulations identified in Task 3. We will also apply the model to identify key links of the supply chain where improved knowledge or changes in systems can have significant effects on delivered volumes and prices of feedstocks. This analysis can proceed in a number of ways.

First, we can identify key capacity limits (or bottlenecks) in the system, and then conduct a rapid sensitivity analysis to determine the marginal benefits (e.g., reduced costs, increased feedstock volumes, improved system responsiveness) of increasing capacity in different parts of the system. Based on this rapid assessment of marginal benefits, we could then conduct a more detailed, structured sensitivity analysis to more accurately determine the effects of adding various levels of capacity to the system.

Second, sensitivity analysis could also be conducted to determine the effects of changing components or processes within the current system. For example, if new loading equipment or procedures are employed (perhaps identified through COEE Project #3), the overall impacts on the supply chain could be evaluated by the model. There may be a significant overall impact if loading time is a limiting factor; however, the impact may be minimal if hauling capacity or some other factor is acting as a bottleneck in the supply chain.

Finally, scenario analysis and some sensitivity analysis will be conducted to evaluate the benefits of improving data or reducing uncertainty in the model. Depending on the final form of the model, these benefits could be evaluated either through sensitivity analysis of the key uncertain parameters (if single-value estimates are used in the model), or through adjustments to the parameter uncertainty ranges (if probability distributions are used in the model to characterize key uncertainties).

Deliverable: Recommendations for improving system performance

Task 5: Integration

This task is focused on insuring effective information flow among the four MTU/MSU COEE projects. For the purposes of Project 1, we are most concerned about the efficient transfer of information to guide the development of the supply chain model – the model conceived in Task 1, formalized in Task 2, tuned and revised by Task 3, and enhanced and exercised in Task 4 requires extensive information from Projects 2 and 3 to allow it to be an adequate quantitative representation of the overall system. And, of course, it is expected that the proposed project may provide considerable guidance to Projects 2, 3, and 4 on opportunities for improvement, additional information requirements, and outreach.

Deliverable: Effective integration activities to receive and disseminate information/knowledge

Allocation of Responsibilities

The overall project will be led by David Watkins (MTU). The project co-leader will be Chris Peterson (MSU). The multi-university team will have teleconferences at least every month and will meet periodically in-person to coordinate their efforts. The table below outlines the various characteristics associated with the proposed project and the individuals that will be responsible for the characteristic.

Characteristic	Responsible Party
Transportation Systems	Graman
Forest Data	Pickens
Cost Dimension of Model	Johnson
Timing Dimension of Model	Sutherland
Gathering Processes	Pickens
Loading & Storage Issues	Pickens

Characteristic	Responsible Party
System Analysis/Optimization	Watkins
Supply Chain Governance	Peterson, Derderian, Knudson
Sensitivity/Scenario Analysis	Watkins, Peterson
Laws, Regulations, & Policies	Solomon, Derderian, Knudson
Process Optimization	Frendewey
Interface/Integration	Johnson, Sutherland, Peterson

Project Timeline, Milestones, and Deliverables

Project Timeline

Task	May 09			Aug 09			Nov 09			Feb 19			May 10			Aug 10			Nov 10			Feb 10		
Construct Conceptual Supply Chain Model	■	■	■	■	■																			
Build/Refine/Implement the Supply Chain Model				■	■	■	■	■	■															
Catalog Policies	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Identify Performance Improvement Opportunities						■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Integration	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Documentation																			■	■	■	■	■	■

Deliverables	Delivery Date
Quarterly written progress updates	7/31, 10/31, 1/31, …
Written annual reports	4/30 annually
Supply Chain Model in Conceptual Form	8/30/09
Software-based form of the Supply Chain Model	10/31/09
Comprehensive list of the policies, regulations, and laws that may affect the supply chain	1/31/10
Summary of simulation model applications & recommendations for improving system performance	10/31/10

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Appendix B: Detailed Literature Summary

Introduction

The literature review examined research to date on producing biofuels from lignocellulosic biomass and identified the gaps where new research can focus. The review was organized into six categories. In each category, a series of critical points were examined. The six categories included the investigation of existing biomass supply chains, different types and forms of feedstock for the supply chains, key drivers of the supply chain, policy related constraints, mathematical models that have been developed for supply chains, and infrastructure requirements for an expended fuel ethanol industry. Summaries of the corresponding literature are provided in the following sections.

Existing supply chain systems for ethanol

This section reviews three existing supply chain systems available for ethanol. The first existing system is the National Biofuels Plan created by the Biomass Research and Development Board (BRDB) that developed a plan to reach government biofuel goals. The second study discussed involves a set of research studies based on the uniform-format feedstock supply system produced by the Idaho National Laboratory. The third study discussed was completed by Sandia National Laboratories, which performed a feasibility analysis for large scale production of biofuels.

National Biofuels Plan (hereafter referred to as 'plan')

This Biomass Research and Development Board (2008) developed a plan that discusses specific government legislation affecting the amount of biofuels required to be in use over the next few years--36 billion gallons per year (BGY) of biofuels by 2022. In order to accomplish this goal, a group called the BRDB was established. The BRDB outlined its plan of action in the study and discussed the required steps needed to reach the government goals. The =areas of focus for the BRDB are (1) sustainability, (2) feedstock production, (3) feedstock logistics, (4) conversion science and technology, (5) distribution infrastructure, (6) blending, and (7) environment, health, and safety.

Sustainability

The first area of action outlined by the Biomass R&D Board is to evaluate the sustainability of biofuels production and use. The plan must try to enhance economic and environmental benefits of biofuels through a successful implementation of an efficient feedstock supply chain. The board suggested to do this by reducing greenhouse gases from the different feedstocks, requiring biofuel production to not adversely impact the environment, focusing on developing cellulosic and other feedstocks that promote sustainability, and stipulating that the EPA assess and report to Congress on environmental impacts.

Feedstock Production

The second action area outlined in the plan is to review feedstock production. The plan outlined different generations of feedstock production. The first generation is ethanol and biodiesel made from corn and soybeans. The second is using residues and "left-overs" from crops and forests as feedstock for the process. The third is using R&D to develop specific types of energy crops that have high yields for biofuels. The board is reviewing factors such as a long-term integrated feedstock research plan, information and research into new energy crops, and the promotion of knowledge sharing between select government groups and agencies involved.

Feedstock Logistics

The third action area of the plan is feedstock logistics which can count for as much as 20% of the cost of finished ethanol. However, Hess et al. (2007) reported that transportation and handling compose nearly 30% of annual cost. Among the areas of focus inside this plan that relate to the Center of Energy Excellence project are storage facilities, preprocessing/grinding equipment, and transportation of feedstock. The board will focus on collaborating with the private sector on the development and deployment of logistics systems.

Conversion Science and Technology

The fourth action area is conversion science and technology in which the need to develop a more economically viable conversion process in order for biofuels to compete in the marketplace. The board is establishing groups to investigate the different conversion processes that will lead to cost-effective and commercially viable options.

Distribution Infrastructure

The fifth area of action for the plan is the distribution infrastructure, which focuses on the need for transporting biofuels, mainly from the Midwest, to areas on the east and west coasts. If this is going to be done via pipeline, the board suggests that research is needed to know the effects of ethanol on pipeline components (e.g. gasket and sealing materials), as well as the cost.

Blending

The sixth area of action for the plan is blending, in which the issue of increasing the acceptable level of blended ethanol in gasoline is addressed. The board stated that research on the effects of ethanol on air quality, automobile design and operation, and pipeline components is needed before increased blending can occur.

Environment, Health, and Safety

The seventh action area of the plan includes environment, health, and safety issues, in which the board stated that it will inventory related Federal government activities, as well as review and summarize related potential issues that may arise from the life-cycle of biofuel. The action plan ends by stating that the critical near term areas of action for biofuel success are feedstock production and logistics, conversion, and distribution and end use.

Idaho National Laboratory (INL)

Hess et al. (2009) performed a research study that identifies the need for a uniform-format, commodity driven supply system for biomass. This is to meet the goals of displacing 30% of the

United States' gasoline consumption in 2004 with biofuels by 2030. In order to do this economically, the feedstock supply system cannot account for more than 25% of the total cost of biofuel production. This report introduced two types of supply systems:

- Conventional bale feedstock supply system, representing current practice, and
- Uniform-format supply system, moving preprocessing to early stages of the system so that the biomass is a commodity.

In an earlier study, Hess et al. (2007) discussed the pioneer feedstock supply system using cellulosic biomass. The authors recommended that following development of the pioneer feedstock supply system, an advanced feedstock supply system would be targeted. In order to economically produce ethanol from biomass at a national level, different conversion processes may be required for ethanol at the biorefinery: biochemical and thermochemical conversion. These conversion processes and the current feedstock supply system were described.

Feedstock Supply System

A challenge in a feedstock supply system highlighted in the research by Hess et al. (2007) is that each supply system tends to be unique for each biorefinery, based on factors like location, size, and harvesting procedures. The costs that make up the minimum cost for ethanol can be broken into feedstock costs and conversion costs. Grower payment, efficiency/capacity, and quality are all aspects of feedstock costs. The research stated that the two main challenges for the feedstock supply system are:

- Improving feedstock logistics mainly though efficiency and capacity operations; and
- Developing a uniform commodity-scale feedstock supply system that can use diverse cellulosic feedstock with standardized supply system infrastructures and biorefinery conversion processes.

This research introduces a pioneer feedstock supply system that can make the supply chain more economically viable at the national level.

Pioneer Supply System

Hess et al. (2007) discussed the pioneer supply system using wheat straw as an example, beginning with production where the largest variable is due to the different demands for a variety of products that compete with the amount of feedstock available for energy production. Common practices for harvesting and collection are described. Storage of the biomass feedstock variables would include shrinkage and material degradation, and preprocessing would occur to enable transportation and handling in a similar fashion by all of the equipment involved. After the pioneer supply system was fully described, an advanced feedstock supply system was introduced.

Advanced Feedstock Supply System

The advanced feedstock supply system described by Hess et al. (2007) assumed that technological advancement will occur in the harvesting and collection processes. This will improve the efficiency, allowing for increased production and overall reduction of supply system costs. More research is in progress to identify losses that occur during storage so that the losses can be prevented in the advanced model. Advances in preprocessing equipment will allow transportation and handling problems to be minimized and enhance product uniformity. The study reports that transporting and material handling account for nearly 30% of the operating cost for a feedstock assembly system. Evaluating new methods can possibly eliminate the need for certain types of equipment used, thus resulting in lower costs.

INL (2006) reviewed a previous study that described a biomass feedstock system for wheat and barley straw. Some critical success factors identified for the feedstock model include:

- Ability to contract straw from a specified distance,
- Capability to field grind straw to customer's specifications,
- Capability to transport ground straw to meet demand, and
- Ability to design a transfer facility that can accommodate inflow of material and refinery demand.

Building on this previous study, the aspects of the INL (2006) study included harvesting, transporting and handling, inventory management, and quality assurance. Some areas of concern were highlighted by INL were the following:

- Cost of straw will increase as the demand increases substantially after the plant is operational,
- Logistics of moving the straw are very complicated,
- Storing the straw may be subject to a variety of fire codes,
- Unloading the truck and transferring the feedstock into and out of storage may not have a practical design, and
- Field fueling issues may arise so equipment might need day tanks that they can be fueled once per day at each site.

Sandia National Laboratories

A joint biofuels system analysis project, "90-Billion Gallon Biofuel Deployment Study", was conducted by Sandia National Laboratories (SNL) and General Motors' Research and Development Center between March and November 2008 (SNL, 2009; West et al., 2008). The project assessed the feasibility, implications, limitations, and enablers of large-scale production of biofuels in the United States. A 'Seed to Station' system dynamics model, Biofuels Deployment Model (BDM), was developed to explore the feasibility of producing 90 billion gallons of biofuels in US. The inputs of the model were derived from previous research (References?) and imported into the model. The inputs were categorized into four major groups, including conversion yield, capital investment/annual capacity per cellulosic plant, energy prices, and feedstock yield improvements.

Sensitivity analyses were conducted to identify the most influential factors that impact the feasibility, cost-competitiveness, and greenhouse gas impact of large-scale ethanol production. Three major matrices were generated: the total volume of ethanol production by 2030; the difference of accumulated cost between the ethanol produced over the life of the simulation and the displaced gasoline; and the difference between the GHG emissions associated with ethanol production over the life of the simulation and those associated with the gasoline that it replaced.

Several steps were involved to perform the sensitivity analyses: importance screening, interaction screening, and fine-tuning of the last step.

A reference/base case was set as the baseline in the sensitivity analyses. A series of assumptions were made in the reference case, such as conversion yield is 90 gallons/ dry ton, and short rotation woody crops (SRWC) are available for cellulosic ethanol production.. The sensitivity analysis found that, for the first metric of ethanol production volume, conversion yield and the availability of SRWC play an important role in achieving the goal. The examination of the combined influence of these two most important factors on ethanol production demonstrated that the goal of producing 90 billion gallons of ethanol per year by 2030 in the U.S. is feasible over the range of the conversion yields from 74 gallons/dry ton to 115 gallons/dry ton. When SRWC and/or energy crops are not available, however, the goal cannot be achieved, even at the highest conversion yield. For the second metric of cost-competitiveness of ethanol relative to gasoline, energy prices were demonstrated as the most influential parameter. It was also identified that the price of crude oil has the greatest influence on the price of energy. However, the competitiveness of price analysis is only valid when the price of crude oil is over $90/barrel.

Further examination shows that the capital cost, conversion yield, and feedstock cost also impact significantly the cost-competitiveness of ethanol with gasoline. For the third metric of GHG gas emission savings relative to gasoline, it was identified that the conversion yield and the boiler efficiency have the largest influence. An increase in the conversion yield of 10 gallons/dry ton (about 11%) would result in only about a 3% decrease in GHG gas emissions, while a 6% improvement in the boiler efficiency (which reduces the amount of energy generation needed) results in a similar reduction in GHG gas emissions.

Different feedstock types involved in supply chains

This section investigates the use of different feedstocks for biomass supply chains, such as agricultural residues, woodchips, forest residues, and energy crops. Searcy et al. (2007) examined two types of biomass: woodchips and agriculture residues, including stover and straw. Aden et al. (2002) developed a process design for producing ethanol using corn stover and conducted related cost estimation analysis. Blackwelder and Wilkerson (2008) highlighted the different aspects and associated supply costs (harvesting, handling, transporting, and preprocessing) for using different types of feedstocks including slash, forest thinnings, and commercial energy wood as biomass.

Slash

Blackwelder and Wilkerson (2008) described slash as the leftover tree tops and limbs from commercial harvesting, stating that 20-30% of the total volume of woody biomass is leftover as slash when harvested. Through model simulation and estimates, the predicted cost of supplying one bone dry ton (bdt) to the plant is $20.50 per bdt. The assumed transportation procedure for this process is to place the slash into a chipper with a loader, with the chipped slash loaded into a truck trailer. The trailer is then brought to the plant gate and unloaded so the conversion process can begin. This scenario does not require an incremental cost of piling the slash because that process is a byproduct of commercial harvesting.

Forest Thinning

Forest thinning, which involves the removal of certain trees that are small or undesirable for commercial harvesting, was also analyzed by Blackwelder and Wilkerson (2008) for supply costs. The projected cost for the plant using forest thinning was $51.85 per bdt. The assumed procedure for moving the woody biomass after harvesting is to move the logs with a forwarder, and then a loader is used to load the logs into a chipper which puts the chips directly into a truck bed. Next, the wood chips are transported to the plant gate and unloaded so the conversion process can begin.

Energy Crops

The third option analyzed by Blackwelder and Wilkerson (2008) was plantation energy crops that are grown specifically for high potential biofuel yield and quick growth. The supply cost associated with this method was found to be $30.52-$34.63 per bdt. The transportation procedures were very similar to the ones outlined for forest thinning.

Stokes (1992) identified countries using forest residue and small trees as energy and described relative harvesting technologies at that time. Countries identified were Denmark, Finland, Norway, Sweden, United Kingdom, Italy, Switzerland, New Zealand, Canada and United States. Harvesting system databases and a transportation database were built for this activity. It was concluded that to increase the use of forest residues and small tree for energy production, the fossil fuel price and the political decisions have significant impacts.

Forest residues

Harvesting systems for forest residues differ depending on where the forest residuals were concentrated. For residues in cutover areas, stand mobile chippers were the most popularly used because the residues had characteristics of being widely spread, small in size, and non-uniform in shape, which make them difficult to compact. For residues that were more concentrated (e.g., on roadsides), drum chippers and tub grinders were commonly used for size reduction.

Small trees

Small trees were described as much easier to harvest compared to forest residues. Small trees can be harvested during thinning, prior to harvests of larger trees for conventional harvest products (pre-harvests), or after harvesting for conventional harvest products (post-harvests). Pre-harvestings were more efficient than the other two and harvested more materials too. The least expensive harvesting technologies involved mechanical felling and bunching, followed by skidding of whole trees and chipping at roadside. Stand-mobile chippers were commonly used in Denmark and the United Kingdom for smaller harvest volumes. In Sweden, drum delimber/debarkers were employed, called the tree-section method, to separate high value pulp chip from low value fuel products.

Mitchell (2005) reviewed two types of integrated biomass harvest systems, one-pass and two-pass harvesting. The one-pass harvesting was defined as the felling and skidding of energywood at the same time when the conventional roundwood products are removed. The two-pass harvesting method involves two operations. Energywood is felled, skidded and chipped first, and merchantable roundwood products are harvested afterwards. The comparison of the two methods showed that the one-pass method is more efficient. Mitchell (2005) also presented the impact of different production methods. Slash and stems, which are longer portions of forest residues, are easy to grapple; however, shorter limbs and tops are not easy to carry with grapplers. Mitchell

(2005) also showed the productivity and cost of using different combination machines, depending on the production type. The study also presents a new technology of bundling and a new type of machine caller bundler. Mitchell (2005) discussed the low transporting efficiency due to the physical characters of forest residues. Lastly, the value of the forest residues was estimated and compared with traditional fuels.

Key drivers of the supply chain

This section discusses research involved in areas that are key drivers of the supply chain. These areas include information management, transportation, and supply chain enablers.

Information Management

Cachon and Fisher (2000) investigated, through mathematical equations, the cost effects that full information sharing versus a traditional, non-information sharing policy has on a supply chain.

The purpose of their investigation was to address the general belief in industry that capturing real-time demand information is important for improving supply chain performance. The study defined traditional information sharing as when the supplier only observes the orders, and full information sharing as when the supplier has instant access to inventory data. The investigation addressed the question of how information technology improves supply chain performance, not necessarily if it does. This can be related to woody biomass systems in which the logger, the supplier, would have orders from the ethanol plant. The full information sharing would provide the logger full access to all the inventory data for the ethanol plant.

The equations used to model the different scenarios were discussed in detail, as well as the results. The mean cost benefit that a full information policy has over the traditional policy on the supply chain was 2.2% in supply chain cost savings. The study concluded from the results that there are savings from lead time and batch size reductions, which are both caused by the implementation of information technology. However, information sharing could have a much larger effect on the supply chain. For instance, if the demand of the product were unknown, full information could be used to detect shifts in the demand process. The research assumed demand was known, retailers were identical, there was one source of inventory, no constraints exist on capacity, firms could not create conflict between other supply chain firms based on incentives, and that the firms were rational in ordering.

Transportation

Mahmudi and Flynn (2006) observed the cost savings between a single transportation system for straw or wood biomass via truck or rail versus a transshipment method that combines the two. The study stated, as is widely accepted, that rail transportation has higher fixed cost than trucks. This is because there are both supplier and carrier components to consider for rail transportation. However, the variable costs are lower for rail than trucks. This means if a transshipment method is to be used for transporting biomass to a facility, the distance has to be such that the savings in variable costs from the second mode of transportation must be able to offset the increase in fixed costs for the system.

Mahmudi and Flynn (2006) also stated there is an optimum number of transshipment terminals that minimize shipping costs, as there are tradeoffs between fixed and variable costs as the number of terminals increases. The study found the optimal rate of biomass per terminal to be 100,000 dry tons of boreal forest harvest residue (FHR) wood chips. The study also highlighted that the minimum economic rail shipping distance for boreal FHR wood chips is 145 km (about 90 miles). In the study, power plants in Canada that were an economic size (130 MW) and were economically capable of using transshipment were analyzed. Transshipment from truck to rail was indeed found to be an economically viable option if rail lines existed that led to the plant.

Supply chain enablers

Edward (2008) discussed the four supply chain enablers: organizational infrastructure, technology, strategic alliances, and human resources management. A group of professionals were interviewed to rank the four enablers and the associated attributes of each enabler. The results of the survey show that organizational infrastructure and its associated attributes topped the list for being the most important enabler of successful supply chain implementation.

The most significant attribute of organizational infrastructure was a business strategy that aligns business units toward the same goal. The second most important attribute was considered to be the need to have a sound process-management methodology in place. A top-management process flow chart was presented to illustrate how these two important attributes are implemented in a company. Next, the technology enabler was analyzed in two parts: IT and manufacturing and material-management technology. For IT, a list of eight categories was used to define the scope of IT in supply chain. The ready availability of coordinated internal data on operations, marketing, and logistics was identified as the most important attribute. For manufacturing and material-management technology, a list of four categories was used to define the scope of the physical technologies, with the design of products and physical processes for supply chain efficiencies topping the list of attributes. For strategic alliances, having expectations clearly stated, understood, and agreed to up front was more significant than other attributes. For human resources management, the most challenging enabling attribute is finding practitioners knowledgeable in supply chain management and finding facilitators to lead the implementation change process.

Policy related constraints

The following section will highlight different policies that can create constraints in a supply chain, including forest management policies, environmental policies, and other public policies.

Forest Policies

Cubbage and Newman (2006) describe the reformation of forest policy over time. They suggest that forest policy is developed through a mixture of implementing reasoned laws and decisions to resolve identified fundamental issues, making small incremental changes to existing policies as time goes on, and making short-term incremental changes while implementing new policy based on social innovation.

International Forestry

Cubbage and Newman (2006) discuss how international forestry and trade has enhanced sustainable forest management. International agreements have been developed to clearly define seven agreed upon criteria for sustainable forest management. The seven criteria include "(1) conservation of biological diversity, (2) maintenance of the productive capacity of forest ecosystems, (3) maintenance of forest ecosystem health and vitality, (4) conservation and maintenance of soil and water resources, (5) maintenance of forest contribution to global carbon cycles, (6) maintenance and enhancement of long-term socio-economic benefits to meet the needs of societies, and (7) development of the legal, institutional, and economic framework for forest conservation and sustainable management (Cubbage and Newman, 2006, pg. 263)". Combined with international agreements, market based-incentives for producing green products have increased the use of sustainable practices.

"Green" Policies

Cubbage and Newman (2006) also describe how intense public pressure to ensure sustainable forest practices is causing a corporate "green" revolution. There are two major U.S. certification programs, the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI). The research highlights that there are no federal or state forests that are certified by these programs. It begins to discuss the expansions being made at the federal and state level on the topic of forests.

Federal and State Policies

Cubbage and Newman (2006) highlight some of the legislation that has been passed over the past decades, such as the initiative to reduce unneeded paperwork for thinning and harvesting to take place. The topic of different state forest policies was addressed and the idea of how corporations have actively pursued environmental agendas on their own that exceed government regulations was highlighted. In the future, forest policy developers have the challenge of meeting widely accepted economic, social, and environmental goals of sustainable development without decreasing the ability of forests to provide for the needs of people.

Environmental Policy

Gallagher et al. (2004) proposed three different possible scenarios for the future of the fuel industry:

- Implementing a renewable fuel standard (RFS),
- Imposing a national ban on the additive MTBE and replace with ETBE, and
- Removing oxygen standards for reformulated fuel.

These scenarios were modeled through simulation and the effects of each change were compared against a baseline scenario which uses existing EPA policies. The research provided an introduction to the three natural resources used in fuel processing: petroleum, natural gas, and biomass. It also investigated the existing emission standards and expected environmental impacts of each formulation of fuel.

Model results showed that implementing a renewable fuel standards would lead to a growth in the additives market by 56%, with 20% growth in refined gasoline output. The ethanol industry also grew in this simulation. Under the scenario where there is a ban on MTBE, gasoline prices were predicted to rise, and ethanol demand was projected to rise moderately as well. Long-run welfare gains for corn-producers and processors rose slightly based on the slight increase in ethanol demand. In the third scenario, removing oxygen standards while still banning MTBE, efficiency was improved, while summer reformulated gasoline prices returned to baseline levels. In all three scenarios, production of gasoline additives (including ethanol) would continue to grow. In the simulations, the economic costs associated with this growth were more than offset by the environmental improvement. The authors concluded that this finding points to the potential expansion of biofuels in the future.

Public Policy

Sissine (2007) summarized the major provisions included in the Energy Independence and Security Act of 2007 and presented the legislative actions under each of the titles in the law. Three key provisions were included in the law: the Corporate Average Fuel Economy (CAFE) Standards, the Renewable Fuel Standard (RFS), and the Appliance and Lighting Efficiency (ALF) Standards (Sissine, 2007). The CAFE provision involves setting of an average fuel economy goal at 35miles per gallon for the combined fleet of light trucks and cars by 2020. The RFS law sets standards for the availability of renewable fuels--by 2020, 36 billion gallons per year of biofuels will be available, increasing from 9.0 billion gallongs per year in 2008. In particular, 21 billion out of the 36 billion gallons per year are expected to come from cellulosic ethanol and other advanced biofuels. Like CAFE, the ALF Standards focus on energy conservation and set requirements for residential and commercial appliance equipment.

Mathematical models for biomass feedstock supply chains

Several mathematical models of biomass feedstock supply chains appearing in the literature were reviewed. These included both simulation and optimization models, as well as cost and multi-objective decision models. Some models focused on specific segments of the supply chain (e.g., transportation, processing methods), while others integrated the full supply chain.

Integrated Supply Chain Models

De Mol et al. (1997) developed both simulation and optimization models of the supply chain and discussed the differences in the approaches. In both approaches, the network structure was defined as having nodes, which correspond to source locations, collection sites, transshipment sites, pre-treatment sites, and the energy plant itself; and arcs connecting the nodes via modes of transportation like road, water, or rail. The study also discussed losses during storage that can be modeled as positive, like moisture losses, or negative like dry matter losses. All information was defined in a database linked to both the simulation and optimization models. Different combinations of the network structures were used to find the optimal design through combined use of simulation and optimization.

In the simulation model used by De Mol et al. (1997), the network structure was fixed, and different parameters like transportation costs, storage losses, and seasonal supply or demand were inputs. The biomass flows for certain time periods were simulated and expected costs and variances were calculated from the results. The simulation model followed a "pull" model where each lot orders stock from the preceding lot to maintain at least the minimum safety inventory level to provide for the lot that is next in line. Results of the simulation model included input and output of biomass, costs for transportation and handling, energy consumption for transportation and handling, and number of transports needed to supply the energy plant.

The optimization model by De Mol et al. (1997) combined different types of biomass, different network structures, and pre-treatment options to develop the optimal network structure. While the simulation model took losses into account for the biomass, the optimization model did not because it only computed annual flows. It was also hard to include time-dependent effects in the optimization model like the simulation model could. The authors also stated that optimization of logistics structures was difficult with the simulation model.

The general conclusions from the modeling by De Mol et al. (1997) are as follow:

- The simulation model showed that the truck is cheapest for short distances, chipping should be done at the plant, and that costs and energy consumption from logistics is a major part of the cost for biomass fuel. (The optimization model's results were similar.)
- The optimization model was recommended for selecting what type of network structure to use when there is a lot of variation, and that the simulation model is recommended when the network structure is fixed or has a small number of possible variations in it.
- Simulation gives more detailed results on biomass logistics, and can be further detailed to make operational decisions from it. (Detailed operational decisions often cannot be made from deterministic optimization models because of the "perfect knowledge" they imply.)

Gronalt and Rauch (2007) discussed the use of simulation modeling to guide the design of a forest fuel network for a region. In the model products are delivered the multiple energy plants with the use of storage terminals. Different scenarios of how many terminals and where each one is located are simulated to search for an optimal network. The point at which the lumber gets chipped--at a central location or on-site is also considered. The authors noted that since harvesting for bioenergy has to compete with harvesting of logs for pulp, paper, and wood manufacturing industries, the first step in designing a regional forest fuel supply network is to identify the target forests and determine how much wood could be used as forest fuel.

In a case study of Austria, Gronalt and Rauch (2007) stated that only 54% of the areas where mechanized harvesting systems could reach could be utilized economically for forest fuels. This was due to lumber claims on certain forests, as well as the inability to harvest specific areas. They proposed that the next step in planning would be to calculate expected demand of forest fuel for the specific region. Once demand is known, the costs associated with the network, including transportation to terminal, terminal costs, and transportation to the plants, would be necessary to design an optimal supply network. Based on the costs as well as the supply and demand, the network could then be designed to find the best spatial allocation for the terminals that minimizes both transportation and chipping costs associated with the network. The study proposed this stepwise heuristic approach as a way to solve forest fuel supply network design problems.

In contrast to this heuristic approach, Gunnarsson et al. (2004) proposed a solution to the forest fuel supply chain network problem through a large mixed integer linear programming model. In their model, the main product used was forest fuel, which was mainly forest residues in harvest areas or byproducts from sawmills. The destination for the forest fuel was a heat plant. This study raised the issues of forests that are owned by the heat plant in which the product would not have to be purchased as opposed to contracted forests in which it would have to be purchased.

The optimization model developed by Gunnarsson et al. (2004) incorporated the issues associated with chipping forest residues in the forest which is more expensive than doing it at a terminal. It is cheaper to transport chipped wood and it could be delivered directly to the heating plants. Non-chipped residues can be stored at a variety of locations, but it is more expensive to transport them. The model also considered variable locations and numbers of terminals involved in the network. Based on calculations of heat demand by the plant, the model determined how much wood to acquire and deliver from each terminal. The model also determined whether or not the wood should be chipped in the forest or at specific terminal locations for transportation purposes. In analyzing scenarios for Sweden, Gunnarsson et al. (2004) showed how their model could be used to support tactical planning and strategic analysis for the supply of forest fuel to multiple heating plants.

Decision Models involving specific drivers of the supply chain

Kumar et al. (2006) evaluated different collection and transportation systems for biomass feedstock systems using a multi-objective decision model called preference ranking organization method for enrichment and evaluations (PROMETHEE). The model developed by Kumar et al. (2006) integrated economic, social, environmental, and technical factors in order to rank alternatives for collection and transportation methods of biomass feedstock. The three collection systems analyzed using PROMETHEE model were baling, loafing, and chopping and ensiling. The collection systems were analyzed using the following criteria: delivery costs, quality of material, emissions, energy consumed, and the maturity of technology. After the analysis was performed, loafing was shown to be the best alternative for collection.

For biomass transportation systems, truck, rail, and pipeline were analyzed. The evaluation criteria included cost, emissions, traffic congestion caused, and maturity of technology. Based on the analysis, rail was shown to be the best alternative for the specific criteria.

Searcy et al. (2007) developed a cost model to estimate transportation costs for two types of biomass and two types of energy production systems, with biomass transported using different modes and a range of transport distances. The two types of biomass examined were woodchips and agriculture residues, including stover and straw. The two types of energy were electricity power and ethanol. Transportation modes for biomass involved truck for short distance transportation, and any combination of truck plus rail, truck plus ship, and truck plus pipelines for long distance transportation. Transportation modes for ethanol involved truck and pipeline. The transportation cost model comprised two components: Distance Fixed Costs (DFC) and Distance Variable Costs (DVC). DFC included loading and unloading costs which are independent of distance traveled, while DVC depends on the travel distance. The transportation cost models were built by Searcy et al. (2007) based on previous research. Transportation cost factors for each case were generated from the models and relative transportation costs were compared between each case. The results showed that truck, rail, and ship have a negligible economy of scale, while pipeline transport has a greater one. Rail and ship were not found to be economical transportation modes unless longer distances were traveled due to the high costs incurred by transshipment. Pipeline transport did not show an advantage over truck until a higher production rate of ethanol is met per day. In general, it was found that it is better to build a conversion plant closer to the biomass than to a population center or a transmission grid.

Another cost model was developed by Aden et al. (2002) to estimate ethanol selling price, based on a series of process design and plant design assumptions. To evaluate the effect of plant size, a tradeoff was examined between the savings resulting from increasing plant size/economies of scale and the increased transportation cost due to increased collect distance of biomass. A formula was presented to illustrate the relationship between plant size and area to collect biomass. The results of the formula also showed the impact of the assumed availability of harvesting acres and the yield of corn stover per acre per year.

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Appendix C: Value of Information Sharing

The Value of Information in the Frontier Renewable Resources Supply Chain

The lack of adequate information sharing throughout a supply chain results in uncertainty that has been shown to be responsible for unmet demand, excessive inventory levels, long lead time, incorrect order quantities, delays in delivery, and increasing overall supply-chain risk. The purpose of this paper is to discuss the activities that influence successful supply-chain information sharing and identify those that are particularly relevant to the Frontier biomass supply chain.

Role of Information in a Supply Chain

Although the literature on the value of information in a supply chain is extensive, we limit our remarks to only those topics that we believe have applicability to Frontier Renewable Resources (Frontier). Information sharing is only an enabler for better coordination and planning in the supply chain [1]. Information serves to connect the various stages of the supply chain, allowing the landowners, loggers, log haulers, rail and facility yard operators to coordinate activities and minimize total supply-chain costs. Information is also crucial to daily operations including production and inventory management.

Information can enable Frontier and its suppliers to become more efficient and more responsive. Accurate information can help a firm improve efficiency by decreasing inventory and transportation costs. In addition to reducing costs, information sharing quickens and smoothes the flow of goods through the supply chain, producing an order of magnitude greater improvement in costs [2]. It can also improve responsiveness by doing a better job of matching supply from loggers to demand at the facility yard and reducing the risk of delayed deliveries to the facility yard.

Components of Information Decisions – Value of Shared Information

Supply chain coordination is primarily based on shared information. Coordination requires each stage in the supply chain to share appropriate information with other stages. Information sharing is critical to a successful supply chain operation. Communication of information should be a common view that provides visibility to all stages of the supply chain. In order to be useful, information must also be accurate, accessible and appropriate [3].

Centralized, up-to-date information should be available in a timely manner. Timeliness and accuracy of shared information are key to improved supply chain performance [1, 2].The reasons for collecting the data should be clear. It is important to collect the right kind of data and avoid meaningless data. While information is always beneficial, one must determine when it is most beneficial and when it is only marginally useful [4]. As more information is shared across the supply chain, the complexity and cost of the required infrastructure and accompanying analysis grows exponentially. The marginal value of information diminishes as more information is available. It is important to determine the minimum amount of information needed to accomplish the task [3]. When the supply chain breaks down, the weak links in the information-sharing process are usually clear.

Processes should be identified as part of the push or pull phase of the supply chain, i.e., the point at which demand information drives the decision-making process. The woody biomass industry has typically been driven by a push model in which the main decisions are related to when and where to cut the trees, followed by pull decisions about transportation to and storage at the facility yard [5].

The Frontier supply chain appears to have both push and pull characteristics. The push-pull boundary is the log storage yards. Loggers and log haulers push harvested logs to the storage yards based on estimates of facility yard demand to insure that there is sufficient inventory for Frontier and other buyers. Push systems typically require elaborate planning systems including contracts, agreements, and ownership and possession (storage) issues. Frontier meets their demand for logs by pulling form the storage yards and delivering to the facility yard. Pull systems require that information on actual shipments to the facility yard be sent rapidly through the entire chain so that the supply of logs continues without interruption. Information drives the decision process, and communicating the decision to the action players results in better control of delivery and inventory.

Frontier must determine how and to what extent they will rely on forecasts to make decisions at the strategic level. Strategic supply chain planning with respect to production, distribution, and delivery requires investments in information technology and planning systems [5]. The demand at the facility yard will be more or less constant. It is the uncertainty of supply of logs to the storage yards that is of greater concern. Suppliers and buyer should exchange knowledge and jointly develop forecasts and replenishment plans. An aggregate plan helps determine the inventory level needed at the storage yards to meet facility yard demand. This activity would also take into account the impact of spring breakup. This plan must be shared across the entire supply chain because it affects both the demand on suppliers and supply at the plant and results in the controlled accumulation of logs in the storage yards. Inventory levels are the most common data shared, as inventory and communication are economic substitutes [1]. The sharing of information reduces uncertainty thereby reducing variability and risk and is typically manifest in reduced lead time and/or less safety stock.

Major Supply Chain Processes

The emergence of supply chain management has broadened the scope of decision making. This broadened scope underscores the importance of addressing all supply-chain processes when making decisions. Processes in the supply chain can be grouped into three process categories:

Customer relationship management (CRM). Focus is on processes between the company and its customers.
Internal supply chain management (ISRM). Focus on processes entirely within the company.
Supplier relationship management (SRM). Focus on processes between the company and its suppliers [6].

A discussion of CRM is not included, as the scope of the Frontier project does not place particular emphasis on interaction between Frontier and its customers. ISRM at Frontier encompasses the management of the facility yard and log storage locations that are directly under its control. From an information sharing standpoint, SRM processes offer several opportunities to improve supply chain performance as it deals with enterprises beyond the direct control of Frontier, namely the loggers and/or log haulers.

Internal Supply Chain Management (ISRM)

The supply planning process in ISRM is of particular interest to this project from an information perspective. This process produces an optimal plan to meet the predicted demand at Frontier, including production and inventory capabilities. Given the size and complexity of the planning activity, there is often little alternative than to arrive at a feasible solution through information sharing. Setting optimal inventory policies requires information on holding costs and the cost of stocking out as well as information on availability at the storage yards and capacity at the facility yard [7].

Supplier relationship management (SRM)

SRM includes those processes that focus on the interaction between FRR and its logging and log hauling partners. This section focuses on the relevant SRM processes and the impact of information sharing on them. It is important to note that a wide range of transactional information must be recorded to execute operations even after the sourcing decisions have been made [7].

Sourcing Planning

One way to lessen the impact of supply chain disruptions is to decide on a portfolio of suppliers and allocate demand among the chosen suppliers. The allocation should be related to an economic delivery quantity for each source and its cost of supply. The low-cost supplier is given large, steady orders independent of demand, whereas the flexible supplier is given small orders that fluctuate with demand. The flexible supplier has small economic delivery quantities and is better able to adjust to the fluctuations. The combination of suppliers results in a better matching of supply and demand at lower cost than using one type of supplier. Given the high cost of developing multiple sources and resulting loss of economies of scale, it is best to do so for critical products of relatively high demand. Logs are such a product to Frontier. FRR uses more than one supplier to mitigate the risk of storms, breakdowns, no plan to cut, and worker absenteeism, as these eventualities can be lessened by pooling among the logger suppliers.Delays for a supply source can be mitigated by carrying inventory or developing a backup source that is more responsive.

The key sourcing objective for critical items is not low price, but assurance of availability. Woody biomass can be seen as a long lead time, critical material to FRR due in part to spring breakup. In this case, purchasing should work to improve coordination of production plans at both the buyer and supplier levels. The presence of a responsive, even if high-cost, alternate supply source can be very valuable for this critical item.

Visibility in the Procurement Process

One goal of the procurement process for direct materials is to support collaboration in the supply chain and match the supply of logs to facility yard requirements ensuring, at least for part of the year, that logs are less than 30 days old. The benefits of collaboration have been explored in the context of transporting logs to mills, including the identification of opportunities to optimizing backhauling operations [5]. The procurement process should thus be designed to make production plans and current levels of log inventory at the facility yard visible to the supplier. This *visibility* allows loggers and log haulers to schedule material delivery to match the needs of the facility yard. The available capacity at the storage yards should be made visible to FRR so that orders for material may be allocated to the appropriate logger to ensure on-time delivery. The procurement process should also have the ability to alert all members of the supply chain of potential mismatches between supply and demand.

Supply Chain Coordination

Information flow among members of the supply chain is one important aspect for coordination in the supply chain. A well-coordinated supply chain is not easy to achieve [1]. The information coordination capability of a supplier is harder to quantify than the buyer's own internal capabilities and it affects the ability of the firm to match supply with demand. Good information coordination also decreases the amplification of demand variation as orders move farther from the end customer. The phenomenon where orders to the suppliers tend to have larger variance than sales to the buyer (demand distortion), and the disproportion propagates upstream in an amplified form (variance amplification), is referred to as the "bullwhip effect." The farther up the supply chain an enterprise is, the greater the distortion of information it receives. Lack of complete or adequate information sharing often leads to a distortion of real demand at the plant. Distortion of demand information occurs when the buyer issues orders based on a frequently updated forecast for logs. As a result, the supplier loses sight of the true demand of the facility. Information distortion can arise when the buyer assesses the possibility of being placed on allocation by the supplier, leading to ordering quantities larger than true demand. Good information coordination also results in lower production, inventory, and transportation costs, while improving responsiveness to the customer. Good coordination results in better replenishment planning, thus decreasing both the inventory carried as well as failed/late deliveries due to the lack of availability [8].

Contracts and Risk Sharing

Information sharing in a supply chain faces several hurdles. The first and foremost is that of aligning incentives of different partners [1]. A supply contract specifies parameters governing the buyer-supplier relationship. In addition to making the terms of the buyer-supplier relationship explicit, contracts have significant impact on the behavior and performance of all stages in a supply chain. When designing a supply chain contract, FRR should be concerned about incentives in the contract that induce information distortion. Ideally, a contract should be structured to discourage information distortion in addition to increasing profits, increasing product availability, coordinating supply chain costs, increasing agent effort, and offering incentives to the supplier to improve performance. Most of the supply chain contracting literature assumes that the supplier must build enough capacity to satisfy any order allowed by the contract [9]. Manyshortcomings in supply chain performance occur because the buyer and supplier are two different entities, each trying to optimize their own profits.

Most supply chain interactions occur over long periods of time, with many opportunities to renegotiate or to interact with spot markets [10]. The supplier sharing in some of the buyer's demand uncertainty is illustrated with a *quantity flexibility contract* (also known as an *options contract*), in which the supplier allows the buyer to make limited changes to forecast quantities for future periods [1]. FRR will likely sign some of these – with an option to harvest any time over a three-to-five year period. FRR would specify only the range of quantities within which they will purchase, well before demand actually occurs. The logger does not need to plan production at the high end of the order range for each buyer. They can aggregate uncertainty across all buyers and build a lower level of surplus inventory than would be needed if inventory were disaggregated at each buyer. FRR can then order closer to the time when the material is needed, when demand is more visible and less uncertain. The aggregation of uncertainty results in less information distortion with a quantity flexibility contract.

A *quantity discount* approach decreases overall costs but leads to higher lot sizes and thus higher levels of inventory in the supply chain. Such an approach may be beneficial to FRR when they need to address building inventories in anticipation of spring breakup. However, a word of caution is in order. Quantity discounts can increase information distortion in the supply chain because such contracts increase order batching. Buyers order less frequently, and any demand variations are exaggerated when orders are placed. The supplier receives information less frequently and all variations are increased because insufficient detail is paid to information sharing.

Delivery and Receiving

Information technology capabilities can facilitate recording transactions between harvest and delivery to the FRR facility yard. Chain of custody information consists of chronological documentation of the source/history of the logs ultimately delivered to FRR. Transfer of possession/ownership would be accompanied by chain of custody information as it relates to logs harvested from certified woodlands.

Internet-based services can be used for more effective control and monitoring of the status of log haulers during the arrival and unloading process at the facility yard. The length of the waiting line depends on the distribution of arrivals and unloading capacity at the plant. When unloading capacity exceeds the arrival rate, the wait time is lessened. Peaks in the arrivals diminish the gains of increased unloading capacity. Unnecessary waiting time at the plant can be diminished by text messaging all concerned when problems exist during unloading and by displaying the length of the waiting line on an internet page that can be accessed by the log haulers [11].

Implementation and Change Management

While it is not the purpose of this paper to address issues involving the implementation of information sharing strategies, we believe it is appropriate to identify some of the work that has been done investigating the success factors that result in effective supply chains.

Building relationships has been pointed out as the key in managing supply chains, instead of investing in technologies [12]. The challenge in the FRR supply chain is to find inroads into the culture and thinking of loggers and log haulers that allow them to see enhanced information sharing as a benefit and not as a risk. Supply chain organizational infrastructure, including how change management programs are led and coordinated, is one of the most important enablers of successful supply chains[13]. Unique aspects of close business relationships between buyer and supplier of timber harvesting and transportation services are continuity, extensive exchange of information, joint development activities, and strong commitment to a continuing relationship [14].

Trust and cooperation become critical ingredients in a supply chain partnership [1]. Credibility is a key factor in exchange of information. At issue is whether or not the receiver should and will trust the veracity of the reported information [9]. Cooperation on the supplier base level will lead to better flow of information and a strengthening of norms and practices, both of which will increase trust between buyer and supplier [14].

If the supplier base is relatively small and the product provided is of strategic importance to the buyer, then a long-term relationship is more likely to emerge. This appears to be the situation at FRR. A long-term relationship between buyer and supplier gives each the opportunity to review the credibility of the other, reward truth telling, and provide the appropriate incentive for truthful information sharing [12]. Internet-based tools can be used to ease the trade between trading partners who know each other for longer periods [11].

We identify two additional articles on the topic of change management that may be of interest to the reader. One describes identifying deeply rooted beliefs and assumptions that put order in a person's world and drive behaviors that unwittingly keep the *status quo* intact [15]. Changing the mental structure that shapes the way they see the world (called frames) requires speaking to people's feelings – the psychological, emotional, and spiritual dimensions that are often ignored [16].

Summary

This report identifies and discusses information-related topics that are believed to be relevant and of significant concern in the FRR supply chain. The approach has been more descriptive rather than prescriptive since the supply chain is currently being modeled and specific issues are difficult to identify and address directly. The Appendix of this report presents relevant material on topics in Information Technologies (IT) for further reading.

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Appendix: Information Technologies

IT Sourcing Software

All processes within the supplier relationship management process are supported by IT software. A discussion of two major IT product areas within sourcing follows.

> *Source*. Sourcing software assists in the qualification of suppliers and helps in supplier selection, contract management, and supplier evaluation. Suppliers are evaluated along several key criteria, including lead time, reliability, quality, and price. This evaluation helps improve supplier performance and aids in supplier selection.
>
> *Supply collaboration*. Supply chain performance can be improved by collaborating on forecasts, production plans, and inventory levels. Software in this area should be able to facilitate collaboration to ensure a common plan across the supply chain [7].

Enabling Technologies

Information makes the supply chain visible to the manager. Information technology (IT) allows the manager to understand how and what technologies to use to gather, share, and analyze information for good decision making. Examples of information technologies [1] that can replace costly logistic flows with information include:

> INTERNET – can convey more information and offer more visibility than electronic data interchange. Communication among supply chain members is made easier because a standard infrastructure (World Wide Web) exists.
>
> ERP – a company-wide information system that provides transparent tracking and global visibility of information in real time. ERP improves the quality of decision making because information is transparent and seamless to upstream suppliers and downstream customers.
>
> RFID – an intelligent identification technology that allows information storage and communication between the item and the data base.
>
> GPS – the real-time locational aspect of sharing information

It is the use of these or other information technologies that can enable FRR to better manage the supply chain processes [6].

Risk Management in IT

Two major areas of risk have been identified in IT. First, the risk involved in installing a new IT system. This risk can be mitigated by implementing in an incremental fashion, running duplicate systems, and/or implementing only the level of complexity needed. Second is the greater the reliance on IT to support decision making and execute processes, the greater the risk that an IT problem can disrupt the firms operations. The biomass supply chain will probably be more concerned with the latter as on-time delivery is very dependent on timely information exchange [6].

General guidelines for making the supply chain IT decision

Develop an IT system that addresses the key success factors. An IT system should be selected based on its ability to give a company an advantage in the areas most crucial to the success of the business. Examples include the ability to set optimal inventories or maximize the utilization of production capacity.

Implement the IT system in incremental steps and measure value. Avoid the "one-big-step" approach of implementation of the IT system in a wide variety of processes at the same time. The impact of failure could cause production to come to a standstill. Start with demand planning and then move into supply planning.
Align the level of sophistication with the need for sophistication. Management must decide how much sophistication a company needs to achieve its goals. Too little sophistication may leave the company with a competitive weakness. Being too sophisticated can lead to a higher risk of possible entire system failure.
Use IT systems to support decision making, not to make decisions. While the IT systems can make several supply chain decisions, it should not make all the decisions. The amount of management effort spent on supply chain issues should not be reduced because a supply chain IT system has been adopted [6].

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Appendix D. Original Input/Output, Metrics for Supply Chain Drivers

Facilities (roadside landings and storage yards) inputs, decision variables, and outputs	

Inputs (Data)	• Location and network connectivity
	• Log availability:
	  o Supply (*i*, *j*, *t*) (tons), where *i* = species, *j* = certified (%), *t* = time period (day)
	• Average storage cost (fixed and variable)
	• Variable harvesting costs ($/ton)
	• Risks
	  o Weather, insects
	• Policies

Outputs	• Storage utilization (% capacity; tons)
	• Log market/supply allocation
	• Facility costs ($/day)
	• Storage costs ($/day)
	• Energy Consumption (MJ)
	  o Energy sources (electricity, gasoline, diesel, …)
	• Emissions (eq kg CO_2/ton)
	  o COx, NOx, SO_2, particulates, …
	• Residues (kg/ton)
	• Social benefits and costs

Decision Variables	• Storage capacity • Storage allocation
Inventory inputs, decision variables, and outputs	
Inputs (Data)	• Quantity at landing (ton) • Age at landing (days) • Moisture content (%) • Market price ($/ton) • Demand variance and planning uncertainties (real-time demand) • Supply/market variance and uncertainties • Seasonal factors • Risks (weather, insects) • Policies
Outputs	• Average inventory • Fill rate • Fraction of time stocked out

	• Residues • Age of logs
Decision Variables	• Number of days of supply • Storage inventory list
Transportation inputs, decision variables, and outputs	
Inputs (Data)	• Road/rail network information • Network capacity (trucks/day, rail cars/day) • Transportation availability (number of vehicles/rail cars) • Unit capacity (tons of logs/vehicle, tons/rail car) • Vehicle weight restrictions • Transportation cost for each mode ($/ton logs) o Multi-modal versus single mode transportation • Loading /unloading cost ($/ton) • Energy consumption rates (MJ/ton-km) • Emissions rates (kg/ton-km) • Risks (road conditions, weather) • Regulations and policies
Outputs	• Fraction transported by different modes • Routes selected • Lead-time (days) • Inbound/outbound costs ($) • Inbound/outbound shipment size (tons) • Energy consumption (MJ) • Vehicle emissions (kg pollution)
Decision Variables	• Mode choice • Routes
Information systems inputs and outputs	

Inputs (Data)	• Network communication
	    o Information flow among the loggers, truckers, storage yards, and mill
	• Inventory information
	    o Sharing demand /logs location and quantity /storage inventory /transportation data
	    o Road network and load restriction information
	    o Seasonal factors (e.g., spring breakup)
	    o Forecasting planning

	• Backhaul information
Outputs	• Cost for information infrastructure (fixed and variable) • Forecast horizon and forecast error • Variance from plan • Response time

Appendix E: Data Requirements Spreadsheet

Supply Chain Model Inputs	Inputs	Information Requests from Other Project Teams (Tentative Data Needs)	Used in Simulation Model?	Used in Optimization Model?
Harvesting Processing	Harvest areas	Total availability of hardwood pulp logs - Standing Crop		X
	Harvest areas	Total availability of hardwood pulp logs - Growth		X
	Harvest areas	Total availability of hardwood pulp logs - Historical Harvesting Patterns		X
	Harvest acreage - low cost	Clearcut-landowner cost to harvest & deliver to landing		X
	Harvest acreage - average cost	Unevent age harvesting-landowner cost to harvest & deliver to landing		X
	Harvest acreage - high cost	Rough ground harvesting-landowner cost to harvest & deliver to landing		X
	Market price	Average price per ton or cord of logs by		
	Seasonal factors	Length of spring breakup by county (historical trends)	X	
	Energy consumption rates and cost	MJ/ton-km	X	
	Emissions rates and costs	kg/ton-km	X	
	Production (demand)	Daily production requirement at mill	X	X
Feedstock Inventory and Availability (Supply)	Land ownership	Availability of feedstock (i.e., county, ownership, acreage, species, certified)		X
	Land ownership	Federal - Forest Service		X
	Land ownership	Federal, not Forest Service		X
	Land ownership	State DNR		X
	Land ownership	State other		X
	Land ownership	Local units of government (munipal and school forests)		X
	Land ownership	Industrial forests		X
	Land ownership	Non-industrial private forest landowners (less than 1000, and greater than 1,000)		X
	Log availability	Logging systems and production rates for systems		
	Target Stock	Target stock at the mill	X	
	Target Stock	Target stock at the yard	X	

Storage	Map layer from GIS	Road connections and rail connections	X	
	Storage capacity (mill)	Average tons	X	X
	Storage capacity (rail sidings)	Average tons	X	X
	Storage capacity (roadside)	Average tons	X	
	Average storage cost at mill	Average cost per ton to store logs per time increment (split between fixed and variable)	X	
	Average storage cost at rail sidings	Average cost per ton to store logs per time increment (split between fixed and variable)	X	
	Location and network connectivity	Location of roadside storage	X	
Transportation	Location and network connectivity	Location of railway sidings/spurs	X	
	Location and network connectivity	Location of harvesting areas	X	
	Distances	Harvest area to mill, harvest are to log yard, and log yards to mill	X	
	Travel Time	Harvest area to mill, harvest are to log yard, and log yards to mill		X
	Road/rail network information	Class A roads within the 150 mile radius; available rail within the 150 mile radius (network)	X	
	Vehicle capacity	Batch size per truck	X	
	Vehicle capacity	Batch size per rail car	X	
	Vehicle availability	Trucks/day	X	
	Vehicle availability	Rail cars/day	X	
	Vehicle availability	Combined truck/rail transportation	X	
	Transportation cost for each mode	Truck transportation cost per ton by origin to destination		X
	Transportation cost for each mode	Multi-mode truck/rail transportation cost per ton by origin to destination		X
	Transportation cost	Transportation cost per mile by truck (per ton)		X
	Transportation cost	Transportation cost per mile by rail (per ton)		X
	Loading/unloading cost	Loading cost for truck		X
	Loading/unloading cost	Unloading cost for truck		X
	Loading/unloading cost	Loading cost for rail		X
	Loading/unloading cost	Unloading cost for rail		X
	Energy consumption rates and cost	MJ/ton-km	X	X
	Emissions rates and costs	kg/ton-km	X	X

Policy	Log availability	Federal forest management plans and state harvest plans		
	Land use restrictions	Public restrictions		X
	Land use restrictions	Private restrictions		X
	Policies	Water pollution and runoff		
	Policies	Logging road policies (report already supplied by Barry)		
	Regulations and policies	Load restrictions by class of road/vehicle		
Risks	Road conditions	Probability of road closure due to construction, weather, accidents, timing of	X	
	Weather	Probability of inclement weather that prevents delivery of feedstock including spring breakup	X	
	Vehicle capacity	Probability of limited truck or rail availability	X	
	Log availability	Probability of variable harvesting	X	
Information Management System	Network communication			
	Inventory information			
	Backhaul information			

Appendix F: Methods for Determining Haul Distances and Timber Volumes

Creating County / Haul Zone Sections

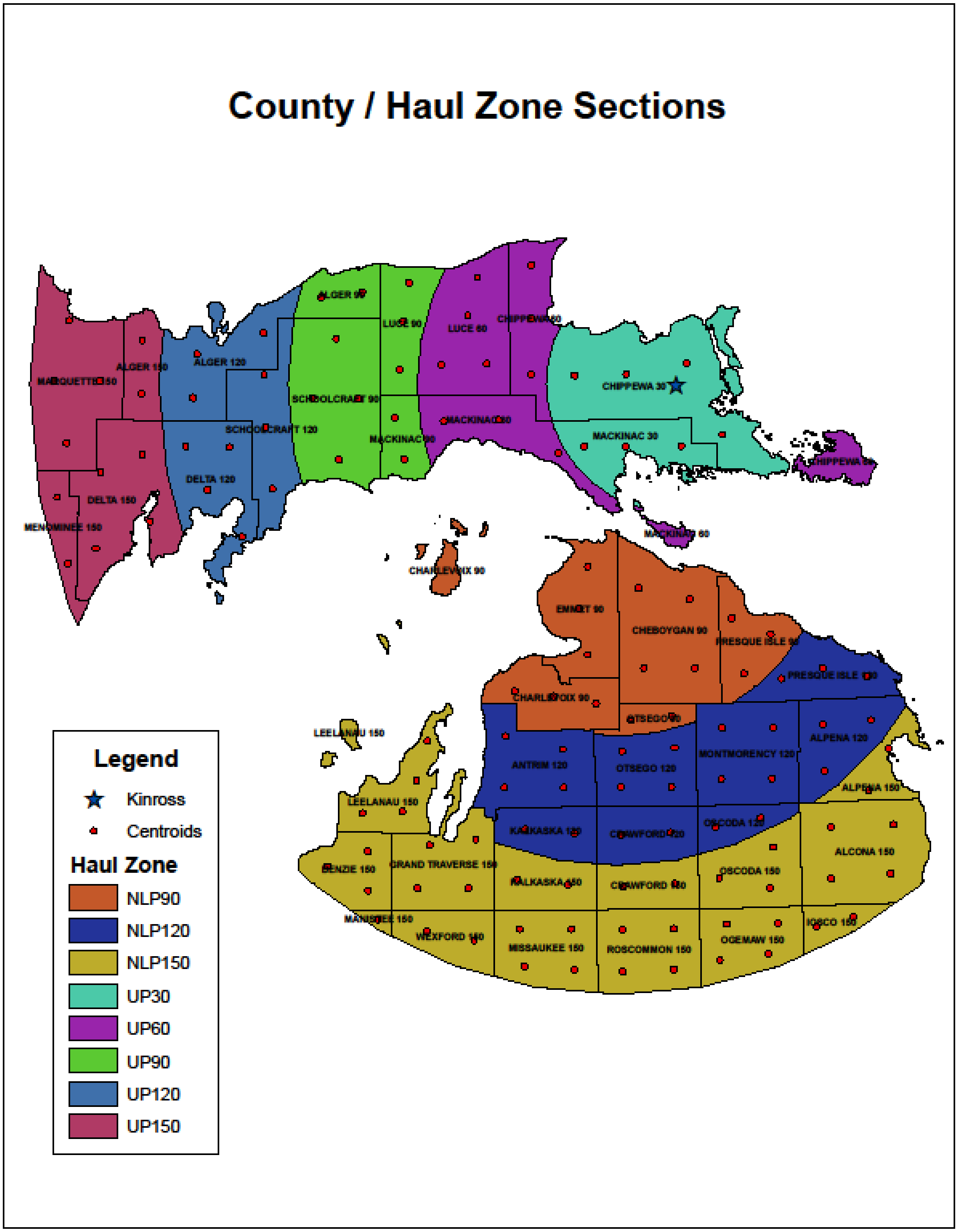
To better determine the volume of available wood, as well as the cost of obtaining it and transporting it to the facility in Kinross, a finer scale of analysis was needed than provided by the nine haul zones used by other projects within the COEE. To accomplish this, the nine original haul zones (UP 150, 120, 90, 60, 30, and NLP 150, 120, 90, 60) were split along county boundaries to produce county / haul zone sections. In many cases the county was split as well, with part of the county in one haul zone and part in another. The county / haul zone sections were named by using the county name followed by the haul zone distance. For example, Mackinac 60 is the portion of Mackinac County within haul zone UP 60, while Mackinac 30 is the portion of Mackinac County within haul zone UP 30. In several cases, small slivers of a county fell in a different haul zone than the rest of the county. These slivers were rejoined with the rest of the county in the other haul zone, which resulted in slightly uneven haul zone boundaries, but kept the county / haul zone sections at a reasonable scale of analysis. Leelanau County was a special case. Originally, Leelanau County was split into two county / haul zone sections, both of which were large enough to be separate sections. However, owing to the Leelanau peninsula, the Leelanau 120 section was farther by road to Kinross than the Leelanau 150 section, even though it was in the closer haul zone. For this reason, all of Leelanau County is included in the Leelanau 150 section. There were 43 county / haul zone sections in total. Additionally, it was felt the Northern Lower Peninsula 60 haul zone would be too small in area for some of the analysis techniques envisioned for this project, so it was merged into the NLP 90 haul zone before being split into county / haul zone sections.

Determining Haul Distances

Placement of Centroids

Before any haul distances could be calculated, starting points had to be assigned. To ensure a relatively even distribution across the study area, each county / haul zone section was subdivided into a number of pieces, depending on its' acreage. A point, referred to as a centroid, was then placed in the center of each piece using the Centroid function in the XToolsPro extension for ArcGIS. The county / haul zone sections, excluding two outliers, ranged between 75,000 and 500,000 acres and were grouped into three classes. The county / haul zone sections from 75,000-200,000 acres were split into two pieces, the sections from 200,001-350,000 acres were split into three pieces, and the sections over 350,000 acres were split into four pieces. Manistee 150 (18,000 acres) was left unsplit. The county / haul zone sections were split into equal sized pieces using the Split Polygon by Area tool in the ET GeoTools extension for ArcGIS. Since the distance from the centroid to the destination would be used to represent the entire piece, it was attempted to make the pieces as square as possible to minimize the distance from the centroid to any edge. Several of the haul zone / county sections that should have been split into three pieces based on acreage, but would have produced long, thin rectangles as a result, were split into four square shaped pieces instead. These sections were Antrim 120, Grand Traverse 150, Missaukee

150, Roscommon 150, Ogemaw 150, and Otsego 120. In total, 130 centroids were placed, as shown in the figure below.



Woods Roads

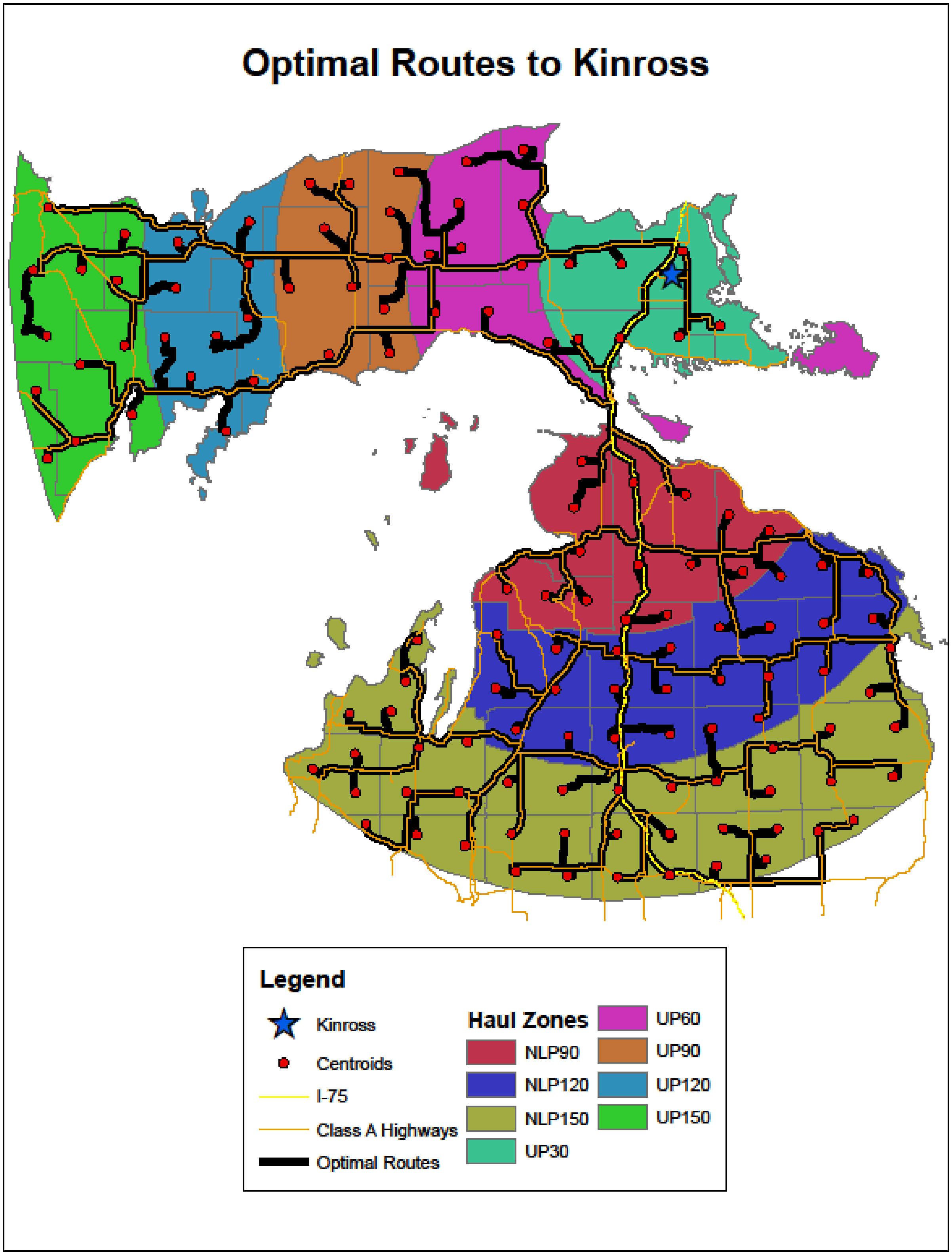
Due to the way centroids were placed they did not fall directly on a public road, which meant the distance along private woods roads from the centroid to a public road needed to be calculated as well. While the woods road distance is short compared to the public road distance, it is an important variable for the Feedstock Supply Chain Model because log trucks must travel at such slow speeds on these roads. The Editor tool in ArcMap was used to draw a path a logging truck would logically follow to go between the centroid and public roads. Air photos and USGS quad maps were first examined to find evidence of existing woods roads nearby, as existing roads are typically used for access whenever possible, due to the expense of building new roads. The Michigan hydrography layer was also overlayed so that stream corridors would not be mistaken for faint woods roads. Where no existing woods roads were evident, the analyst drew a logical path for one. To aid in this task, elevation contour lines on USGS quad maps were consulted to choose a path that followed flatter terrain and the hydrography layer and quad maps were used to avoid wetland areas and limit new stream crossings. If the centroid was within 500 feet of a public road a straight line from the centroid to the road was drawn, unless there was an obvious woods road nearby, in which case the path followed the woods road. The assumption was that the distance is so short a new road would be built straight to that point if no other road was present. For points farther than 500 feet away from a public road, the path drawn attempted to intersect an existing woods roads seen on the air photo or quad map in as short a distance as possible and then follow existing woods roads to the nearest public road.

A point, called the route starting point, was placed at the intersection of the woods road and public road. The route starting points, since they are located on a public road, served as the starting points for the determination of optimal route distances to be described next.

Determination of Optimal Route Distances

The final step was to determine the route a logging truck would take once it reached a public road. To do this, the Network Analyst extension for ArcGIS was used to build a road network from a shapefile of public roads within the study area obtained from Robert Handler via Jason Holmes. Then the Closest Facility tool within Network Analyst was used to determine the optimal route for a logging truck to take along the road network from each route starting point to a destination, either the Kinross facility or a rail siding. The optimal route was defined as the fastest path, not necessarily the shortest. To obtain the fastest path, roads with high speed limits that require few stops were preferred. The road preference was developed from road classifications done by Robert Handler and later by Jason Holmes. I-75 was given the highest preference, followed by other Class A highways, such as M-28 and US-127, then by paved local roads, then by unpaved local roads. Another reason to favor I-75 and the other Class A highways is that they are not closed to logging truck traffic during spring break-up. For the roads to be properly favored in the Closest Facility tool, exaggerated travel speeds had to be assigned to each road class. These were used to calculate the time it would take to travel each road segment, which the Closest Facility tool then used to find the fastest route. Once this optimal, fastest, route was found, the length of the route was combined with the corresponding woods road length for a total distance to the destination. To ensure that the fastest route had been chosen, feasible alternatives for each optimal route were investigated. When the fastest route had not been chosen, the barrier function within the Closest Facility tool was used to block roads that were not part of the fastest route, so that the Closest Facility tool would then choose the fastest route. Finally, the total lengths of the routes from centroids to the destination for all of the centroids within a county / haul zone section were averaged to produce one distance for each county / haul zone section.

A similar procedure was used to calculate the optimal route to the closest rail siding available for use by the Kinross facility. The only difference is that distances for centroids within the same county / haul zone section were not averaged, but rather were listed individually. This is because centroids within the same county / haul zone section frequently were not closest to the same rail siding. Centroids close to Kinross were excluded from this analysis since it would be more efficient to truck logs directly to the facility and centroids in the Northern Lower Peninsula were also excluded since there is no rail connection between the two peninsulas. See the figure below.


Optimal Routes to Kinross
Legend
Kinross
Centroids
I-75
Class A Highways
Optimal Routes
Haul Zones
NLP90
NLP120
NLP150
UP30
UP60
UP90
UP120
UP150

Volume, Harvest Cost, and Availability of Wood

This information was calculated using Forest Inventory and Analysis (FIA) data supplemented by additional data on the ownership of private land. The FIA data were first separated into harvest cost and ownership categories. Then the volume of wood in each county / haul zone section was calculated for each harvest cost and ownership combination.

Harvest Cost Definitions

Lowest Cost: Forestland designated as Aspen Forest Type Group. Expected to have the lowest harvest cost because clearcutting is the most common silvicultural treatment for this forest type.

Low Cost: Forestland designated as Oak Forest Type Group. A low harvest cost is expected because shelterwood is a common silvicultural treatment for this forest type.

Medium Cost: All Forest Type Groups other than Aspen and Oak. Expected to have a medium harvest cost because selection system is the most common silvicultural treatment or, in the case of softwood forest type groups, there is a low volume of hardwoods.

High Cost: Any Forest Type Group located on slopes greater than 20% or assigned a Physiographic Group of hydric. A high harvest cost is expected because of limitations due to the site conditions.

The forest type group was used only to help determine the harvest cost. The volume totals included the volume of all hardwood species and aspen regardless of the forest type group, since the Kinross facility can utilize them all and it is unusual to only harvest one species if a stand contains several.

Ownership Definitions

Ownership is an important variable because some types of owners will choose to harvest their land more than others. The rate of harvesting will be determined as part of the Feedstock Supply Chain Model, but the ownership categories to be used were defined as follows.

Federal: Forestland listed in the FIA dataset as being owned by the Federal government.

State / Local: Forestland listed in the FIA dataset as being owned by state or local governments. No distinction is made between the two ownerships in the FIA dataset.

Private: Forestland listed in the FIA dataset as being owned privately (Northern Lower Peninsula only).

For the Upper Peninsula, a distinction was made between private forestland belonging to corporate and noncorporate owners, since corporate owners are more likely to harvest. No distinction in private ownership was made for the Northern Lower Peninsula because no corporate ownership data was available for that area. This is not seen as a concern because there

is little private corporate land in the Northern Peninsula and it is typically managed for hunting leases where harvest levels are similar to those on private noncorporate land.
Using ArcGIS, the FIA dataset was intersected with a layer that contained the lands owned by four corporate forest landowners: Plum Creek, Longyear, Forest Land Group, and International Paper, to determine the volume of wood on these lands. The two categories of private forestland in the Upper Peninsula are defined as:

Private Corporate: All FIA plots that intersected the GIS layer of corporate forest landowners, regardless of the ownership listed for the plots in the FIA dataset.

Private Noncorporate: All FIA plots that did not intersect the GIS layer of corporate forest landowners and were listed as privately owned.

The ownership listed in the FIA dataset was ignored for those plots that intersected the corporate forest landowner layer due to the error built into the plot locations to prevent disturbance of the FIA permanent plots. This shifting of plot locations resulted in several plots being displayed on private corporate lands in the GIS system that were actually on federal or state /local owned land. It is assumed that a number of plots that actually were on private corporate land were also erroneously displayed due to the error built into the plot locations. However, the identity and timber volume of these plots cannot be determined. Since it is known that the plots labeled as federal or state / local ownership were erroneously displayed, they were used as substitutes for the plots that were actually located on private corporate land that were assumed to be erroneously displayed as well. A problem arose in that the private corporate plots that were erroneously displayed were essentially counted twice. They were correctly counted as part of the private corporate volume in the form of the federal and state substitute plots. They were also incorrectly added to the private noncorporate volume total, since they matched the private noncorporate definition (labeled as privately owned in the FIA dataset, not displayed on private corporate land). To correct for the extra volume added to the private noncorporate total, the volume of each federal or state substitute plot was subtracted from the private noncorporate volume for the county / haul zone section in which that substitute plot fell. This had the added benefit of making the sum of the private corporate and private noncorporate volumes equal the volume of all the private lands in the Upper Peninsula before they were split into corporate and noncorporate categories.

Appendix G: Land Ownership Maps

Appendix H: Optimization User's Instructions

Optimization user interface									
Global control variables									
			All data values "made up" as of 3-31-11						
			We have proprietary data for some cells, and are working with						
				MTU Project 3 to get rail transport costs					
			Many cells, such as ownership harvesting decisions,						
				represent scenarios that can be influenced via prices offere					
Percentage of wood lost in debarking =				10%					
Percentage of "cull" that will be harvested as pulp =				60%					
Transportation costs				($/Mile)					
	Class A highway miles			$3.00					
	Other public roads			$3.00					
	Woods roads (private)			$6.00					
				($/Ton)					
	Cost to load truck at landing			$2.00		Probably can treat as fixed costs			
	Cost to unload truck at mill			$1.00			because always done		
	Cost to unload truck at rail siding			$1.25		Cost to load and unload somewhere			
	Cost to load rail cars			$1.00			from $2 to $4		
Harvest costs				($/Ton)					
	Aspen			$10.00					
	Shelterwood			$12.00					
	Standard Selection			$15.00					
	Rough or Wet Ground Selection			$18.00					
Cost to transport one wet ton to Kinross by rail from:				($/Ton)					
	Gulliver								
	Newberry								
	Seney								
	Shingleton								
	Plains								
				Cost of wood		Cost to transport			
				delivered to siding		by rail			
Rail spurs outside the 150 mile haul zone				($/Ton)		($/Ton)			
	Michigamme - Longyear								
	Outside yard 2								
	Outside yard 3								

Supply available control variables								
	Owner	Industry	Small Private	DNR	USDA FS			
% harvest to "pulp"		85%	85%	85%	85%			
Issue: We need to fraction out the harvest already being used by someone else. I think the most								
justifiable data we have is from the TESSA Systems report, and that I should look into using their data								
for each haul zone split by UP and NLP. This is done on the next page.								
		% growth harvested						
		Industry	Small Private	DNR	USDA FS			
Aspen		80%	70%	75%	50%			
Maple	(Low Cost)	70%	50%	60%	50%			
Maple	(High Cost)	50%	40%	40%	50%			
Oak		80%	60%	70%	50%			
Upland HW		80%	60%	70%	50%			
Lowland HW		50%	40%	40%	50%			

Appendix I: Simulation Users Instructions

CoEE Supply Chain Simulation Model User's Manual

Huihui Lin and David Watkins

Feb. 27th, 2012

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Output Data Summary .... **Error! Bookmark not defined.**

- Output Data I: Output in Reports 160
- Output Data II: Output in Excel .... **Error! Bookmark not defined.**
- Output File: *Outputs of CoEE Supply Chain Simulation with 46 harvest areas.xls* .... **Error! Bookmark not defined.**

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Introduction

A supply chain simulation model for a bio-fuel facility is developed using the ARENA software. The facility is located in Chippewa County's Kinross Township in Michigan's Upper Peninsula, as shown in Figure 1. The simulation model currently includes 46 harvesting areas (43 areas corresponding to counties and 30-mile haul zones within 150 miles of Kinross plus three for areas in the U.P. farther away than 150 miles), 1 truck yard in the L.P., and 3 log yards at rail spurs in the U.P.

The simulation lasts for one year, using a daily time step, and the start day is selected by user.

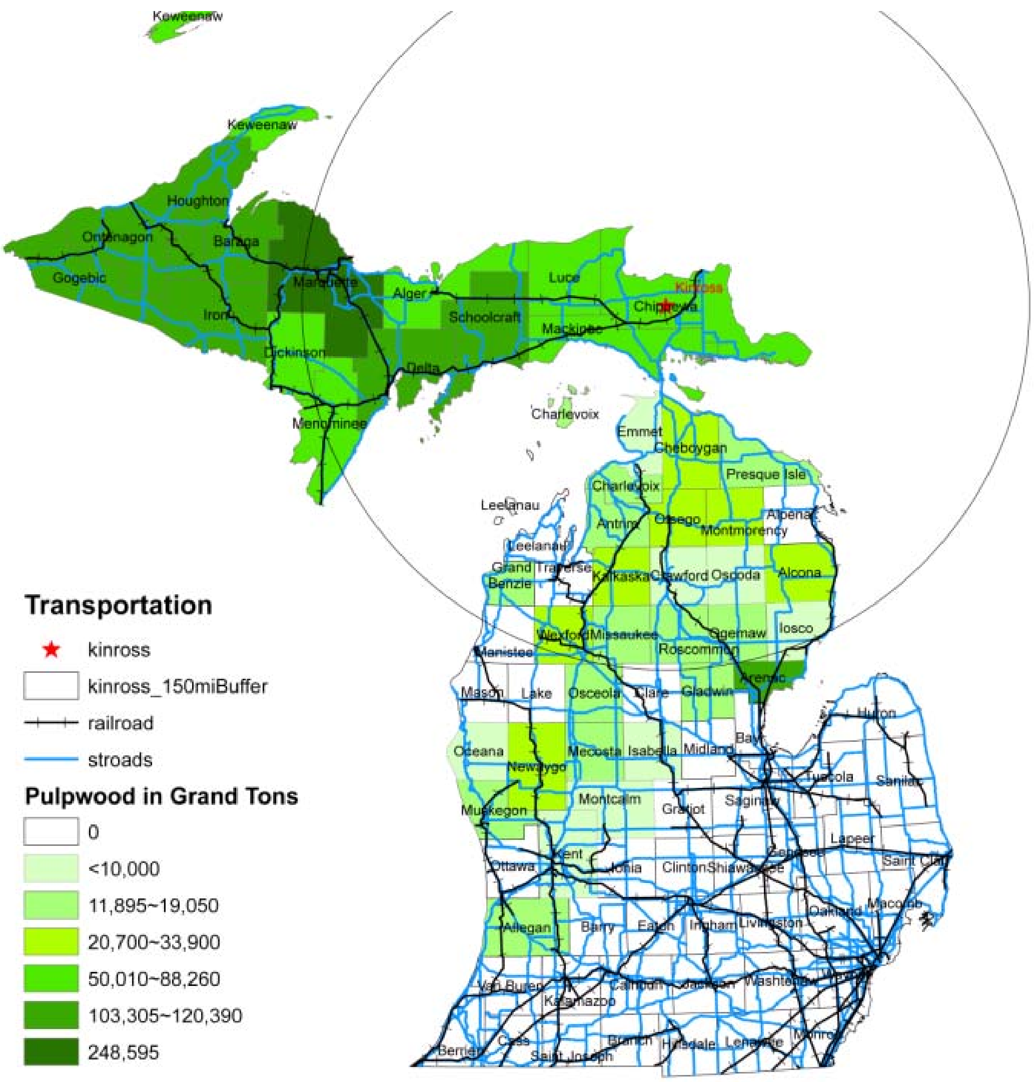


Figure 1: Map of Michigan showing the location of the bio-fuel plant and a 150-radius.

A Brief Introduction to Arena

Double click on the Arena file "CoEE_Supply_Chain_Simulation_Model.doe" to open the simulation model.

As shown in Figure 2, the main Arena window is divided into several sections.

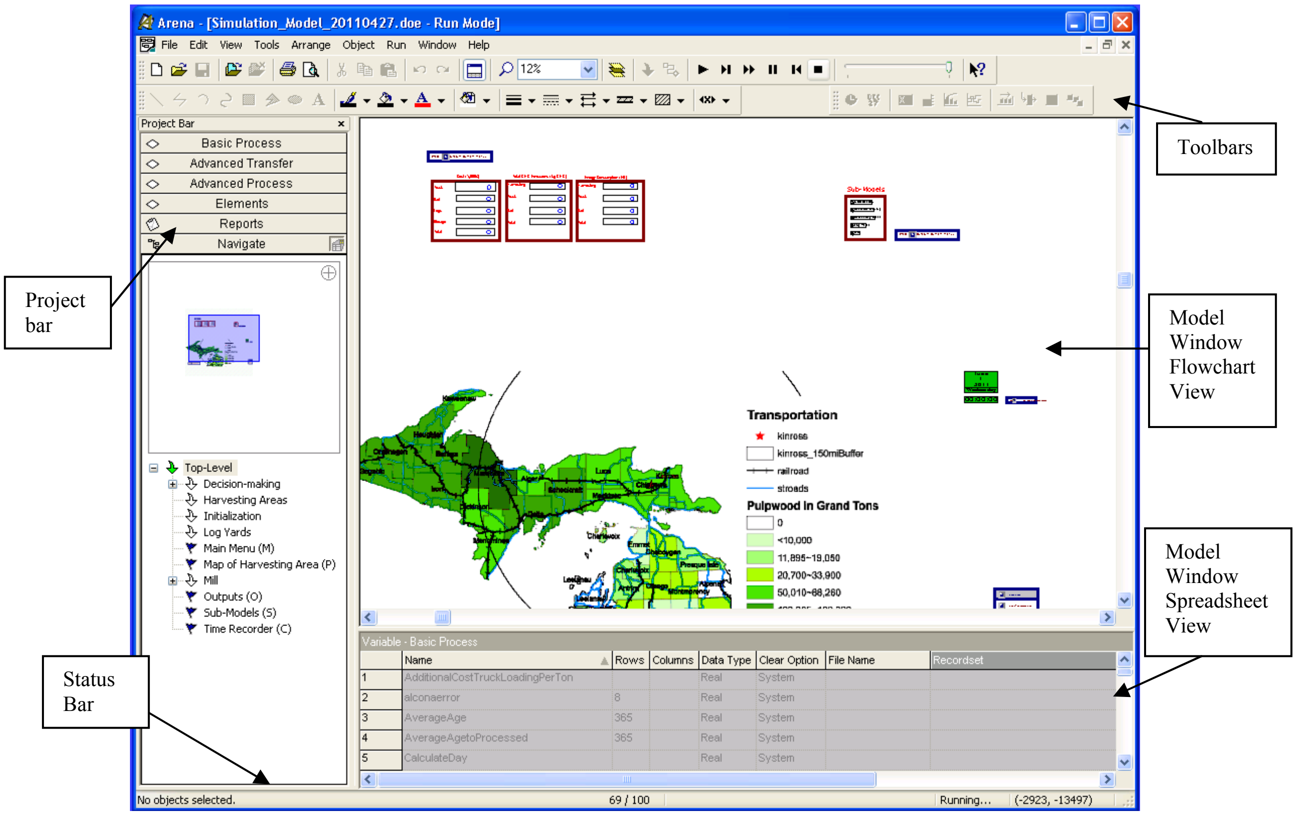
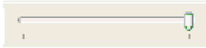


Figure 2: Main Arena Window for the simulation model

At the top left of the Arena window are the File, View, Tools, Arrange, Object, Run, Window, and Help menus and toolbars. To learn the function of these buttons, you may use help button which is in the first line of the toolbars. Click on to add the question mark to your mouse arrow, and then click on a toolbar button or menu button to get help on it. A help window will show up.

The most useful button on the toolbar for controlling simulations is: . Use the Go command ( ) to initiate or continue a simulation run. If a simulation has been stopped, this continues the run from the point at which it was last interrupted. Use the End command ( ) to terminate a run session. You should click on it after all replications are done to restore the edit mode, meaning you are allowed to make changes to data or program logic. You also can click this button to terminate a simulation if you don't need results from the run session. The Pause command ( ), is used to interrupt the run at any point in the simulation. After interrupting a run, you may use the Go, Step ( ) or Fast-Forward ( ) commands to continue the run. The fast-forward function gives us some of the increased speed of a non-animated simulation run while staying in the animated environment. It's most beneficial if you want to gain execution speed and still view the animation during certain periods of the run. The Run Speed button () may be used when animation is on. Drag it to left to slow down the animation so you can see where each entity comes from and where it goes. Drag it to right to speed up the animation so the simulation takes less time.

On the right, the model window taking up most of the screen can be split into two regions: the flowchart view and the spreadsheet view. It's often helpful to see both views, but you can choose to see only one of the views by clicking on Split Screen under the View menu or clicking on  in the toolbar. You can also left click and hold on the split line to adjust the size of the two views by sliding the split line up or down as shown in Figure 3. The flow chart view contains the model's graphics, including the process flow chart. The spreadsheet view can display model data such as variables.

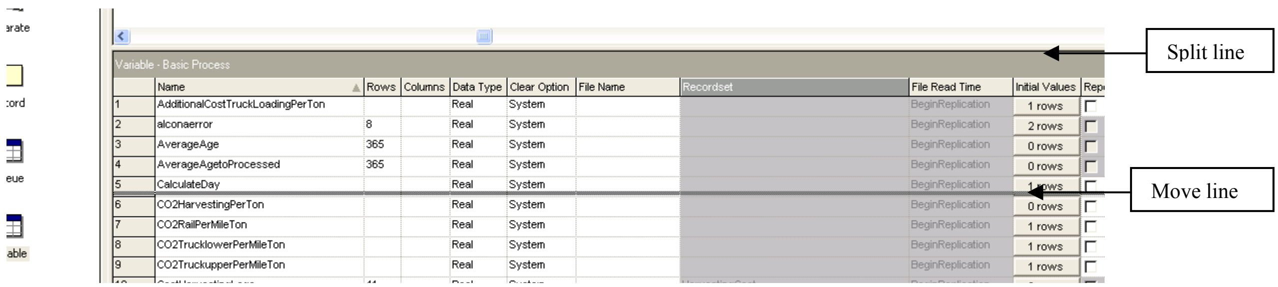


Figure 3: Arena Window for the simulation model

At the bottom of the Arena window in Figure 2 is the status bar, which displays various kinds of information on the status of simulation, depending on what's going on at the moment. It displays the (x, y) coordinates of mouse pointer's location usually, and it also displays the replication number being executed, as well as the total number of replications to be run during simulation.

Along the left edge of the Arena window in Figure 2 is the project bar, which hosts panels containing different objects, displaying one panel at a time. Click on the panel name to see details of that panel. There are four panels containing components of this simulation model: Basic Process, Advanced Transfer, Advanced Process and Elements, which contain modules with which we build the model. Below the Elements on the project bar is "Reports", which will display another panel containing the results of a simulation after it is run.

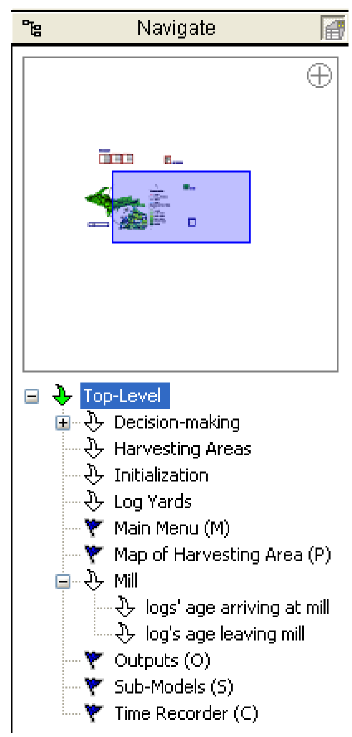


Figure 4: Navigate Panel

The Navigate panel, as shown in Figure 4, allows you to display different views of the model. The  button on the right of the horizontal Navigate bar is pressed to open the “mini map” of the model window in the top of the panel, and pressing it again will shut the mini map window. The blue box in the mini map shows the location and zoom size of the active window's current view. Clicking anywhere in the mini map changes the current view to that spot. Drag the blue box around to pan to other regions of the window, or resize it. Click ⊞ to open sub-models ⊞, and click on ⊟ to close them.

Simulation Model Interface

A special interface is accessible in the top level of the simulation model, which can be observed on the flowchart view. The main menu for the interface appears immediately after opening the simulation model (double clicking on the Arena file "CoEE_Supply_Chain_Simulation_Model.doe"), as shown in Figure 5. The main menu only works when the mouse pointer locates it in the flowchart view. As it indicates, you can press "P" on keyboard to access the map of harvesting area, press "O" to access the Outputs (as shown in Figure 6, which is only available when animation is on), press "S" to access the Sub-models list (as shown in Figure 7 in which you can click on the sub-model name to the flowchart of your interest), press "C" to access a clock (as shown in Figure 8 which would show you the progress of the simulation, again only when animation is on), or press "A" to Network Animation screen when animation is turn on during simulation. You always can return to the main menu by pressing "M" on the keyboard.

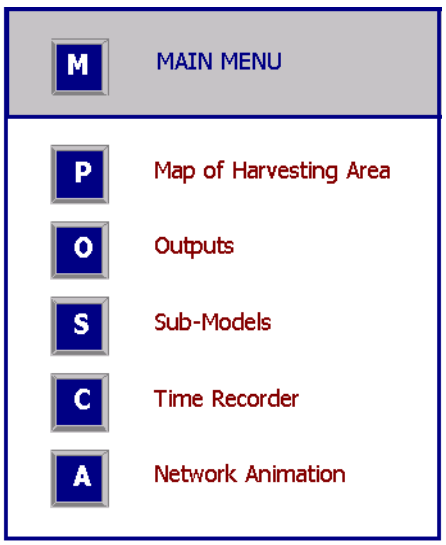


Figure 5: Main Menu on the Interface

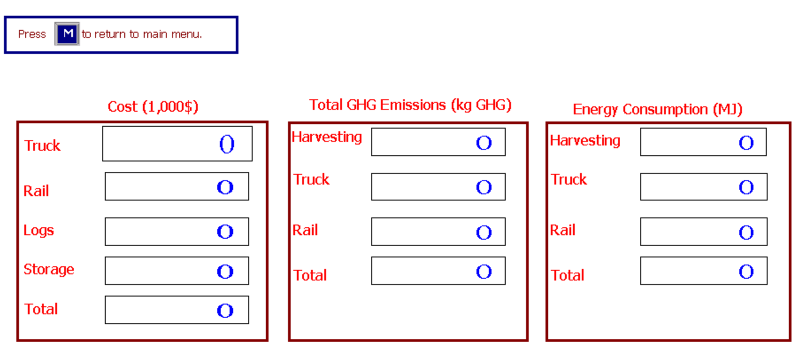


Figure 6: Outputs shown on the Interface. When the animation is on, values in the output boxes change during simulation.

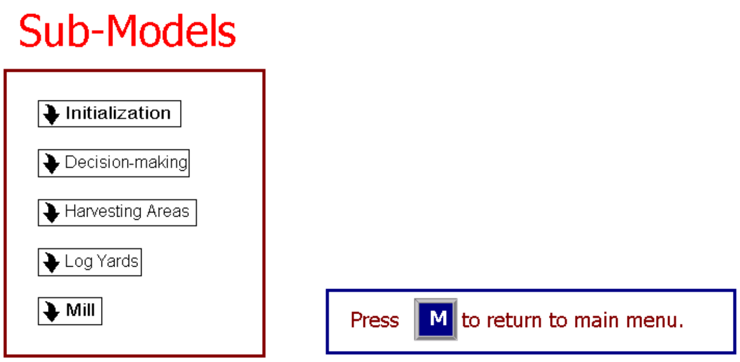


Figure 7: Sub-Models list on the Interface

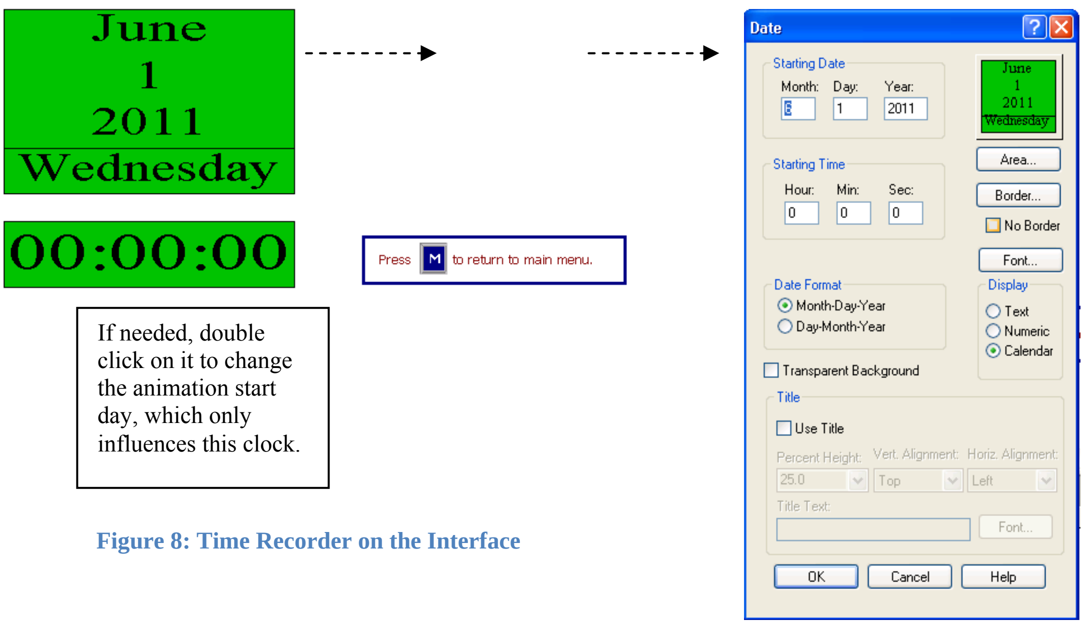
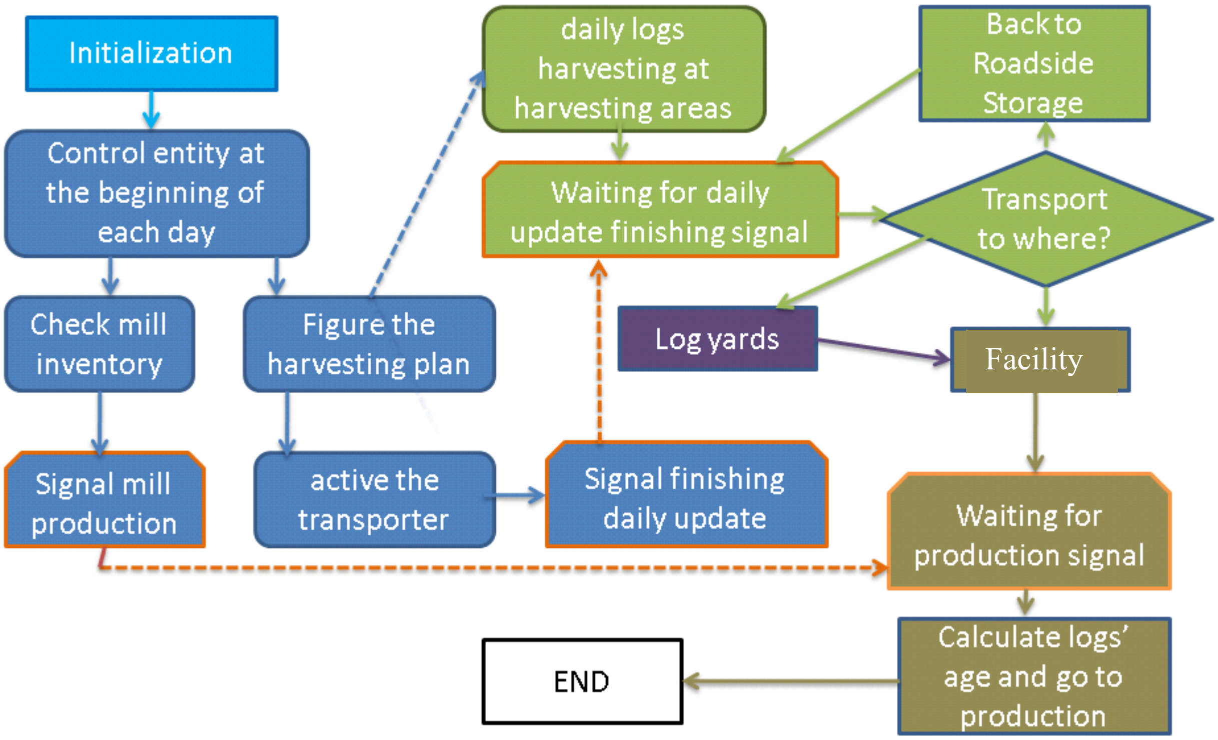


Figure 8: Time Recorder on the Interface

Logic of the Simulation Model

This model developed by Arena simulates the forest-based bio-fuels supply chain for the plant in Kinross. A schematic of the overall model logic is shown below.



Legend:

Harvesting area | Log yards | Facility | Decision making | Initialization

Information /signal - - - - - - - - - - ▶

Log transportation/activity ———————▶

(1) Initialization is the module that reads in data from Excel before every replication;

(2) The Decision Making module controls the model (i.e, a one-year simulation) and sends signal to control production at the mill and transportation from the harvest areas;

(3) The Harvesting Area module has 46 separate flowcharts representing 46 different harvesting areas;

(4) The Log Yards module includes 8 separate flowcharts representing available 3 truck yards and 5 rail yards, but 1 truck yard and 3 rail yards are recommended to be selected for simulation;

(5) The Facility (Mill) module receives logs from the harvesting areas and storage yards and sends them to production.

Input Data Summary

There are two ways that data are input to the model. Some data are read from an Excel spreadsheet file, and other data are entered directly into the 'Parameter setting' window as shown below, which was developed using Visual Basic.

The following are the data required to run a simulation:

1) Lifecycle cost data: transportation cost, annual storage cost, harvesting cost, emissions, fuel use;

2) Inventory data: initial inventory/log age, reorder/target level inventory, capacity of storage yards;

3) Harvesting data: harvesting plan

4) Transportation data: transportation plan, transporter (rail, truck) data;

5) Spring Breakup data: start day, period (for each harvest area);

Input Data I: Parameter Setting Window

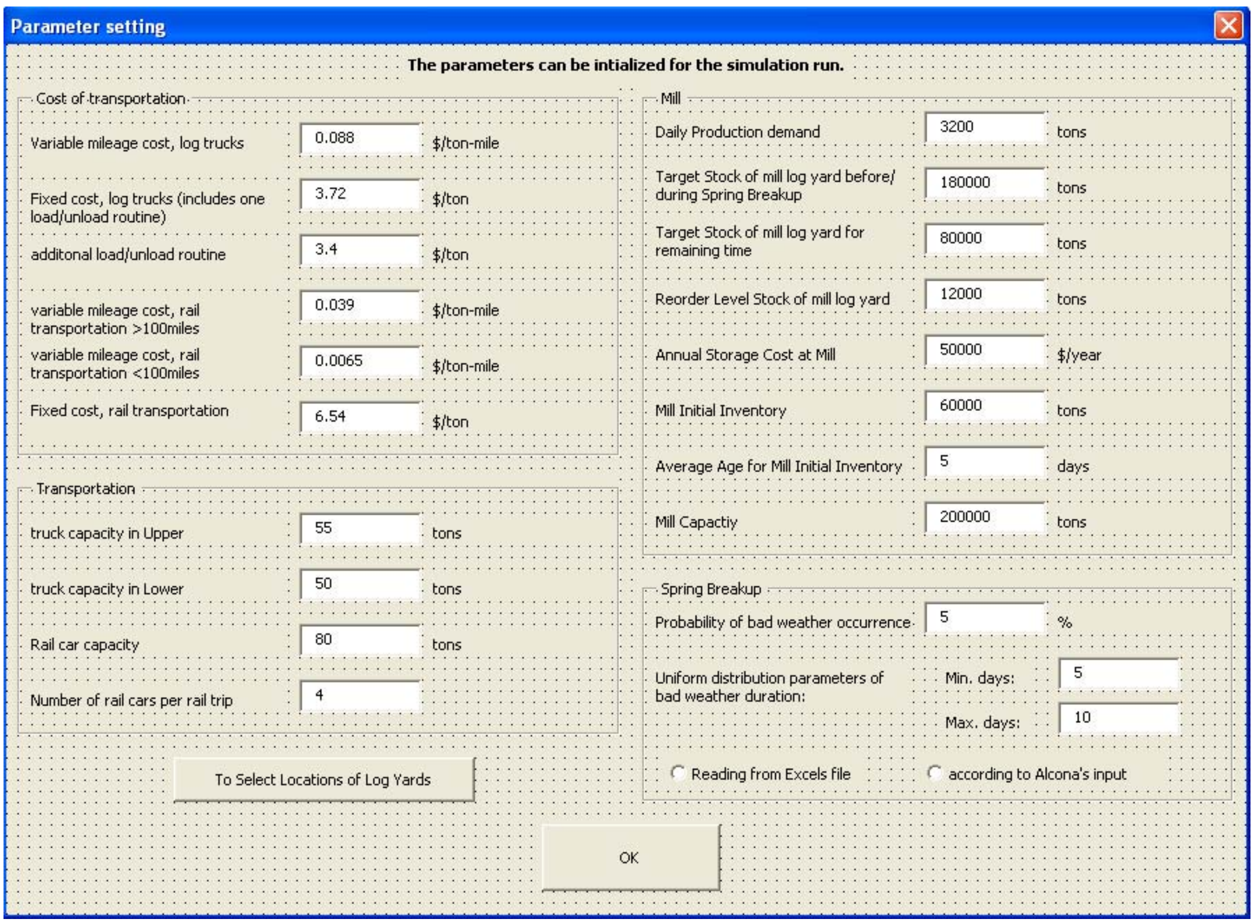


Figure 9: Parameter Setting Window

Five types of data are given by this window, as described below: Cost of Transportation, Transportation Capacity, Facility (Mill) data, Log yards location, Spring Break-up extension probability due to bad weather, and the method of Spring Break-up modeling.

Transportation cost includes mileage cost and load/unload cost for truck and rail. One thing worth mention here is that cost of Diesel fuel is mileage cost is considered in mileage cost by:

New Variable Cost, $/ton-mile = Base Variable Cost + (Current Price Fuel-Base Price Fuel)*Surcharge;

So for truck: ***New Variable Cost, $/ton-mile = 0.0744 + (Current Price Fuel-2.67)*0.01143***;

For rail: ***New Variable Cost, $/ton-mile = 0.0364 + (Current Price Fuel-2.67)*0.0024***.

Transportation Capacity asks for the capacity of trucks in the L.P. and U.P., the capacity of rail cars in the U.P., and the number of rail cars per rail trip.

Mill data includes daily production demand of the mill, target/reorder level inventory, storage cost in the mill yard, initial inventory in the mill yard, age of logs in the initial inventory, and the capacity of mill storage.

Log yards locations are selected by click on the button "To Select Locations of Logs Yards". 1 truck yards and 3 rail yards are recommended for simulation.

The user selects the method for modeling Spring Breakup. Either specific scenarios are read from the Excel file, or else scenarios are generated by the simulation model based on historical data from 2005 to 2010. The statistical equations used to generate Spring Breakup scenarios are available upon request. The probability of bad weather occurrence and its uniform distribution parameters are defined here as well.

Input Data II: Excel Input File

Input data is saved in the file “CoEE Supply Chain Simulation with 46 harvesting areas.xls”. Data would be listed by the name of worksheet as below.

(1) Harvesting

Harvesting data, as shown in Figure 10, constitutes the annual harvesting plan, which lasts 52 weeks for 46 harvesting areas, in units of 50 tons. Columns represent harvesting areas, and rows represent the weeks of the year, starting with the user-specified start date. Consider harvesting area # 2 and week 2 for example: if the first day of simulation is June 1, 2011, then the log's production in harvesting area #2 during the second week (which is from June 8, 2011 to June 15, 2011) is 13.0 × 50 tons, which equals 650 tons.

Logs production (50 tons /week)	Harvest Area #1 Alcona 150	#2 Alger 120	#3 Alger 150	#4 Alger 90	#5 Alpena 120	#6 Alpena 150	#7 Antrim 120	#8 Benzie 150	#9 Charlevoix 90	#10 Cheboygan 90	#11 Chippewa 30	#12 Chippewa 60
Week 1	7.7	13.0	13.0	10.5	8.0	4.1	20.7	9.8	17.6	23.8	30.4	18.3
Week 2	7.7	13.0	13.0	10.5	8.0	4.1	20.7	9.8	17.6	23.8	30.4	18.3
Week 3	7.7	13.0	13.0	10.5	8.0	4.1	20.7	9.8	17.6	23.8	30.4	18.3
Week 4	7.7	13.0	13.0	10.5	8.0	4.1	20.7	9.8	17.6	23.8	30.4	18.3
Week 5	7.7	13.0	13.0	10.5	8.0	4.1	20.7	9.8	17.6	23.8	30.4	18.3
Week 6	7.7	13.0	13.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 7	7.7	13.0	13.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 8	7.7	13.0	13.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 9	26.4	31.1	11.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 10	26.4	31.1	11.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 11	26.4	31.1	11.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 12	26.4	31.1	11.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 13	26.4	31.1	11.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.8	30.4	18.3
Week 14	25.9	30.4	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.3	29.8	17.9
Week 15	25.9	30.4	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.3	29.8	17.9
Week 16	25.9	30.4	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.3	29.8	17.9
Week 17	25.9	30.4	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.3	29.8	17.9
Week 18	25.9	30.4	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.3	29.8	17.9
Week 19	25.9	30.4	11.0	10.3	7.8	4.0	20.2	9.6	17.3	23.3	29.8	17.9
Week 20	25.9	30.4	11.0	10.3	7.8	4.0	20.2	9.6	17.3	23.3	29.8	17.9
Week 21	25.9	30.4	11.0	10.3	7.8	4.0	20.2	9.6	17.3	23.3	29.8	17.9

Logs production (50 tons /week)	#13 Crawford 120	#14 Crawford 150	#15 Delta 120	#16 Delta 150	#17 Emmet 90	#18 Grand Traverse 150	#19 Iosco 150	#20 Kalkaska 120	#21 Kalkaska 150	#22 Leelanau 150	#23 Luce 60	#24 Luce 90
Week 1	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 2	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 3	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 4	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 5	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 6	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 7	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 8	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 9	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 10	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 11	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 12	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 13	5.4	6.4	21.3	13.9	19.9	10.4	2.6	8.7	5.4	9.9	20.9	11.5
Week 14	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3
Week 15	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3
Week 16	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3
Week 17	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3
Week 18	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3
Week 19	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3
Week 20	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3
Week 21	5.3	6.3	20.9	13.6	19.5	10.2	2.5	8.5	5.3	9.7	20.4	11.3

Logs production (50 tons /week)	Harvest Area #1 Alcona 150	#2 Alger 120	#3 Alger 150
Week 1	7.7	13.0	13.0
Week 2	7.7	13.0	13.0
Week 3	7.7	13.0	13.0
Week 4	7.7	13.0	13.0

Figure 10: Harvesting Plan in Excel Input File

(2) Spring Break-up

Although the user may enter any data for spring break-up scenarios, it would seem reasonable to simulate historical events. "Historic Start Date" is the historic start date of spring break-up for each county; "Period" is the duration of spring break-up for each county; "Daily Logs Production in Spring Break-up" is the daily harvesting plan during spring break-up, in units of 50 tons.

As noted spring break-up data could also be specified as a set of probabilistic parameters which are read from the 'Parameter setting' window. Data are read in from Excel if the user wishes to simulate specific spring break-up scenarios. The available scenarios, as shown in Figure 11, are data from 2006, 2007, 2008, 2009 and 2010, which can be selected at the beginning of simulation. The user can also change any of them to a scenario of interest.

	Harvesting Area	Daily Logs Production in Spring Break-up (50 tons/week)	2010 Historic Start Date	2010 Period (Days)	2009 Historic Start Date	2009 Period (Days)	2008 Historic Start Date	2008 Period (Days)	2007 Historic Start Date	2007 Period (Days)	2006 Historic Start Date	2006 Period (Days)
1	**Alcona 150**	2.1	62	36	68	50	77	43	71	45	68	40
2	**Alger 120**	2.5	67	43	76	55	78	56	71	53	69	49
3	**Alger 150**	0.9	67	43	76	55	78	56	71	53	69	49
4	**Alger 90**	0.8	67	43	76	55	78	56	71	53	69	49
5	**Alpena 120**	0.6	65	31	68	46	77	38	71	41	67	41
6	**Alpena 150**	0.3	65	31	68	46	77	38	71	41	67	41
7	**Antrim 120**	1.7	62	24	68	40	71	42	67	27	65	38
8	**Benzie 150**	0.8	67	11	68	29	72	34	68	22	67	20
9	**Charlevoix 90**	1.4	62	30	68	51	70	40	57	52	65	43
10	**Cheboygan 90**	1.9	67	25	72	43	77	37	71	36	67	37
11	**Chippewa 30**	2.4	67	29	76	56	78	49	72	48	65	35
12	**Chippewa 60**	1.5	67	29	76	56	78	49	72	48	65	35
13	**Crawford 120**	0.4	67	19	65	41	72	38	81	30	68	56
14	**Crawford 150**	0.5	67	19	65	41	72	38	81	30	68	56
15	**Delta 120**	1.7	60	51	72	50	72	56	68	54	67	70
16	**Delta 150**	1.1	60	51	72	50	72	56	68	54	67	70
17	**Emmet 90**	1.6	61	28	68	40	70	43	60	61	60	36
18	**Grand Traverse 150**	0.8	69	15	68	40	74	32	64	29	67	27
19	**Iosco 150**	0.2	67	25	68	43	77	38	71	40	69	27
20	**Kalkaska 120**	0.7	68	24	65	46	77	37	71	43	65	38
21	**Kalkaska 150**	0.4	68	24	65	46	77	37	71	43	65	38
22	**Leelanau 150**	0.8	62	24	68	40	71	42	67	27	65	38
23	**Luce 60**	1.7	68	46	77	59	78	57	74	90	68	76
24	**Luce 90**	0.9	68	46	77	59	78	57	74	90	68	76
25	**Mackinac 30**	1.2	67	23	76	60	77	86	72	74	69	104
26	**Mackinac 60**	1.2	67	23	76	60	77	86	72	74	69	104
27	**Mackinac 90**	0.5	67	23	76	60	77	86	72	74	69	104
28	**Manistee 150**	0.2	64	25	68	38	73	36	72	25	72	22
29	**Marquette 150**	3.0	67	47	76	63	78	66	71	57	68	61
30	**Menominee 150**	0.4	60	43	70	48	71	50	68	53	66	49
31	**Missaukee 150**	0.8	64	15	65	35	72	38	71	22	65	30
32	**Montmorency 120**	1.6	57	32	65	54	77	33	60	30	60	36
33	**Ogemaw 150**	0.5	67	29	64	51	77	40	66	41	67	34
34	**Oscoda 120**	0.4	67	32	70	48	77	43	71	45	72	32
35	**Oscoda 150**	0.7	67	32	70	48	77	43	71	45	72	32
36	**Otsego 120**	1.1	62	27	68	44	72	48	68	26	68	35

Figure 11: Spring Breakup Data in Excel Input File

Note that start days in spring breakup are the only time input data that are not based on the simulation start day. They are always based on Jan. 1 of the simulation year or the next year. For example, if we start at June 1, 2011 (the 152nd day of the year), the first week in the harvesting plan would be from June 1 to June 7, but a start day of spring breakup of 76 would be the 76th day from Jan. 1, 2012. In other words, the start day of spring breakup would be March 7, 2012, as March 7, 2011 has already passed before simulation starts. In this way, the spring breakup start day is not recalculated every time the simulation start day is changed.

(3) Transportation_truck

Transportation input for truck includes the available trucks for each harvest area in the U.P. every day (TruckUpper), the available trucks for each harvest area in the L.P. every day (TruckLower) for regular timing, the available trucks totally for three months before spring breakup and the period during Spring Break-up and the fraction gives the ratio of trucks which can do 2 trips.

(4) Transportation_rail

Transportation input for rail includes the available rail cars in the U.P. every day (Rail) for regular timing, three months before spring breakup and the period during Spring Break-up.

(5) TransportationPlanning

	Harvesting Area	Normal percentage to log yards %	Percentage before spring break-up (90 days before) %	Percentage during spring break-up %
1	**Alcona 150**	100	50	15
2	**Alger 120**	100	50	15
3	**Alger 150**	100	50	15
4	**Alger 90**	100	50	15
5	**Alpena 120**	100	50	15
6	**Alpena 150**	100	50	15
7	**Antrim 120**	100	50	15
8	**Benzie 150**	100	50	15
9	**Charlevoix 90**	100	50	15

Figure 12: Transportation Planning Data in Excel Input File

Transportation planning data includes the percentage of logs transported to a storage yard, with the rest going directly to the mill, assuming both inventories of the mill yard and log yard are less than their target level. Different percentages may be specified for the period before Spring Break-up, during Spring Break-up, and during the remainder of the year.

As part of the transportation plan shown in Figure 12, different percentages are specified for different periods. Take harvesting area #2 for example, it would send all of its harvested logs to rail yard during Spring Break-up, half of its harvested logs to the mill and half to the log yard during the three months before spring breakup, and 15 percent to the yard and 85 percent to the mill during the remainder of the year.

(6) Harvesting Cost

Harvesting cost data may also be different in different time periods for each harvesting area. These costs are in units of $/ton green timber. Note that harvesting costs in harvest area #44, #45 and #46 include other operational costs as well, as these three harvest areas are used to simulate places where logs may be purchased.

(7) LogYards

Data for yards includes target level stock, reorder level stock, annual storage cost (in units of \$/year), initial inventory, age of the initial inventory (in units of days), and capacity of the yard. Inventory information of rail yard is represented as the number of rail cars, for example, if the rail car capacity is 80 tons and the capacity of rail yard 1 is 100, then its capacity is 100*80=8000 tons. Inventory information of truck yard is in units of tons. Note as the entity used to simulate logs represents logs of 5 tons in the simulation model, a multiple of five is required as the initial inventory, reorder/target level inventory of truck yards. For example, even if the number of 24 is entered in the initial inventory, only 4 entities would be created which are 20 tons totally (24 tons /5 tons=4.8 ≈ 4 entities).

(8) Network

Network data is the distance from each harvesting area to the storage yards and the mill, in units of miles.

(9) Roadside Storage

Roadside storage data includes annual storage cost (\$/year), initial inventory (tons), and log age (days) for the initial inventory for the aggregate roadside storage in each harvesting area.

(10) Emissions & Energy Consumption

The preliminary CO2 emission and fuel consumption data are shown in Figure 12.

CO2 Emission	
at Harvesting Area	18.4 kg GHG/ton green timber
from Rail Yard Machinery	0 kg GHG/ton green timber
from Truck Yard Machinery	0 kg GHG/ton green timber
from Mill Yard Machinery	0 kg GHG/ton green timber
from transportation by truck upper	0.183 kg GHG/ton green timber-mile
from transportation by truck lower	0.183 kg GHG/ton green timber-mile
from transportation by rail	0.035 kg GHG/ton green timber-mile

Fuel Consumption	
at Harvesting Area	215 MJ/ton green timber
from Rail Yard Machinery	0 MJ/ton green timber
from Truck Yard Machinery	0 MJ/ton green timber
from Mill Yard Machinery	0 MJ/ton green timber
from transportation by truck upper	2.1 MJ/ton-mile
from transportation by truck lower	2.1 MJ/ton-mile
from transportation by rail	0.397 MJ/ton-mile

Figure 12: Data of Emissions & Energy Consumption in Excel Input File

Both emissions and fuel consumption are caused by harvesting equipment, machinery in yards, and rail and truck transporters. As shown above, the unit of CO2 emissions is kg GHG, where GHG stands for greenhouse gas (CO2 equivalent), and the unit of fuel/energy is MJ.

(11) Weibull distribution

As the start day and duration of spring breakup in county Alcona are assumed to be Weibull distributed, the parameters (a, b) are required at the beginning of the simulation if the input way of spring breakup is "According to the Alcona's input". See more details about methods of spring breakup in section (4) under "Run a Simulation".

This is a sheet in Figure 13 showing user how the parameters (a, b) would influence the random value produced and helping user get reasonable parameters to put into the model.

The parameters a=13.256, b=70.6925 for start day and a=12.94, b=107.94 for end day in Alcona County are developed based on historical data by Matlab.

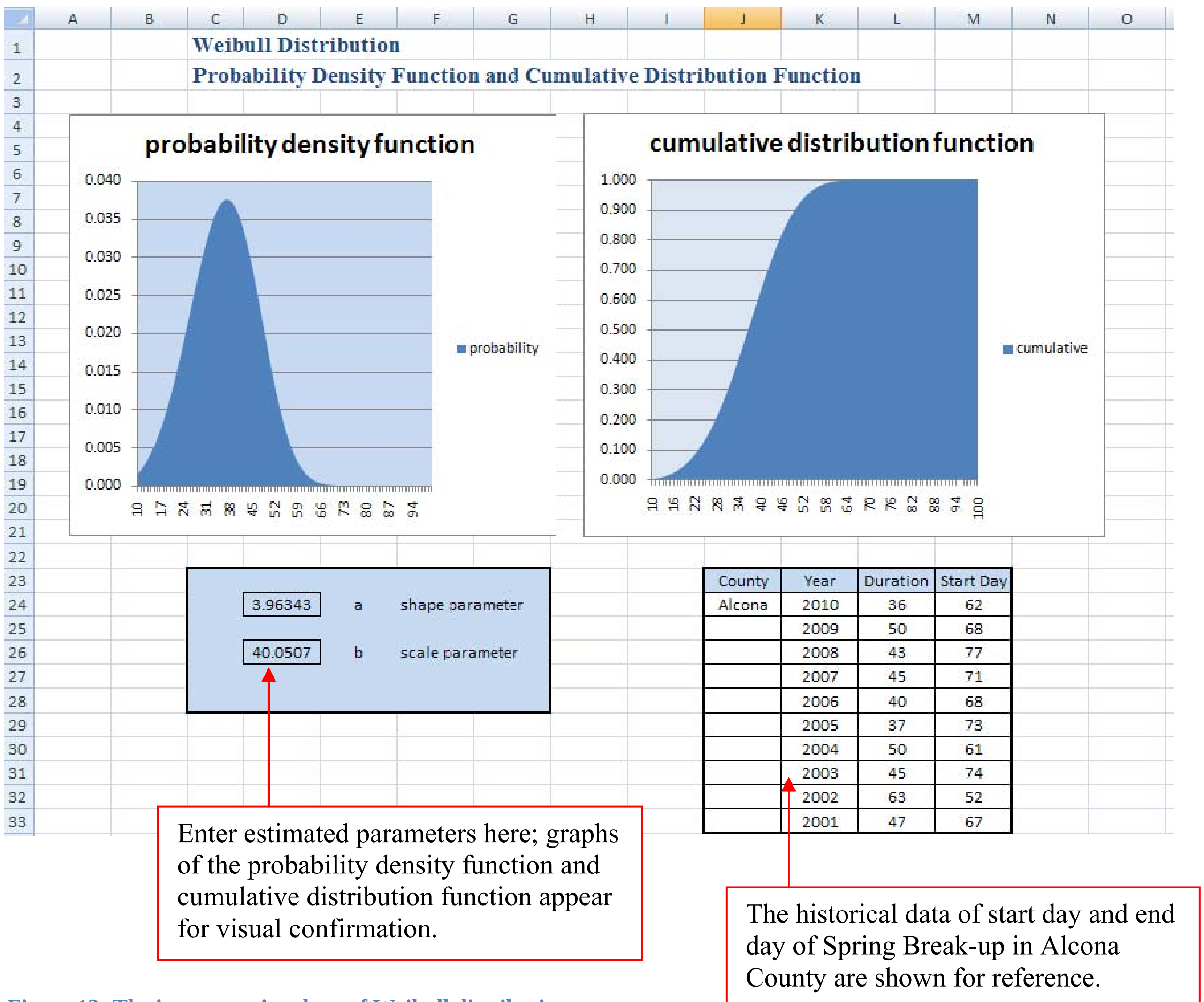


Figure 13: The interpretative sheet of Weibull distribution

(12) Input data from VB

The input data from "Parameter setting" window would be kept here, in case user would like to check the value just used.

Run a Simulation

(1) Set the number of replications and simulation start time:

a. Open Setup under the Run menu.

b. Choose the tab Replication Parameters as shown.

c. Enter a number in the box ‘Number of Replications’.

d. User may also change the simulation start day here; and the simulation would end 1 year later.

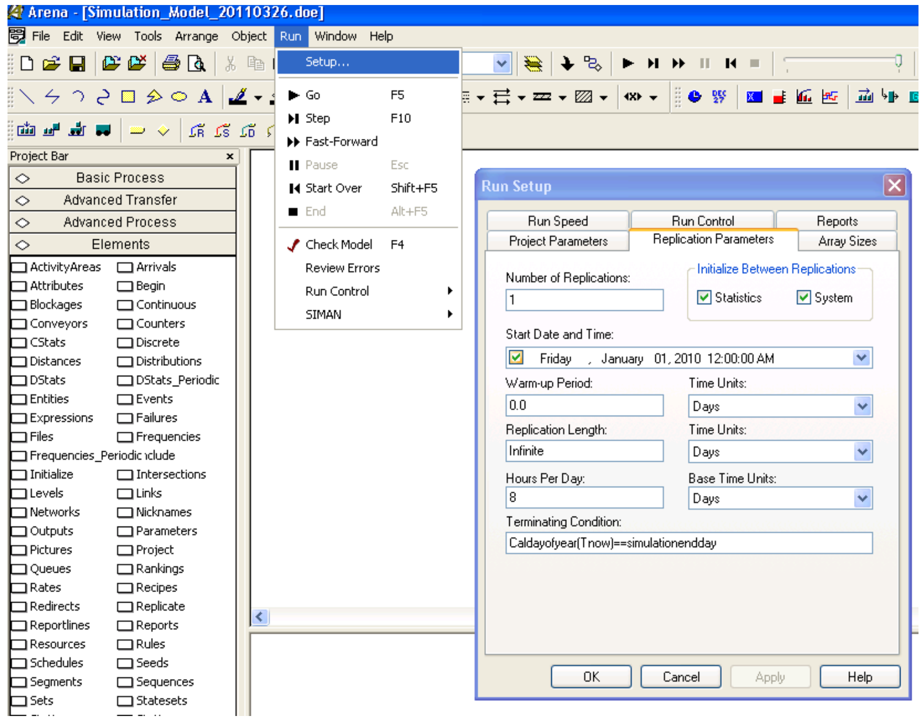


Figure 14: Screenshot of Run Setup window

e. Other important features in the Replication Parameters dialog re shown in Figure 15 as below.

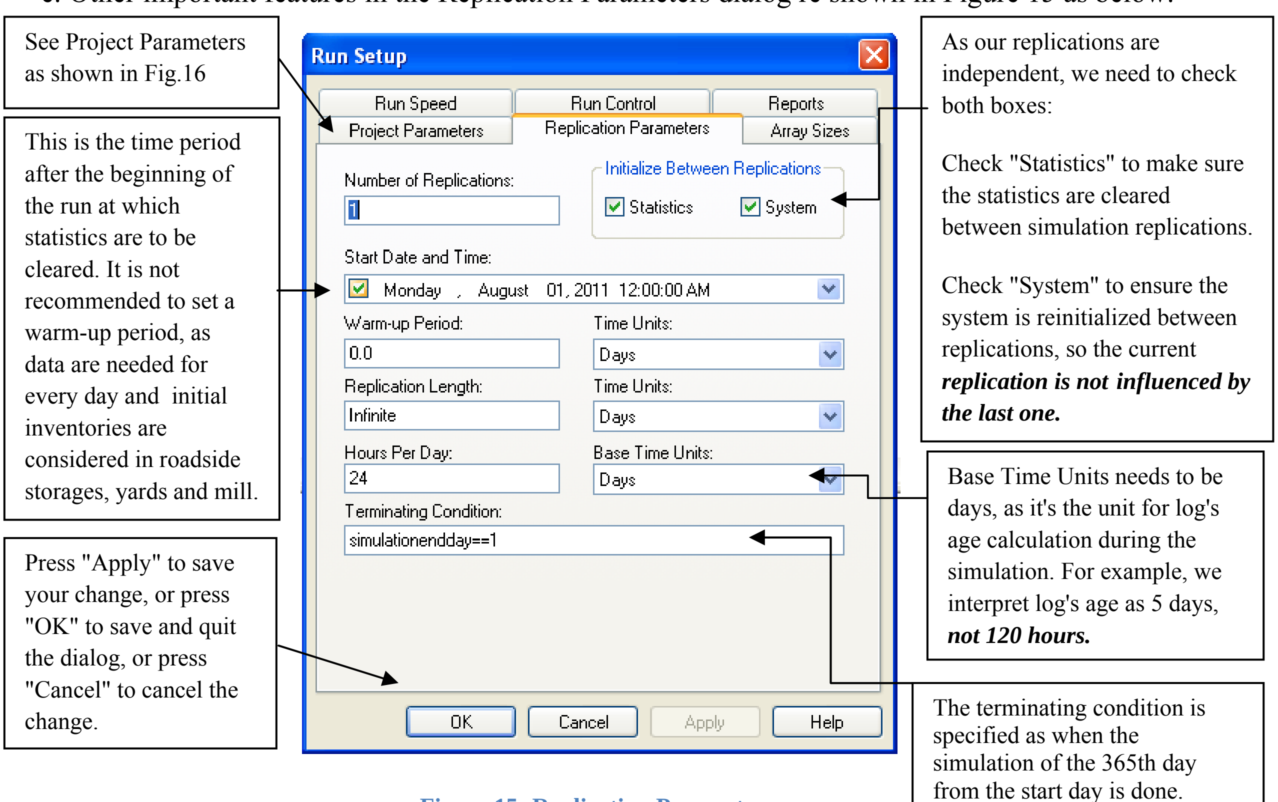


Figure 15: Replication Parameters

f. Before each simulation be sure to check the "Entities" and "Queues" under Statistics Collection in the Project Parameters window, as the calculation of log's age is based on the entities' time of creation, which would not be tracked if the entities statistics collection is turn off. The item "Queues" needs to be checked also. Other items may also be checked to see the statistics in a report after simulation (optional).

g. The conception "Entity" is a specified term used in the Arena software. It represents the item created to simulate specific object. In the simulation model, three types of entities are created: "Logs" is created to simulate the logs' activities; "DailyControl" is used to control the simulation; and "Entity 1" is used to read in data from Excel file.

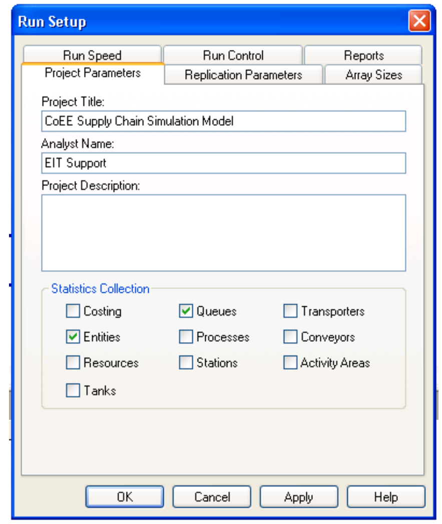


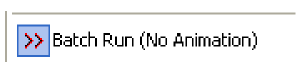
Figure 16: Project Parameters in Run Setup Window

(2) Turn off the animation to speed up the simulation

On the developer's computer, it takes half an hour to finish a replication with animation, but it only takes 2 minutes for a replication without animation, so it's highly recommended to turn off the animation when running multiple replications.

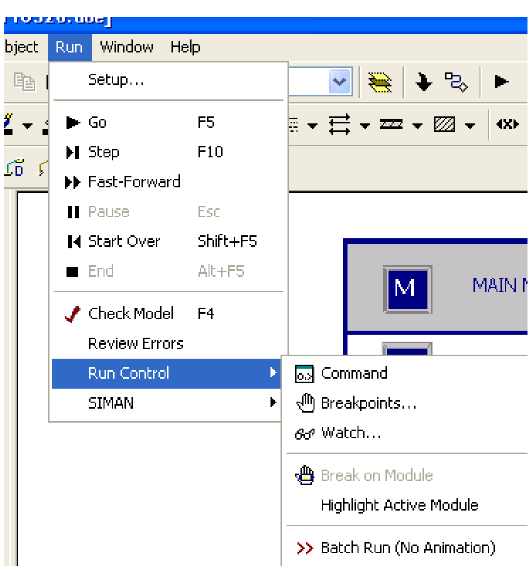
a. Choose Run Control under the Run menu as shown in Figure 17.

b. Click on >>Batch Run (No Animation) to turn off the animation.

c. If the arrow button 

is highlighted, this means animation has been turned off already. If the arrow button is not highlighted, this means animation is on.

d. If you want to see the animation and you've changed the simulation start day in the Run Setup dialog, please change the start day in the animation clock, as shown in Figure 8.



(3) Run the simulation

a. Choose 

under the Run menu, or press Go command () on the toolbar, or press the F5 key to start a simulation.

Figure 17: Run Control under Run menu

(4) Input data in the Parameter setting window, as shown below.

a. Change data then click OK (The default value here would show up with the window.).

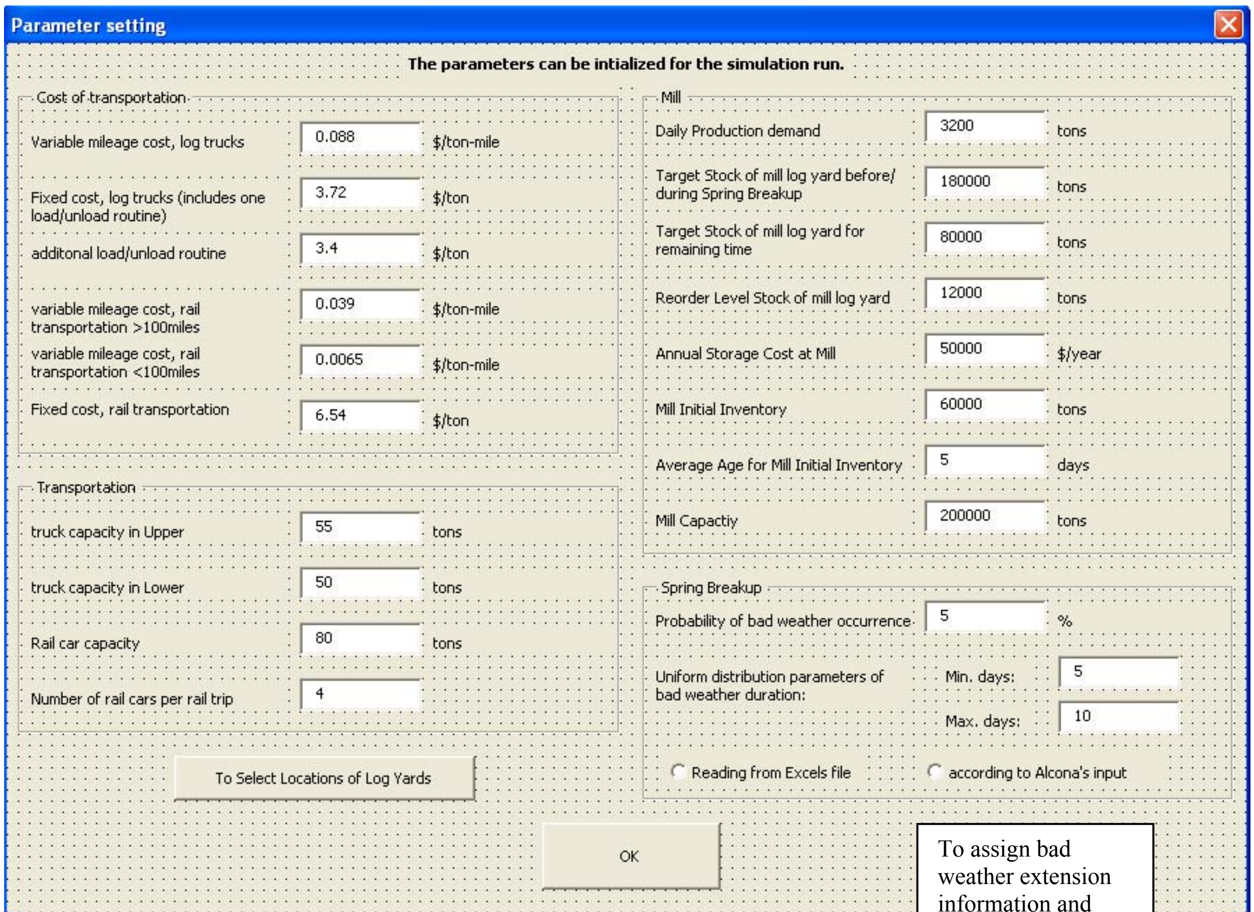


Figure 18: Parameter setting window

b. The data read in this way is listed in the preceding section, "Input Data I: Parameter Setting Window".

c. Other data is read in from an Excel spreadsheet, as described in the preceding section "Input Data II: Excel Input File".

d. To select location of log yards from available ones, press the "To Select Locations of Log Yards" button, and another map window opens as shown in Figure 19. Three rail yards and one truck yard are recommended for simulation. Default yards are Plains, Shingleton and Gulliver for rail yards, and Onaway for the truck yard. Press OK after selection to go back to the Parameter setting window.

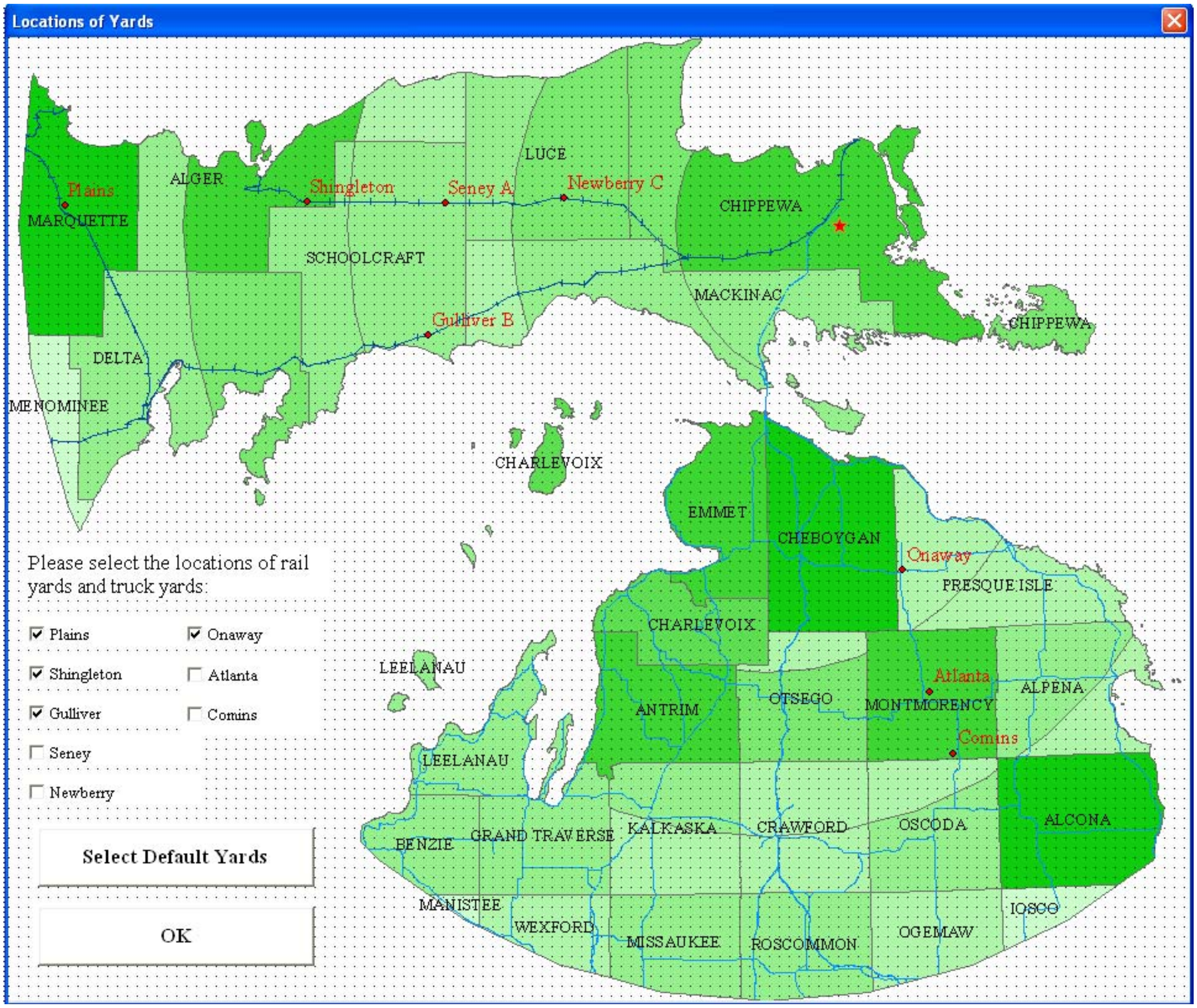


Figure 19: Log yards selection window

e. If "Reading from Excel file" is chosen, another window opens as shown in Figure 20. Choose one or multiple historical years and then click OK. Note that if you input 7 for Number of Replications in the Run Setup Window, as shown in Figure 15, but choose only 4 historical years here, then the other 3 replications will be based on Alcona County's input with default parameters.

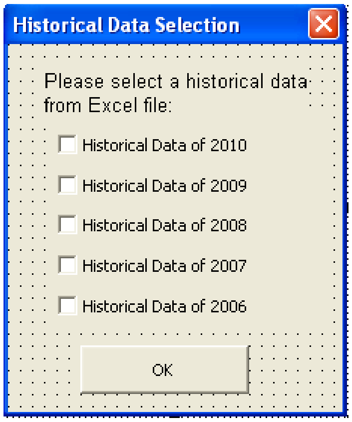
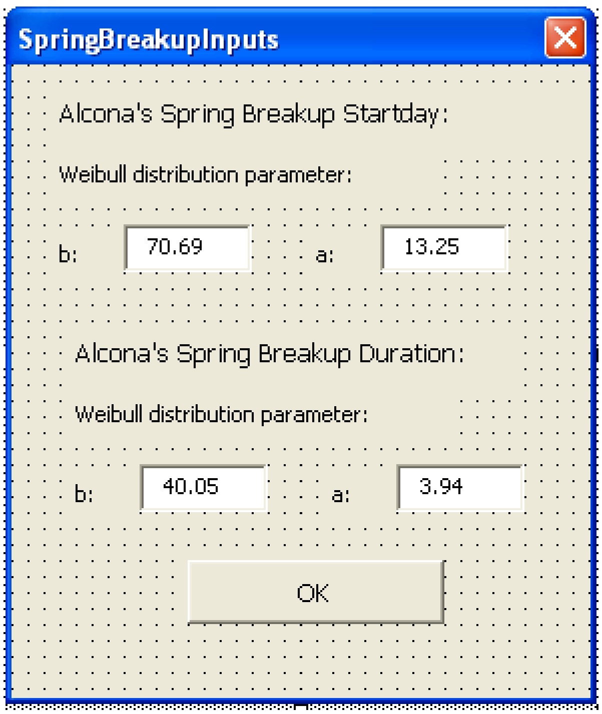


Figure 20: Spring Breakup Historical Data Selection Window



f. If "According to Alcona's input" is chosen, then another window opens as shown in Figure 21. The user can choose the distribution parameters of the start day and duration of Alcona County's spring breakup, and then the other counties' start days and durations would be calculated according to the relationship developed from historical data from 2005 to 2010. All days calculated here are specified as days from Jan. 1. For example, the minimum end day 108 means the 108th day from Jan. 1, which is April 17. Note that if the simulation were started in June 1, 2011, the spring breakup in Alcona County might end in April 17, 2012.

Figure 21: Spring Breakup Calculation Window

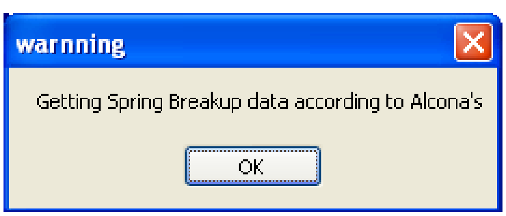


Figure 22: Warning Window

g. If the user forgets to select a way to input spring breakup data before clicking on OK in the Parameter setting window, a warning window opens as shown in Figure 22, and the simulation reads data according to Alcona County's.

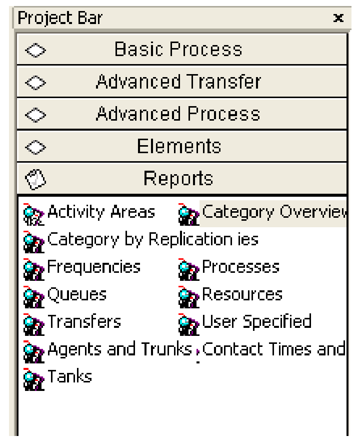
h. Note the day in Spring Breakup table in input file based on the Jan. 1 of the simulation year, but all other time input data, such as the weeks in transportation plan, are based on simulation start day.

i. To suspend the simulation, press ⏸ on toolbar. (Please see details about these buttons in the section "A Brief Introduction to Arena".)

(5) View the simulation reports created by Arena:

a. A message box appears when the simulation ends:

b. Click ‘Yes’ to see the reports, or ‘No’ to ignore them;



c. Even if you click ‘No’, you can still see the reports by going to the Reports panel as shown in Figure 2 (also shown on the right).

d. Note these reports are rewritten when a new simulation begins.

e. These reports include information from the modules in Arena, such as the entity, queue, activity area or others selected in Figure 16. These results may not be helpful to the user, but may be relevant to the program developer. Viewing the results in Excel output file is highly recommended for the user. Please see details in the section "Output Data Summary" of this manual.

(6) View the results written out to a spreadsheet

a. Open "Outputs of CoEE Supply Chain Simulation with 46 harvest areas.xls" which should be in the same folder as the Arena model (executable file with ".doe" in its name);

b. The data written out to this spreadsheet are described in Section "Output Data Summary".

Output Data Summary

Output Data I: Output in Reports

Two different reports are currently written--one is a category overview report, and the other is a category report by replications. The category overview report provides statistics that are summarized over all replications, while the 'categories by replications' reports are specific to each replication.

3.3.1 Entity data

This report provides the time data and of the number of entities entering and leaving the model. Time data includes VA time (value-added time), NVA time (non-value-added time), wait time, transfer time, and the total time for entities, which are logs in the model.

3.3.2 Queue data

This report provides the waiting time and number of e logs waiting in the queue. Queues are used to model the event of waiting prior to a select or a hold-type block (such as requiring a transporter, or waiting for signal). For example, 'Request Trucks at Yard 11.Queue' refers to the queue of logs in yard1 that are waiting to be transported by trucks.

3.3.3 User specified data

Other customized reports may be generated.

Output Data II: Output in Excel

Output data in Excel includes total cost, emissions and energy consumption; inventory in roadside storages, yards and mill; log age; unit storage cost; spring breakup; and transportation summaries.

Total cost (the cost over the whole year) includes transportation cost, harvesting cost and storage cost. Total emissions include emissions from rail, truck, machinery in yards, and harvesting. Total energy consumption includes fuel use by transporters, yard machinery, and harvesting activities. Log age data includes average age and maximum age in the mill stock. Transportation data indicate the number of trucks and rail cars used.

Each of these outputs is available as a time series plot (either daily or cumulative) and as a single total value for the simulation (cumulative at the end of the year). These output data are saved in file 'Outputs of CoEE Supply Chain Simulation with 46 harvest areas.xls' as follows:

(1) Max age of log leaving

The maximum age of logs leaving mill for production every day, for multiple replications;

(2) Average age of log leaving

The average age of logs leaving mill for production every day, for multiple replications;

(3) Max age of log arriving

The maximum log age of logs arriving at mill every day, for multiple replications;

(4) Average age of log arriving

The average log age of logs arriving at mill every day, for multiple replications;

(5) Mill Inventory

The mill yard inventory with target level inventory information in mill yard, for multiple replications, in units of days (one day represents storage feeding mill production for one day), and the daily logs transported to mill by rail for the 1st replication;

(5) Log yard 1 inventory

The log yard 1 inventory, with reorder level and target level inventory information in log yard 1, for multiple replications, in units of tons;

(6) Rail yard 1 inventory

The rail yard 1 (rail yard 1 is log yard 4) inventory, with reorder level and target level inventory information in rail yard 1, for multiple replications, in units of tons;

(7) Roadside storage 1 inventory

The roadside storage 1 inventory, for multiple replications, in units of tons;

(8) Total cost

The total cost information, for multiple replications, in units of $1000;

(9) Total fuel consumption

The total fuel consumption information, for multiple replications, in units of MJ;

(10) Total Emission

The total CO_2 emission information, for multiple replications, in units of kg GHG;

(11) Spring breakup information

The start day and duration of Spring Breakup for each replication, in case the user is interested in the differences between each replication.

(12) Unit Storage Cost

The unit storage cost in mill, log yards and roadside storages in units of $/day-ton;

An example of model output is shown in Figure 23, which is part of a table of mill inventory values (in units of days). The first column represents the day of the simulation; the column named "mill inventory/days" represents the daily mill inventory in unit of days, meaning the inventory enough for how many days of production; the column named "replication" gives the replication information; the "Reorder/tons" column gives the reorder level inventory in the mill in units of tons; the "Target/tons" column gives the target level inventory in mill in units of days; and the first column under "logs by rail/tons" represents the daily logs transported to the mill by rail in units of tons, and the last column under "logs by rail/tons" represents the total logs transported by rail up to that time. Taking the first day for example, if the simulation starts on June 1st, 2011, then on June 1st, 2011, the mill has an inventory of 18.75 days which means 18.75*3200 tons, where the daily production 3200 tons is defined in the "Parameter setting" window, while the reorder level is 3.75*3200 tons and the target level is 25*3200 tons, and no logs have been transported to the mill by rail.

day	mill inventory/ days	replication	Reorder /days	Target /days	logs by rail /tons	
1	18.75	1	3.75	25	0	0
2	17.75	1	3.75	25	0	0
3	16.9390625	1	3.75	25	0	0
4	16.509375	1	3.75	25	0	0
5	16.4421875	1	3.75	25	0	0
6	16.246875	1	3.75	25	0	0
7	16.209375	1	3.75	25	0	0
8	16.0453125	1	3.75	25	0	0
9	15.9765625	1	3.75	25	0	0
10	15.678125	1	3.75	25	275	275
11	16.1203125	1	3.75	25	1320	1595
12	16.21875	1	3.75	25	605	2200
13	16.38125	1	3.75	25	1320	3520
14	16.3703125	1	3.75	25	935	4455
15	16.66875	1	3.75	25	1265	5720
16	17.1109375	1	3.75	25	1320	7040
17	17.58125	1	3.75	25	1265	8305
18	17.43125	1	3.75	25	605	8910
19	17.4890625	1	3.75	25	990	9900
20	17.9453125	1	3.75	25	1265	11165
21	17.93125	1	3.75	25	1265	12430
22	18.2359375	1	3.75	25	660	13090
23	18.184375	1	3.75	25	990	14080
24	18.659375	1	3.75	25	1265	15345
25	18.7328125	1	3.75	25	1265	16610
26	19.03125	1	3.75	25	1265	17875
27	19.4515625	1	3.75	25	990	18865

Figure 23: Mill Inventory in output file

Figure 24 is a graph of mill inventory for a set of three replications which would appear in the same worksheet, with the mill inventory data above. As the legend indicates in the graph, the three replications of mill inventory are indicated by the name of "replication i". Also shown are the target level inventory, which changes in different time periods in this simulation. More explanation is provided in Figure 24 below. Another graph showing the daily log transported by rail to mill of replication 1 is below the Mill Inventory one.

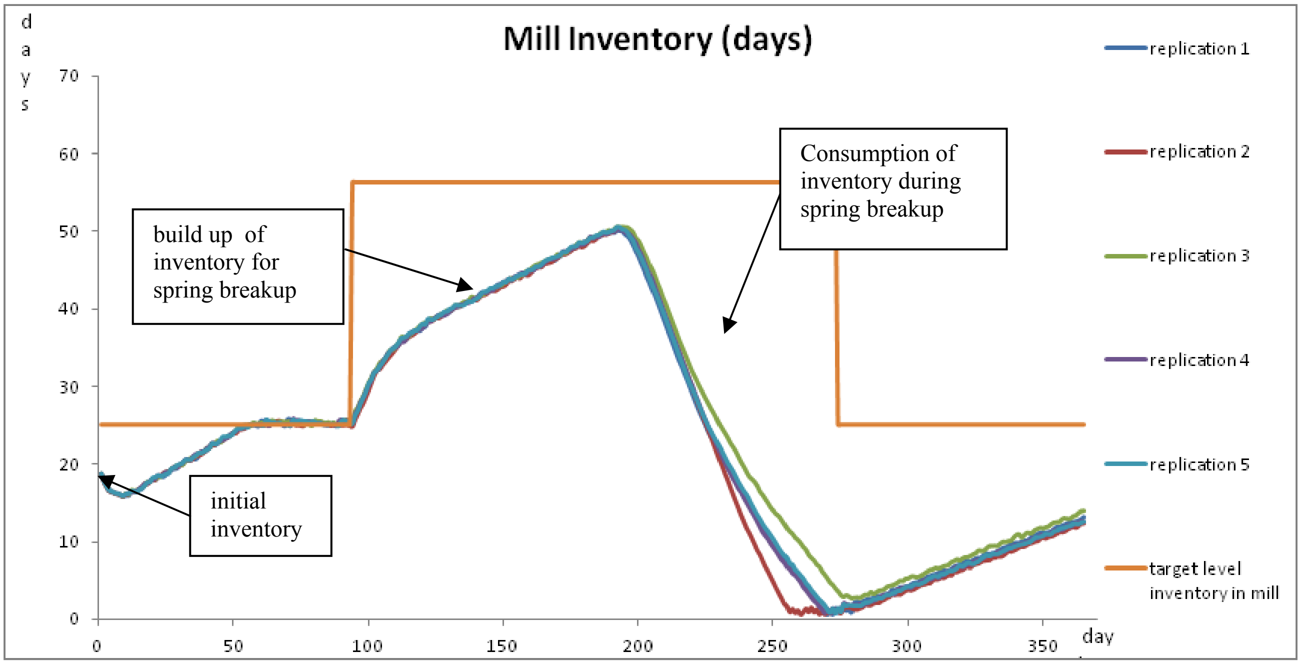


Figure 24: Facility (Mill) Inventory Graph

Output File: Outputs of CoEE Supply Chain Simulation with 46 harvest areas.xls

The output file "Outputs of CoEE Supply Chain Simulation with 46 harvest areas.xls" is the file keeping simulation results, and some Marcos developed by Visual Basic is used to interpret the results easily.

If you would like to check the results after simulation, open the Excel file "Outputs of CoEE Supply Chain Simulation with 46 harvest areas.xls ". An interface as shown in Figure 25 will show up.

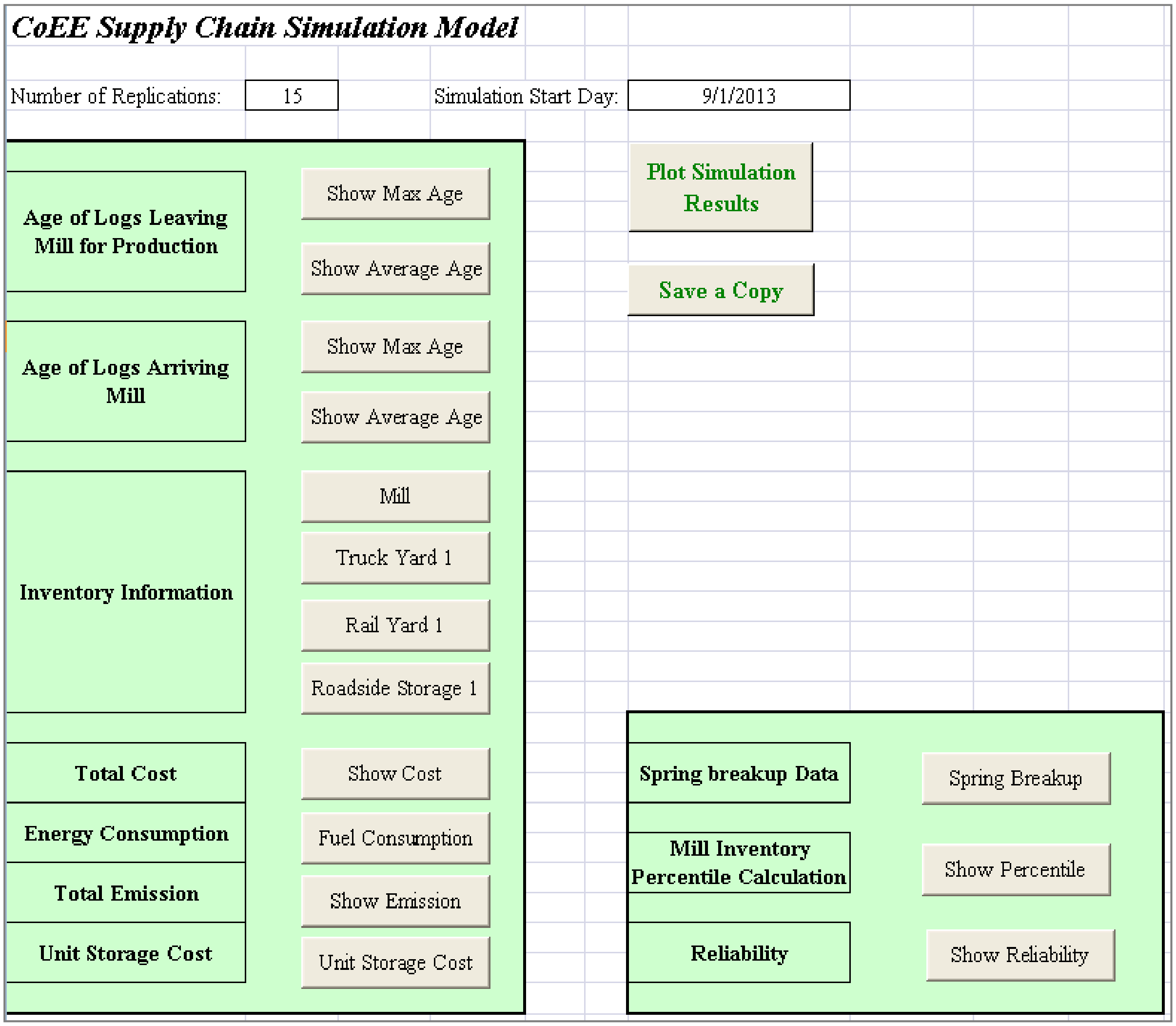


Figure 25: Interface in the output file

"Number of Replications" gives the total replications in the simulation.

"Simulation Start Day" gives the first day for simulation. Every replication begins at that day, and ends 365 days later.

"Plot Simulation Results" button gives an easy way to plot the results. Press it, a window as shown in figure 26 will show up. You can choose one replication or multiple ones of your interest in the "From" box and "To" box. All available replications are listed in the drop-down menu. The number in the "To" box must be equal to or greater than the number in the "From" box, otherwise an error message as shown in figure 27 shows up after you press the OK button.

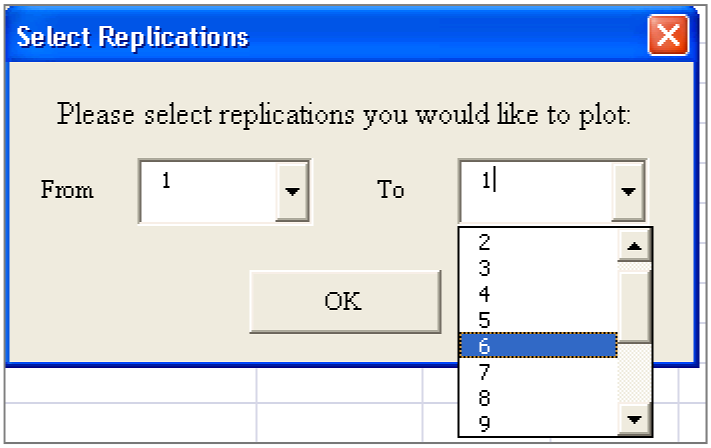


Figure 26: Interface in the output file

Figure 27: An error message

For example, if you've run 5 replications, and "from 1 to 3" were picked to be plotted, the raw number of simulation results for the five replications are still kept in the file, but only replication #1, #2 and #3 would show up in the graph.

"Save a Copy" button will help you save the current file in one step. Current simulation results will be covered by a later one, so if you want to save the current one for reference, you can press this button. A new file named with the current time will be created, and a message saying Save Successfully shows up. Alternatively, you can also go to the main menu of the Excel, choose Save As, and input a file name.

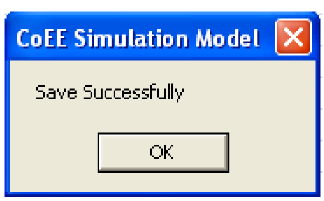


Figure 28: A save successfully message

All the navigation buttons in the interface are explained in the following figure.

Figure 29: Navigation Buttons in Interface

Each of these outputs is available as a time series plot (either daily or cumulative) and as a single total value for the simulation (cumulative at the end of the year). These output data are saved in the file 'Outputs of CoEE Supply Chain Simulation with 46 harvest areas.xls' as follows:

Max age of log leaving sheet is the sheet showing the daily maximum age of logs leaving mill for production, as shown in figure 30. Average age of log leaving sheet, Max age of log arriving sheet and Average age of log arriving sheet are similar to this one.

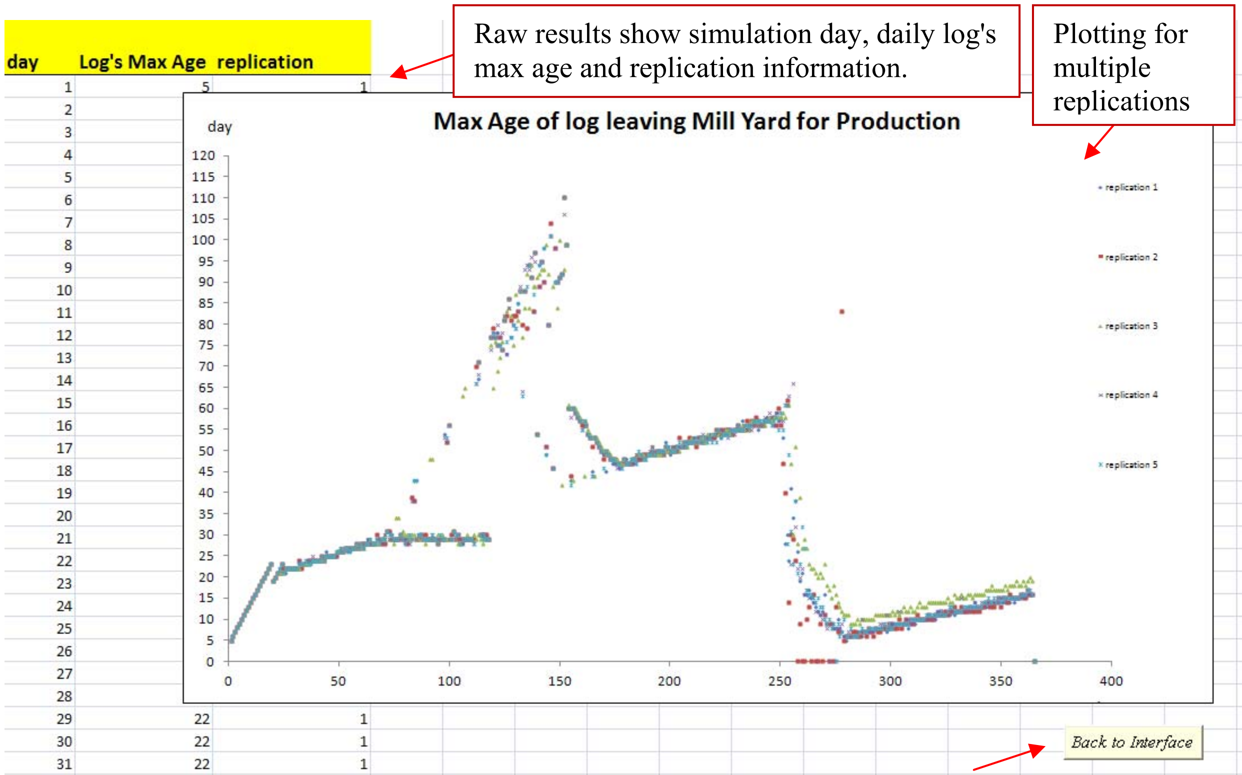


Figure 30: Max age of log leaving sheet

Mill Inventory sheet is the sheet showing mill yard inventory and target level inventory, and the daily logs transported to mill by rail for the 1st replication as shown in figure 31. Log yard 1 inventory sheet, Rail yard 1 inventory sheet and Roadside storage 1 inventory sheet are similar to this one.

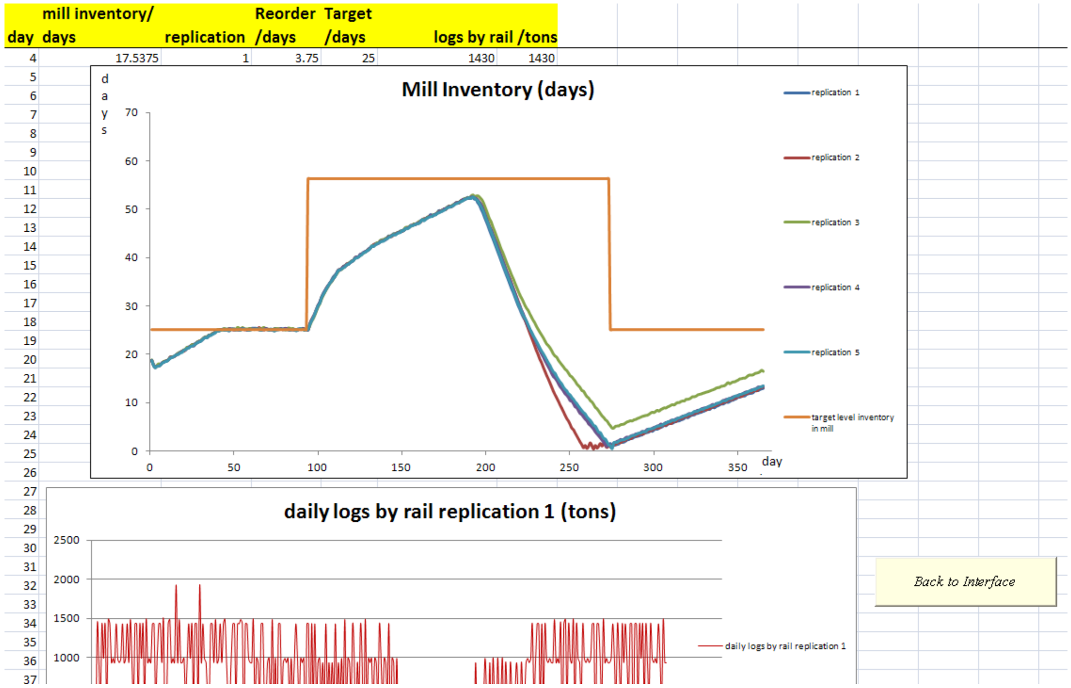


Figure 31: mill inventory sheet

Total cost sheet keeps the total cost information as shown in figure 32, total fuel consumption sheet and total emission sheet are similar to this one.

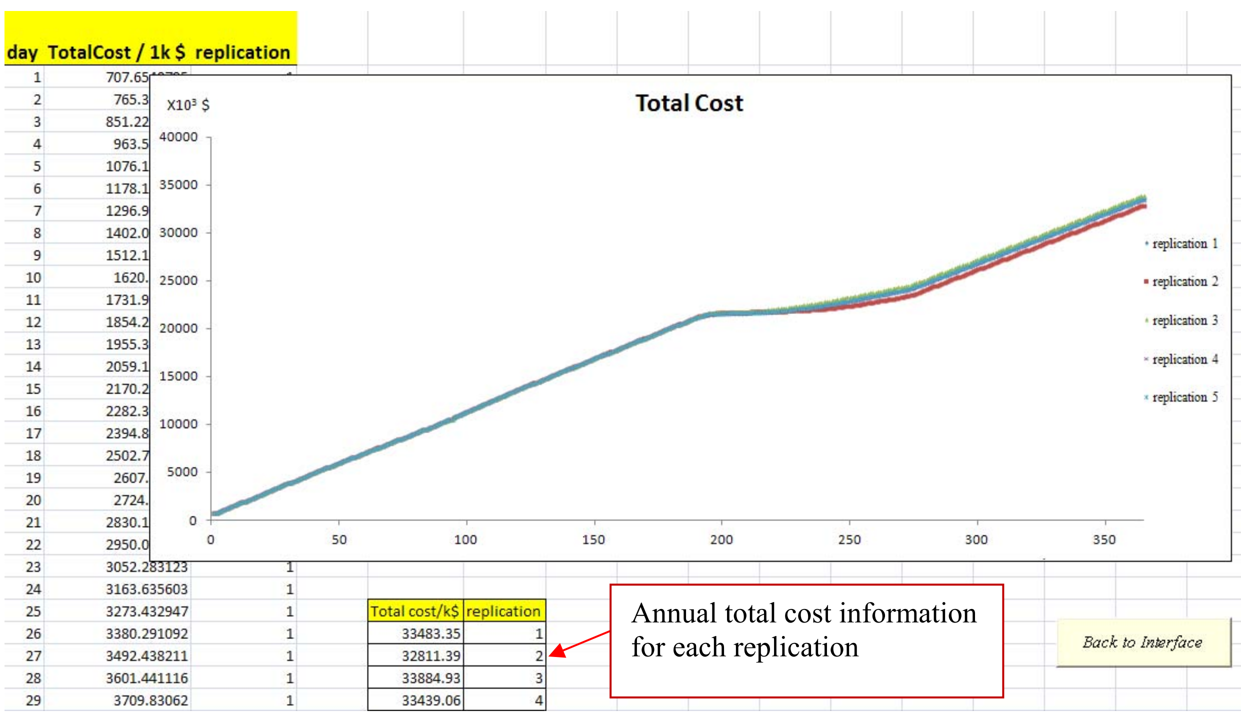
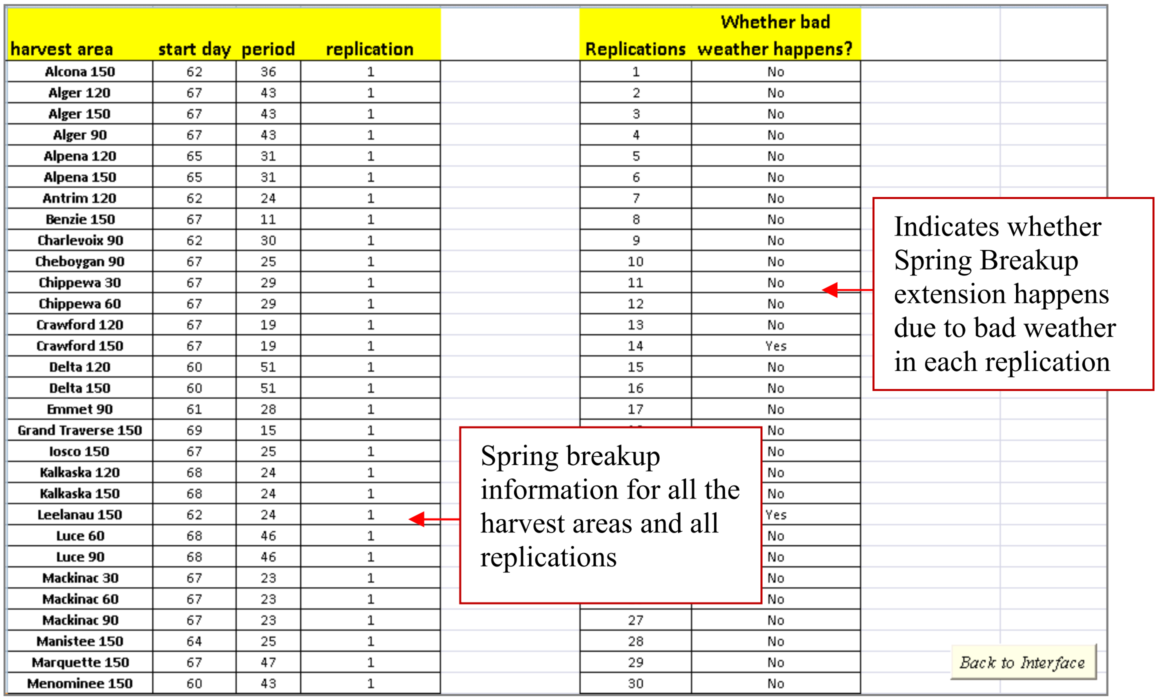


Figure 32: total cost sheet

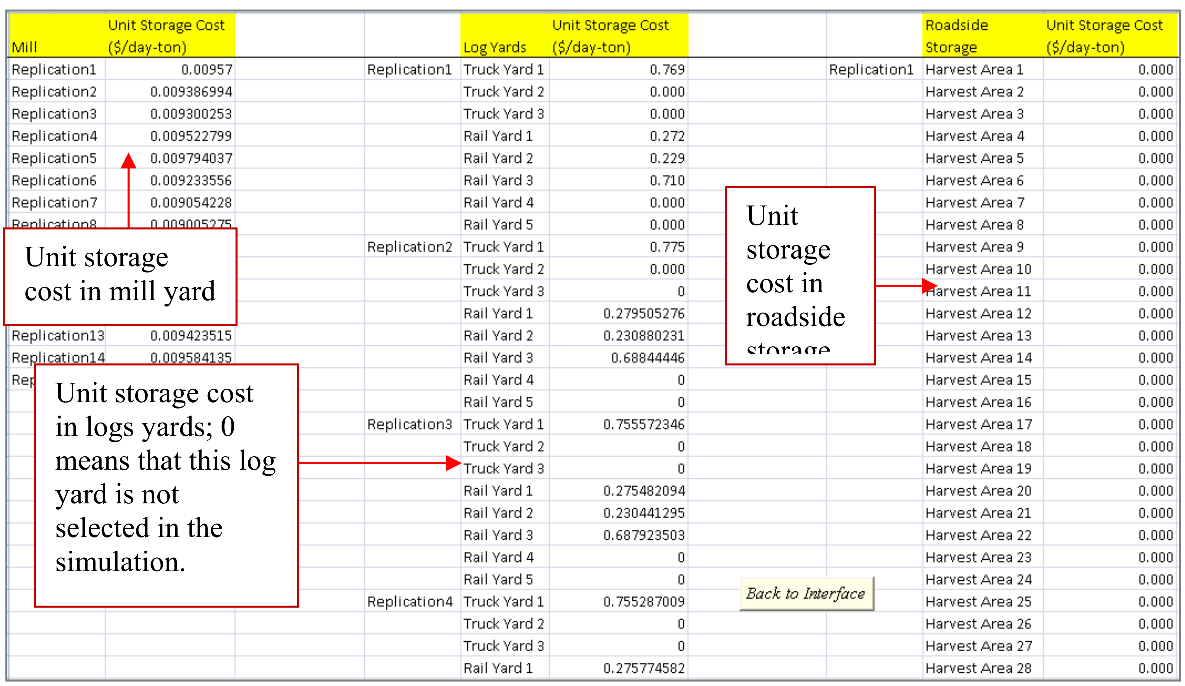
Spring breakup sheet as shown in Figure 33 keeps the spring breakup data used for the simulation.



harvest area	start day	period	replication		Replications	Whether bad weather happens?
Alcona 150	62	36	1		1	No
Alger 120	67	43	1		2	No
Alger 150	67	43	1		3	No
Alger 90	67	43	1		4	No
Alpena 120	65	31	1		5	No
Alpena 150	65	31	1		6	No
Antrim 120	62	24	1		7	No
Benzie 150	67	11	1		8	No
Charlevoix 90	62	30	1		9	No
Cheboygan 90	67	25	1		10	No
Chippewa 30	67	29	1		11	No
Chippewa 60	67	29	1		12	No
Crawford 120	67	19	1		13	No
Crawford 150	67	19	1		14	Yes
Delta 120	60	51	1		15	No
Delta 150	60	51	1		16	No
Emmet 90	61	28	1		17	No
Grand Traverse 150	69	15	1			No
Iosco 150	67	25	1			No
Kalkaska 120	68	24	1			No
Kalkaska 150	68	24	1			No
Leelanau 150	62	24	1			Yes
Luce 60	68	46	1			No
Luce 90	68	46	1			No
Mackinac 30	67	23	1			No
Mackinac 60	67	23	1			No
Mackinac 90	67	23	1		27	No
Manistee 150	64	25	1		28	No
Marquette 150	67	47	1		29	No
Menominee 150	60	43	1		30	No

Figure 33: Spring breakup sheet

Unit Storage Cost sheet as shown in Figure 34 keeps the unit storage cost in mill, log yards and roadside storages.



Mill	Unit Storage Cost ($/day-ton)		Log Yards	Unit Storage Cost ($/day-ton)		Roadside Storage	Unit Storage Cost ($/day-ton)
Replication1	0.00957	Replication1	Truck Yard 1	0.769	Replication1	Harvest Area 1	0.000
Replication2	0.009386994		Truck Yard 2	0.000		Harvest Area 2	0.000
Replication3	0.009300253		Truck Yard 3	0.000		Harvest Area 3	0.000
Replication4	0.009522799		Rail Yard 1	0.272		Harvest Area 4	0.000
Replication5	0.009794037		Rail Yard 2	0.229		Harvest Area 5	0.000
Replication6	0.009233556		Rail Yard 3	0.710		Harvest Area 6	0.000
Replication7	0.009054228		Rail Yard 4	0.000		Harvest Area 7	0.000
Replication8	0.009005275		Rail Yard 5	0.000		Harvest Area 8	0.000
		Replication2	Truck Yard 1	0.775		Harvest Area 9	0.000
			Truck Yard 2	0.000		Harvest Area 10	0.000
			Truck Yard 3	0		Harvest Area 11	0.000
			Rail Yard 1	0.279505276		Harvest Area 12	0.000
Replication13	0.009423515		Rail Yard 2	0.230880231		Harvest Area 13	0.000
Replication14	0.009584135		Rail Yard 3	0.68844446		Harvest Area 14	0.000
Rep			Rail Yard 4	0		Harvest Area 15	0.000
			Rail Yard 5	0		Harvest Area 16	0.000
		Replication3	Truck Yard 1	0.755572346		Harvest Area 17	0.000
			Truck Yard 2	0		Harvest Area 18	0.000
			Truck Yard 3	0		Harvest Area 19	0.000
			Rail Yard 1	0.275482094		Harvest Area 20	0.000
			Rail Yard 2	0.230441295		Harvest Area 21	0.000
			Rail Yard 3	0.687923503		Harvest Area 22	0.000
			Rail Yard 4	0		Harvest Area 23	0.000
			Rail Yard 5	0		Harvest Area 24	0.000
		Replication4	Truck Yard 1	0.755287009		Harvest Area 25	0.000
			Truck Yard 2	0		Harvest Area 26	0.000
			Truck Yard 3	0		Harvest Area 27	0.000
			Rail Yard 1	0.275774582		Harvest Area 28	0.000

Figure 34: Unit storage cost sheet

Percentile sheet as shown in Figure 35 provides a way to perform mill inventory percentile calculation. The calculation is recommended when many replications have run.

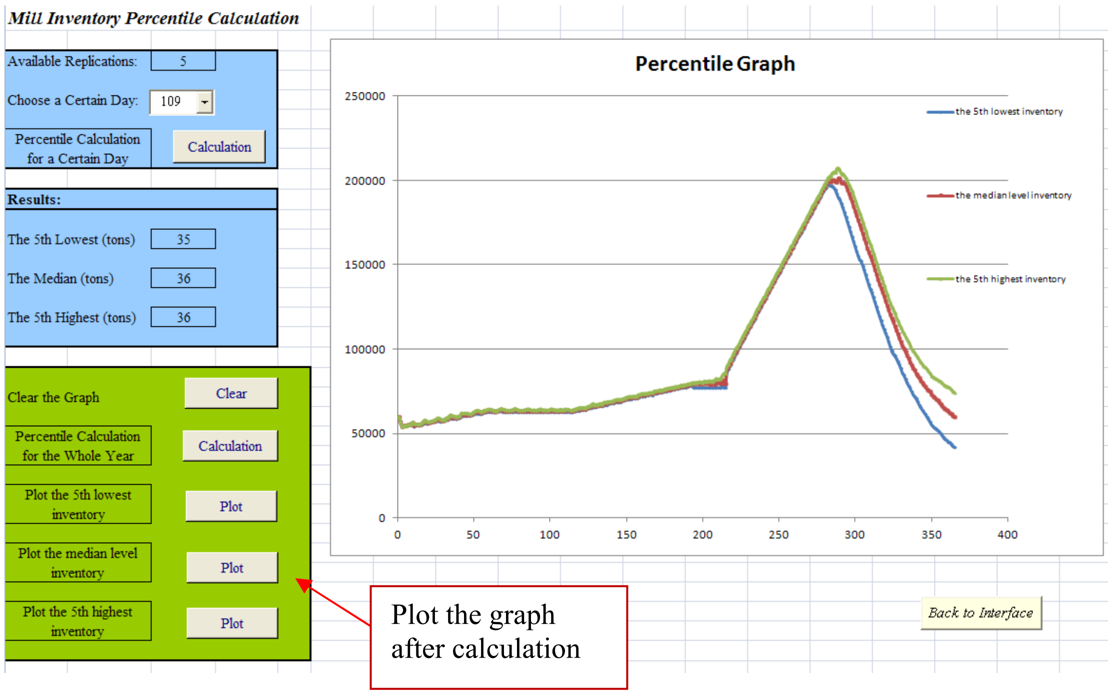
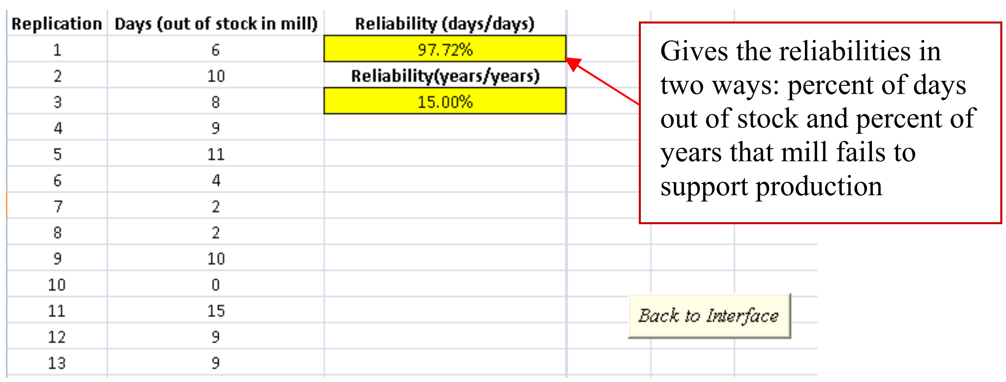


Figure 35: percentile sheet



Replication	Days (out of stock in mill)	Reliability (days/days)
1	6	97.72%
2	10	Reliability(years/years)
3	8	15.00%
4	9	
5	11	
6	4	
7	2	
8	2	
9	10	
10	0	
11	15	
12	9	
13	9	

Figure 36: reliability sheet

Examples for the Arena Output Analyzer

The Output Analyzer component of Arena provides an easy-to-use interface that simplifies data analysis and allows you to view and analyze your data quickly and easily.

The following examples show how to use the Output Analyzer to interpret and analyze the results of simulation studies.

(1) Example 1: a easy way to make a plot for variables that are not in the output excel file

For example, if you are interested in the harvest cost for multiple replications, but only total cost is wrote out into the output file, the Arena Output Analyzer provides an easy way to interprets it. More available expressions in simulation model are presented in the Developer's Guide.

Step 1: An entry is needed in the Statistic module under Advanced Process Template to establish the single overall output performance measure. As shown in Figure 37, the name and report label are both harvest cost, and the type is time-persistent. To enter the expression we want to track over time, right click in that field and choose Build Expression. A window named Expression Builder would show up as in Figure 37. Click down the three via Advanced Process Variables → Expression → CostofLogs, which represents the total harvest cost in unit of dollar. Make a file-name entry, harvest cost.dat, in the output file field. File with extension "dat" is one type of readable files for Output Analyzer.

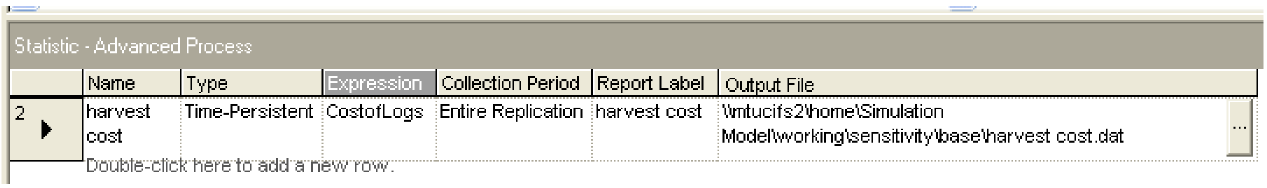


Figure 37: Screenshot of statistic module

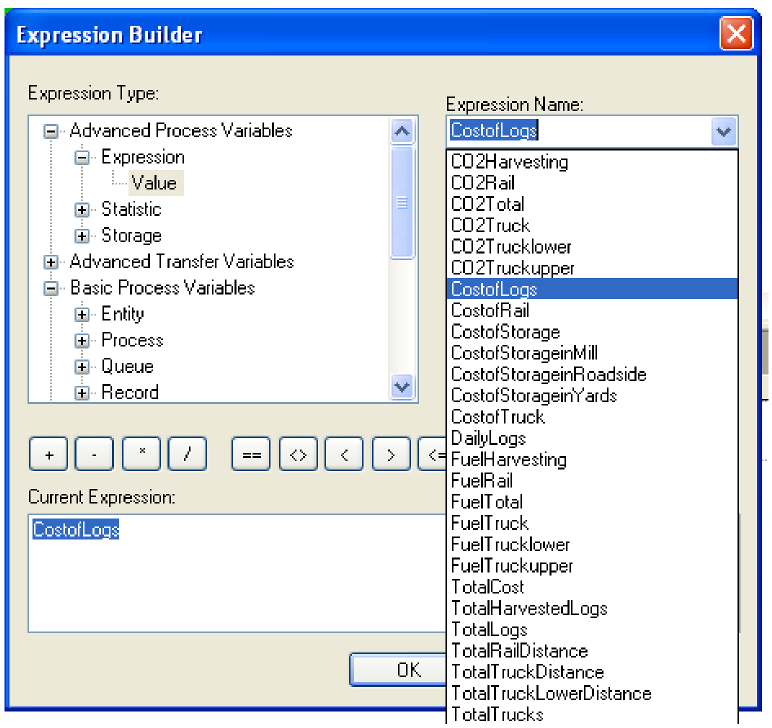
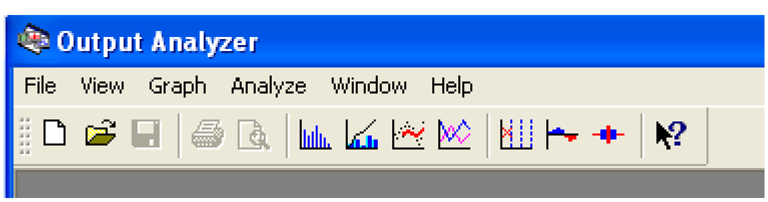


Figure 38: Expression Builder window



Step 2: run the simulation model.
Step 3: plot by the Arena Output Analyzer after the run is complete.

Select Plot on toolbar( ) or Graph > Plot as shown in Figure 39.

Figure 39: Screenshot of Arena Output Analyzer

Add the .dat file, and select "All" in the Replication filed of the Data File dialog box, and type in a title, and change the axis labels as shown in Figure 40.

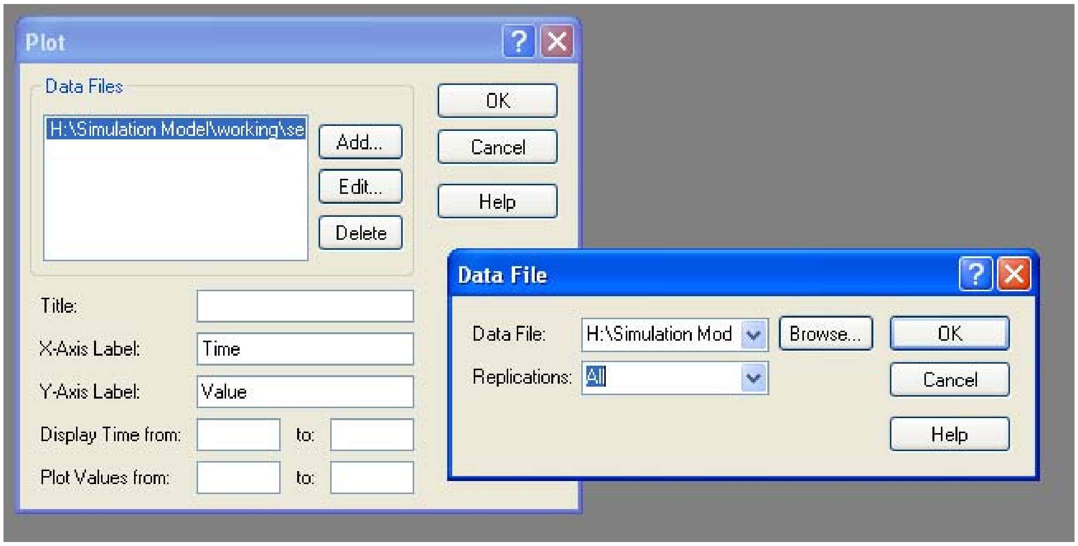


Figure 40: Plot dialog box

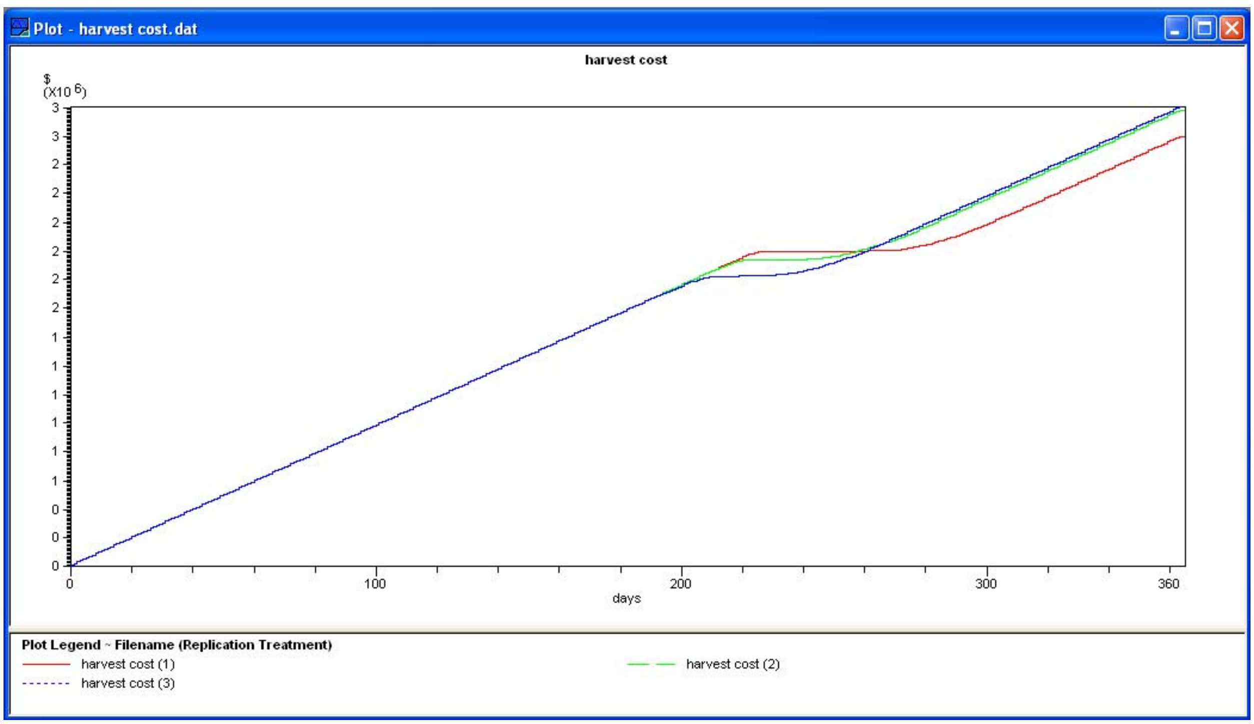


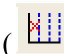
Figure 41: Resulting plot of harvest cost across the replications.

(2) Example 2: an easy way to compare means of a certain variable across replications with different scenarios

In this example, we are going to compare the means of mill inventory across two replications.

At first, data should be exported as shown in the example 1 step 1 and step 2. We keep the mill inventory data from the scenario with a longer spring breakup in file "mill inventory longer sb.dat". And the data from the scenario with a shorter spring breakup is kept in file "mill inventory shorter sb.dat".

Step 3: prepare ".flt" file from ".dat" file for mean comparison

As the output file always contains time-persistent data. We must first Batch/Truncate the data. Doing this, select Batch/Truncate on toolbar () or Analyze > Batch/Truncate obs'ns... as shown in Figure 42.

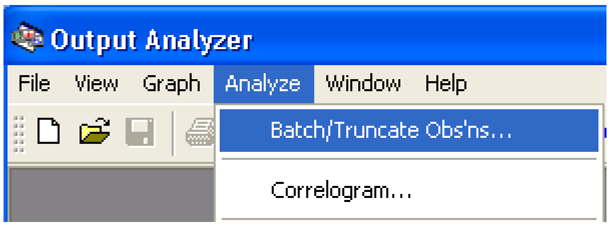


Figure 42: Screenshot of Arena Output Analyzer

Browse for the file mill inventory longer sb.dat, and select "All" or input integer representing the replication number, such as 1 in this example, in the Replication box. You could type in a title, and choose the truncation type and input initial observations/times or choose the batch type and input size. Or you could just leave them in blank as shown in this example. The Truncation Type and Initial Obs/Time fields specify the type of truncation to perform and the number of initial observations or time period to truncate. The Batch Type specifies the type of batching to be performed. The batching averages values in the original dataset that occurs in the Batch Size to create a single new observation. So if you leave all these fields in blank, the truncated initial time would be zero, which is the way in this example to show the original sample as a year period data.

A new file with ".flt" created by Batch or Truncate is specified in Save Batch Means in File field, as it is "mill inventory longer sb.flt" in this example as shown in Figure 43.

The other truncated file named "mill inventory shorter sb.flt" would be created in the same way as above.

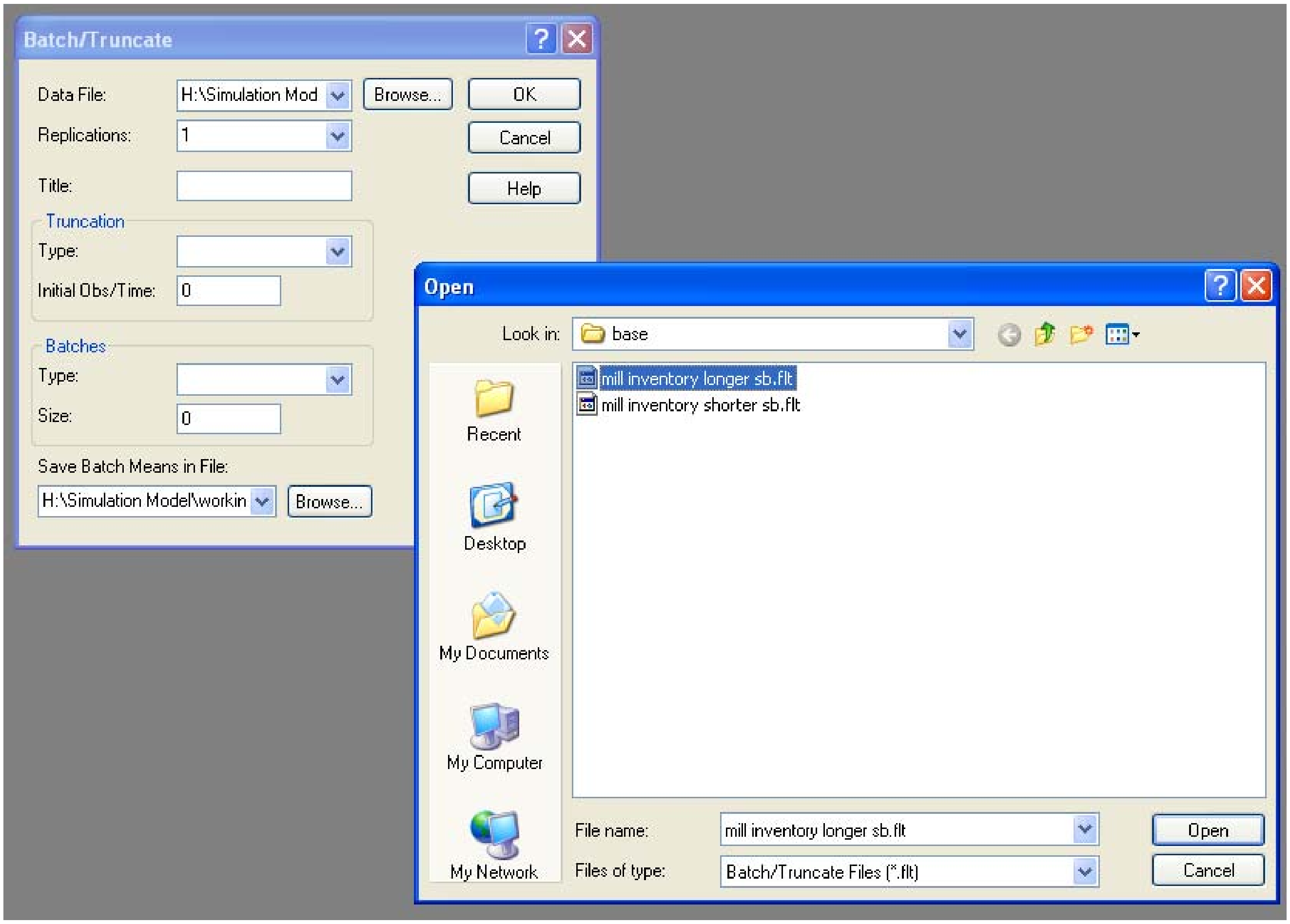


Figure 43: Batch/Truncate dialog box

Step 4: complete the comparison via Analyze > Compare Means

The Compare Means dialog box is shown in Figure C8. We first add the data files in Data Files. Press the button Add..., the Data Files dialog box is shown up as in Figure 44. A pair is choosing file "mill inventory longer sb.flt" as A, "mill inventory shorter sb.flt" as B, and input 1 as their replication number. You can add multiple pairs at one time.

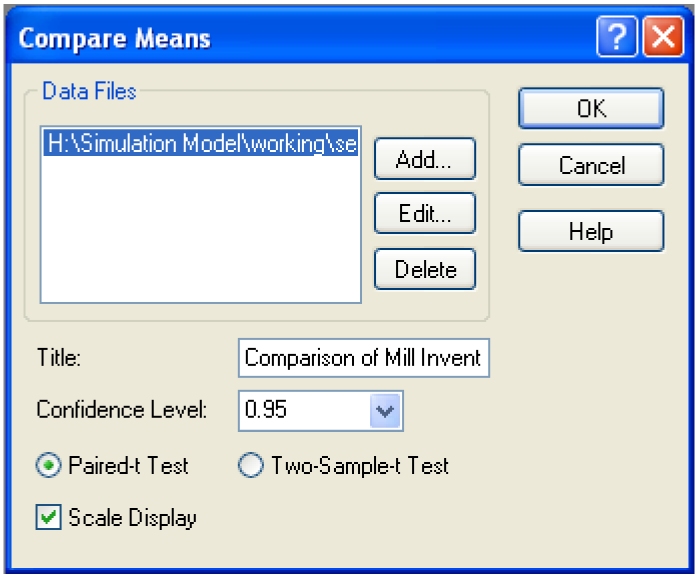


Figure 44: Compare Means dialog box

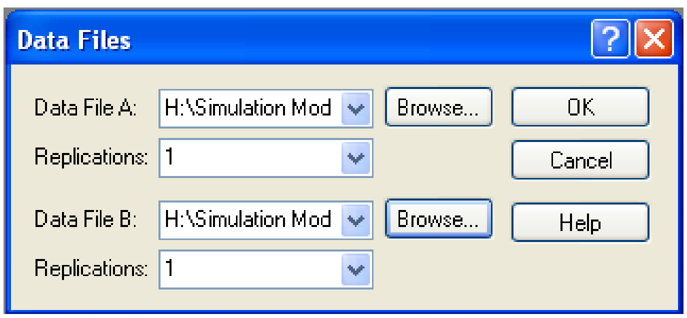


Figure 45: Data Files dialog box

And then fill in a title, accept or change the confidence level for the comparison. The option button group for Paired-t Test and Two-Sample-t Test refers to an issue of random number allocation and statistical independence. The Paired-t Test is the default way, which calculates the difference between each pair of observations across the two data files. The Two-Sample-t Test is usually used when we take deliberate steps to make the scenarios statistically independent. We choose the first one as the test way here, and check the box Scale Display to make a visual comparison. Press Ok, the result window, which is shown in Figure 46, shows up with the result of the difference between the sample means, the standard deviation, the half-width corresponding to the specified confidence level, the minimum and maximum observations, the total number of observations of each data file.

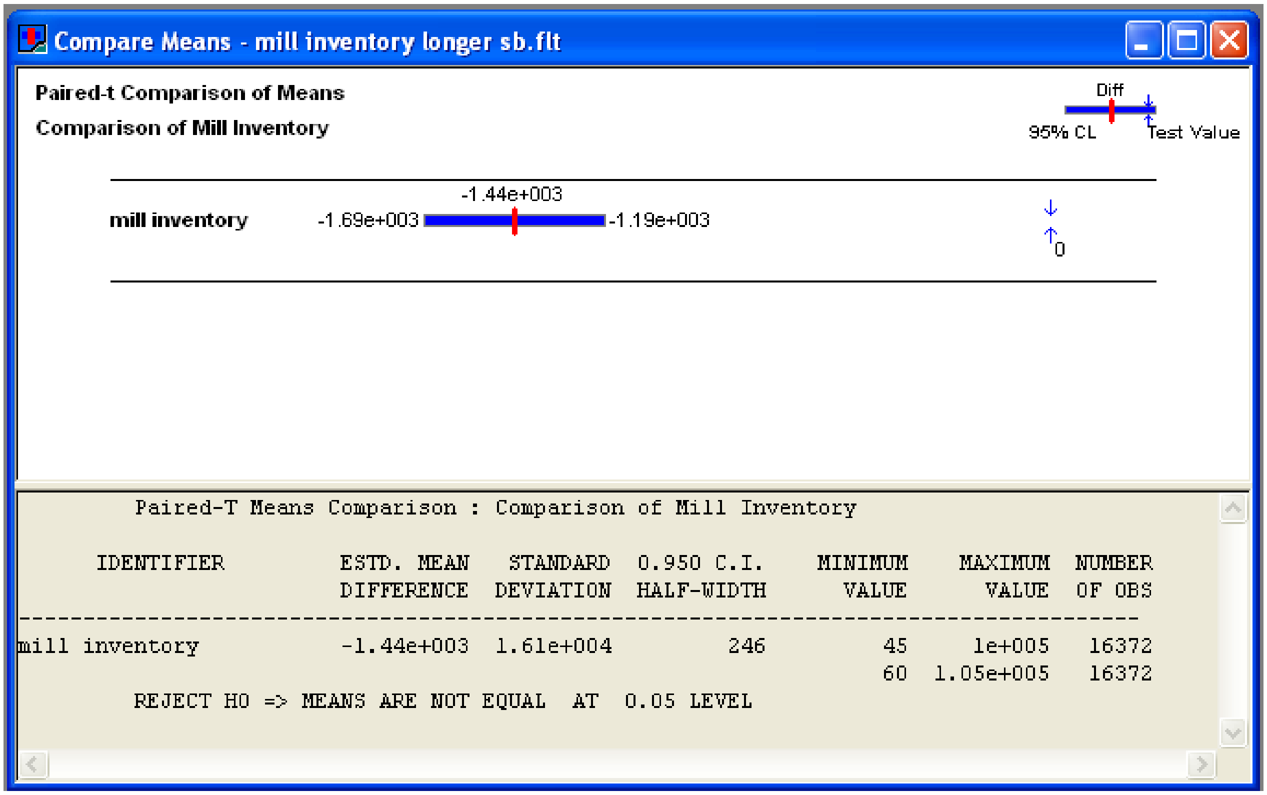


Figure 46: Results comparison window

The Output Analyzer does the subtraction of means in the direction A - B, in other world, file A is the base case. As we can see in the results window, the average mill inventory from longer spring breakup is less than shorter spring breakup, which is a reasonable result because less logs are harvested during longer spring breakup while facility continues to consume the inventory.

(3) Example 3: to forecast values by calculating the moving averages

The Moving Average option generates smooth data by averaging the actual observations of a specified data file, and also can be used to generate an exponentially weighted moving average forecast.

In this example, we would calculate the moving average and produce forecast for the file "mill inventory longer sb.dat" from last example by the Moving Average option.

At first, data are required to export into .dat file similar to step 1 and step 2 in the first example.

Step 3: to truncate the data first as it's time-persistent, the same procedure is shown in step 3 in example 2.

Step 4: to open Moving Average dialog box as shown in Figure 47 by selecting  on toolbar or Graph > Moving Average...

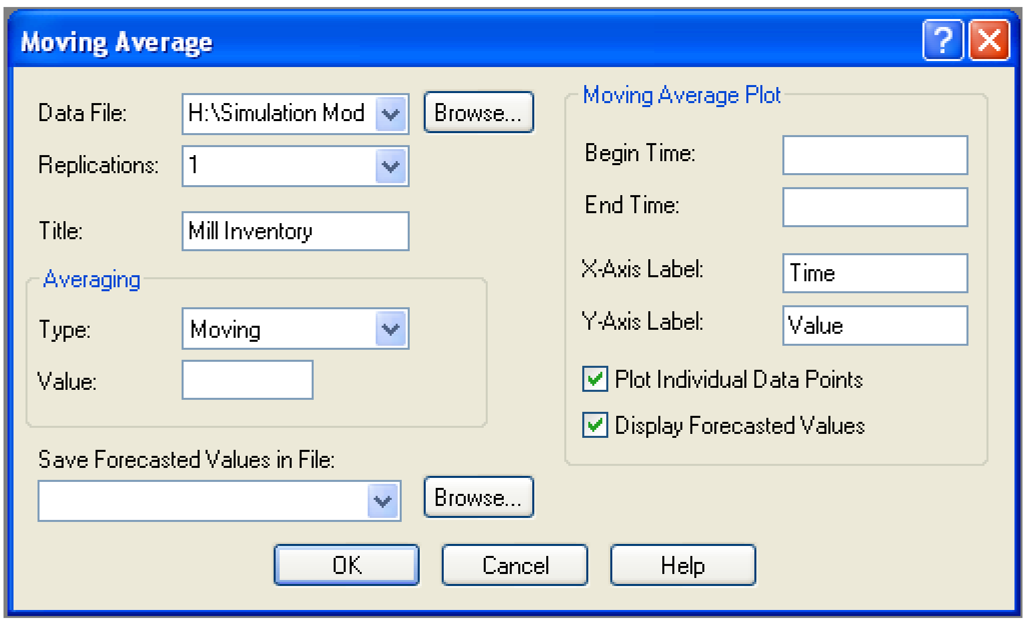


Figure 47: Moving Average dialog box

Choose target file "mill inventory longer sb.flt", fill in the replication number or maybe the title too.

If the Begin Time in Moving Average Plot field is specified, then the calculation of average/smoothed data would begin at the specified time. The changes in Begin Time are likely to change forecasted values. End Time may be specified as a limit on the time range for which the forecasted values are calculated and displayed. The changes in End Time don't affect the actual forecasted values. The option Plot Individual Data Point below is used to instruct the Output Analyzer whether to draw the individual observed values on the plot and list them in a table as well. Similarly, the other option Display Forecasted Values is used to decide whether to list a table of forecasted values. We recommend that both types of information are included.

Averaging Tying includes Moving average, Cumulative average and Exponential smoothing. The Averaging Value below that gives number of periods to be included for Moving average, or allowed minimum data points for Cumulative average, or a factor to generates an exponentially weighted moving averages for Exponential smoothing. The default value is 10, 5 or 0.1 respectively for the three types, if the value field is left in blank.

File to which forecasted values are written are saved in the file specified in Save Forecasted Values in File field, so there is no save if this field is left in blank.

Press OK to show the results window as below.

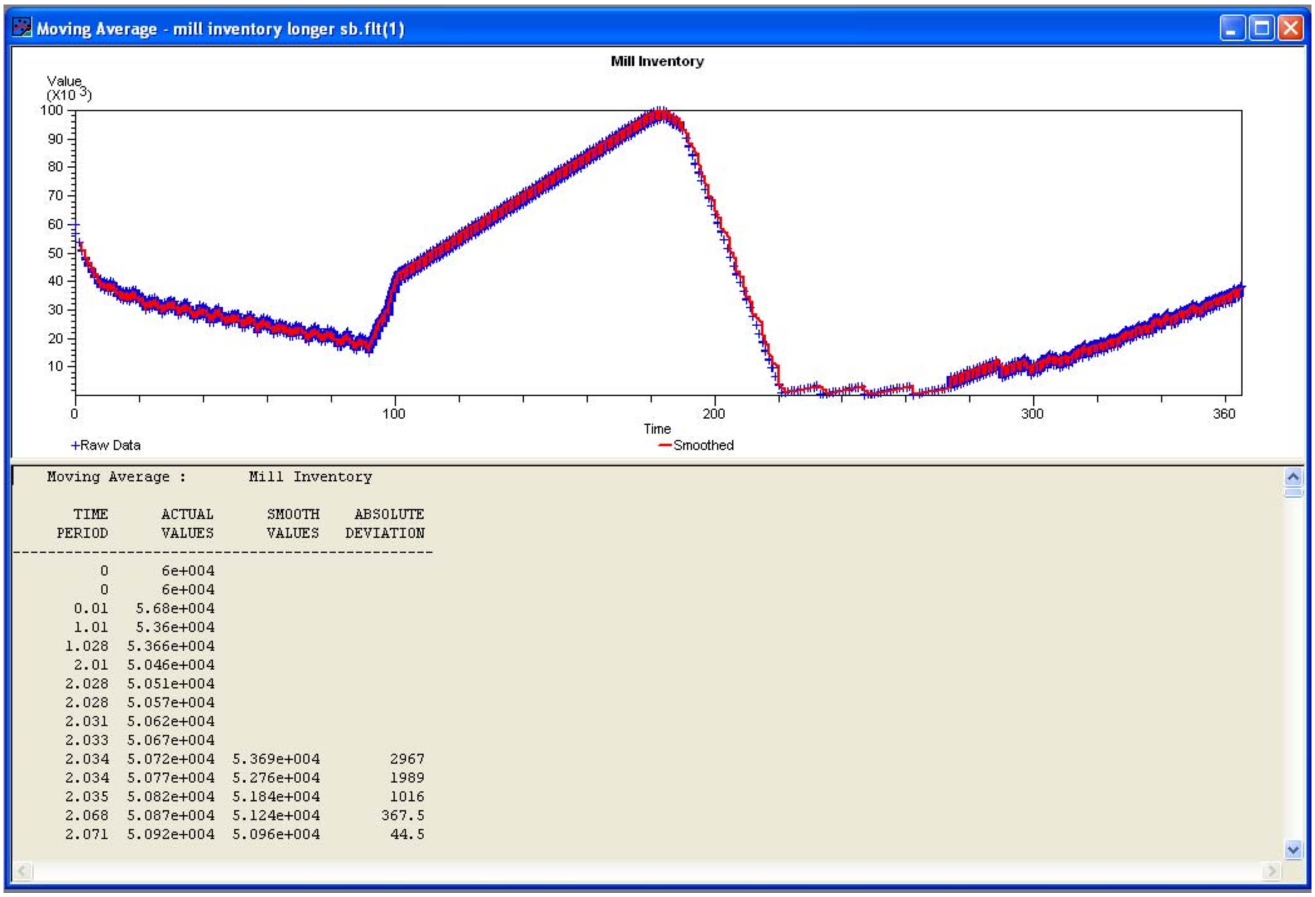


Figure 48: Moving Average results window

We can also check the smooth values by open Graph > Table as shown in Figure 49. Add the forecasted file which ends with .fst to Data Files, type in Title and other field as you need, then press OK to show the table.

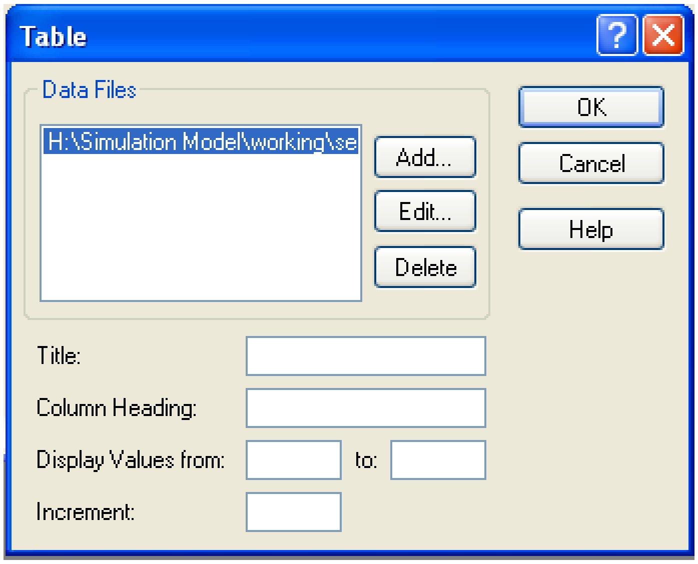
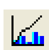


Figure 49: Table dialog box

(4) Example 4: to generate a histogram of a certain variable

A histogram of the variable whose history is stored in Data file can be created via Histogram command which is  in the toolbar or Graph > Histogram...

At first, data should be exported as shown in the example 1 step 1 and step 2. In this example, we are going to plot a histogram for mill inventory data which are kept in "mill inventory.dat".

The Histogram dialog box is shown in the Figure 50. Type in the number of replication or choose All or Lumped in the Replications field. Option All would presents the data from all replications in the file, and option Lumped would lump data from multiple replications.

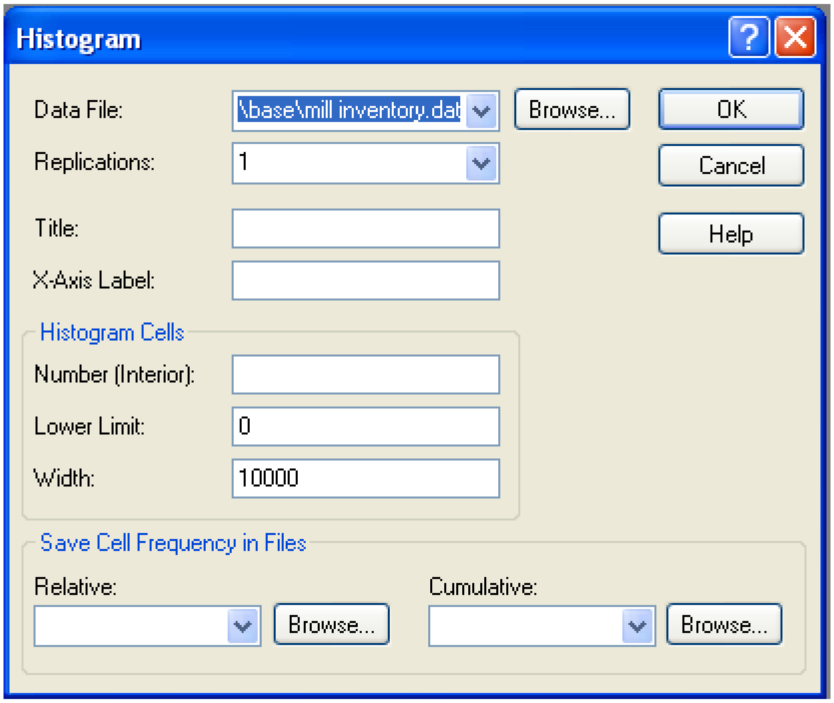
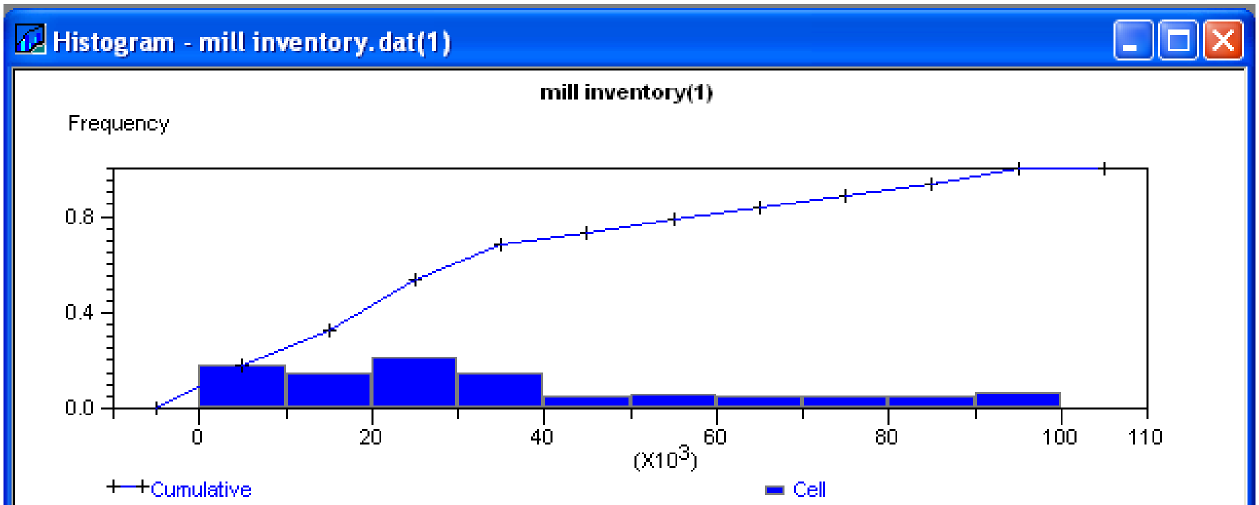


Figure 50: Histogram dialog box

The characteristics of a histogram are defined by specifying the three Histogram Cells values: Number (Interior), Lower Limit and Width. Lower Limit is the lower cell limit for the first interior cell, and the Width is the width of each interior cell. Also, an open cell would be added to each end of the graph to tabulate observations that do not fall into the interior cells. For this example, we just type in 10000 as the Width.

The cell frequencies and relative cumulative frequencies computed for the histogram could be saved by specifying either or both of the Save Cell Frequency in Files fields.

Press OK to see the results window as shown in Figure 50.



Histogram Summary
mill inventory(1)

Cell	Cell Limits From	Cell Limits To	Abs. Freq. (Time) Cell	Abs. Freq. (Time) Cumul.	Rel. Freq. Cell	Rel. Freq. Cumul.
1	-Infinity	0	0	0	0	0
2	0	1e+004	66.75	66.75	0.1829	0.1829
3	1e+004	2e+004	52.65	119.4	0.1443	0.3271
4	2e+004	3e+004	76.29	195.7	0.209	0.5361
5	3e+004	4e+004	53.35	249	0.1462	0.6823
6	4e+004	5e+004	19.06	268.1	0.05223	0.7345
7	5e+004	6e+004	20.02	288.1	0.05484	0.7893
8	6e+004	7e+004	18.01	306.1	0.04935	0.8387
9	7e+004	8e+004	17	323.1	0.04658	0.8853
10	8e+004	9e+004	16.98	340.1	0.04653	0.9318
11	9e+004	1e+005	24.89	365	0.0682	1
12	1e+005	+Infinity	0	365	0	1

Figure 51: Histogram results window

We can see that Histogram option generates both a table listing the cell and cumulative data as well as a graphical plot of this information in Figure 15. We can also tell that almost 70 percent of data fall in the range from 0 to 40000 tons (as 0.1829+0.1443+0.209+0.1462 in the column relative frequency cell), which means mill inventory are less than 40000 tons for approximately 70 percent time in the year.

Available Expressions for Output in the Simulation Model

expression	unit	meaning	recommended form for output	property
TotalTruckUpperDistance	miles	the total distance travelled by truck in U.P.	TotalTruckUpperDistance*0.001	cumulative
TotalTrucksUpper		the total number of trucks used in U.P.	TotalTrucksUpper	cumulative
TotalTrucksLower		the total number of trucks used in L.P.	TotalTrucksLower	cumulative
TotalTrucks		the total number of trucks used	TotalTrucks	cumulative
TotalTruckLowerDistance	miles	the total distance travelled by truck in L.P.	TotalTruckLowerDistance*0.001	cumulative
TotalTruckDistance	miles	the total distance travelled by truck	TotalTruckDistance*0.001	cumulative
TotalRailDistance	miles	the total distance travelled by rail	TotalRailDistance	cumulative
TotalLogs	tons	the total logs during the year, including harvested logs and initial inventory in mill, log yards or roadside storages	TotalLogs*0.001	cumulative
TotalHarvestedLogs	tons	the total harvested logs during the year	TotalHarvestedLogs*0.001	cumulative
TotalCost	dollars	the whole cost including transportation, harvesting and storage	TotalCost*0.001	cumulative
FuelTruckupper	MJ	fuel consumed by truck during transportion in U.P.	FuelTruckupper*0.001	cumulative
FuelTrucklower	MJ	fuel consumed by truck during transportion in L.P.	FuelTrucklower*0.001	cumulative
FuelTruck	MJ	fuel consumed by truck during transportion	FuelTruck*0.001	cumulative
FuelTotal	MJ	total fuel consumed during the whole process	FuelTotal*0.001	cumulative
FuelRail	MJ	fuel consumed by rail during transportion	FuelRail*0.001	cumulative
FuelHarvesting	MJ	fuel consumed during harvesting	FuelHarvesting*0.001	cumulative
DailyLogs	5 tons	the daily harvested logs	DailyLogs*5	instantaneous
CostofTruck	dollars	the cost of truck	CostofTruck	cumulative
CostofStorageinYards	dollars	the storage cost in all logs yards	CostofStorageinYards	annual
CostofStorageinRoadside	dollars	the storage cost in roadside storage	CostofStorageinRoadside	annual
CostofStorageinMill	dollars	the storage cost in mill yard	CostofStorageinMill	annual
CostofStorage	dollars	the storage cost	CostofStorage	instantaneous
CostofRail	dollars	the cost of rail	CostofRail	cumulative
CostofLogs	dollars	the cost of harvesting	CostofLogs	instantaneous
CO2Truckupper	kg GHG	emission caused by truck in U.P.	CO2Truckupper*0.001	cumulative
CO2Trucklower	kg GHG	emission caused by truck in L.P.	CO2Trucklower*0.001	cumulative
CO2Truck	kg GHG	emission caused by truck	CO2Truck*0.001	cumulative

CO2Total	kg GHG	total carbon emission	CO2Total*0.001	cumulative
CO2Rail	kg GHG	emission caused by rail	CO2Rail*0.001	cumulative
CO2Harvesting	kg GHG	emission caused by harvesting	CO2Harvesting*0.001	cumulative

Appendix J: Simulation Developer's Guide

CoEE Supply Chain Simulation Model Developer's Manual

Feb 27th. 2012

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Introduction

A supply chain simulation model for a bio-fuel facility is developed using the ARENA software. The facility is located in Chippewa County's Kinross Township in Michigan's Upper Peninsula, as shown in Figure 0. The simulation model currently includes 46 harvesting areas (43 areas corresponding to counties and 30-mile haul zones within 150 miles of Kinross plus three for areas in the U.P. farther away than 150 miles), 1 truck yards in the L.P., and 3 log yards at rail spurs in the U.P. The simulation lasts for one year, using a daily time step, and the start day is selected by user.

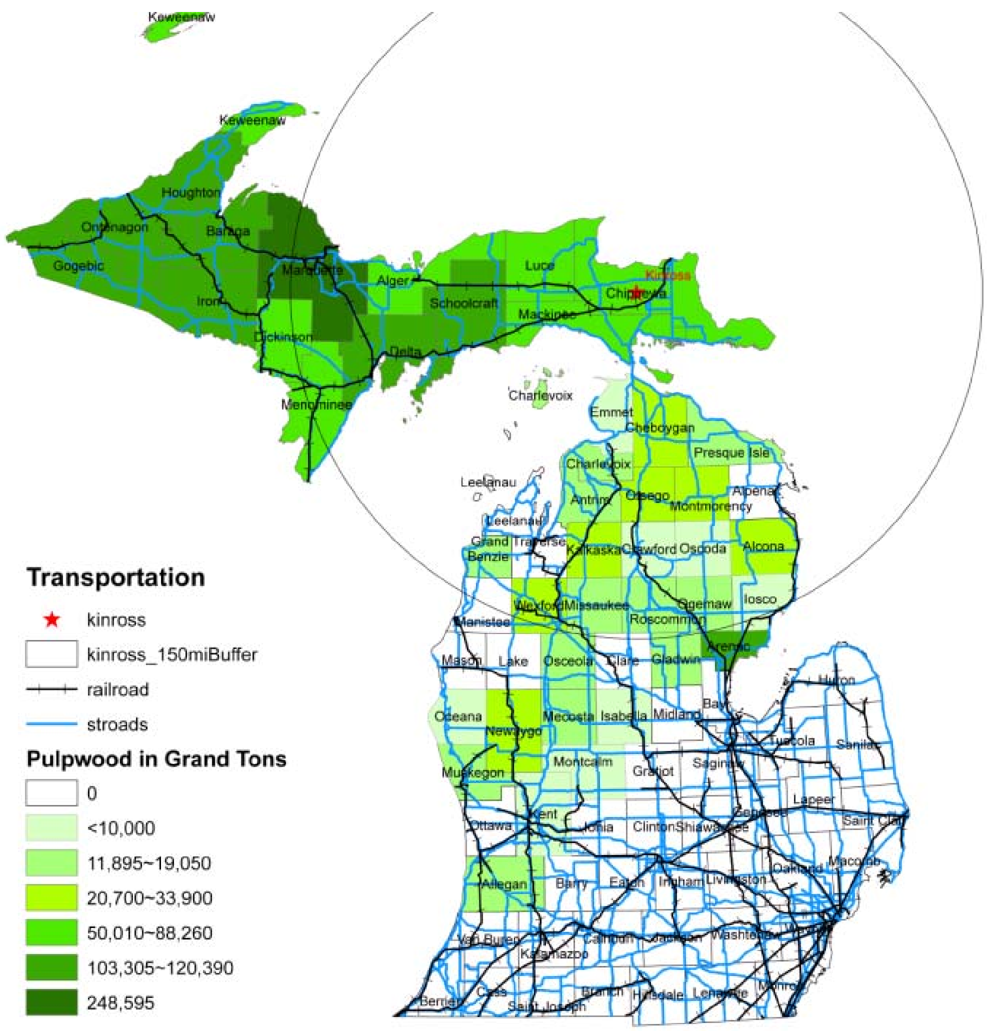


Figure 0: Map of Michigan showing the location of the biofuel plant and a 150-mile radius.

Model Logic

Figure 2 shows the logic of the supply chain model, which consists of several modules marked by different colors. At the beginning of each day, decisions are made based on inventories, and signals are sent to harvesting areas and the mill. Those signals trigger the transportation of logs in the supply chain.

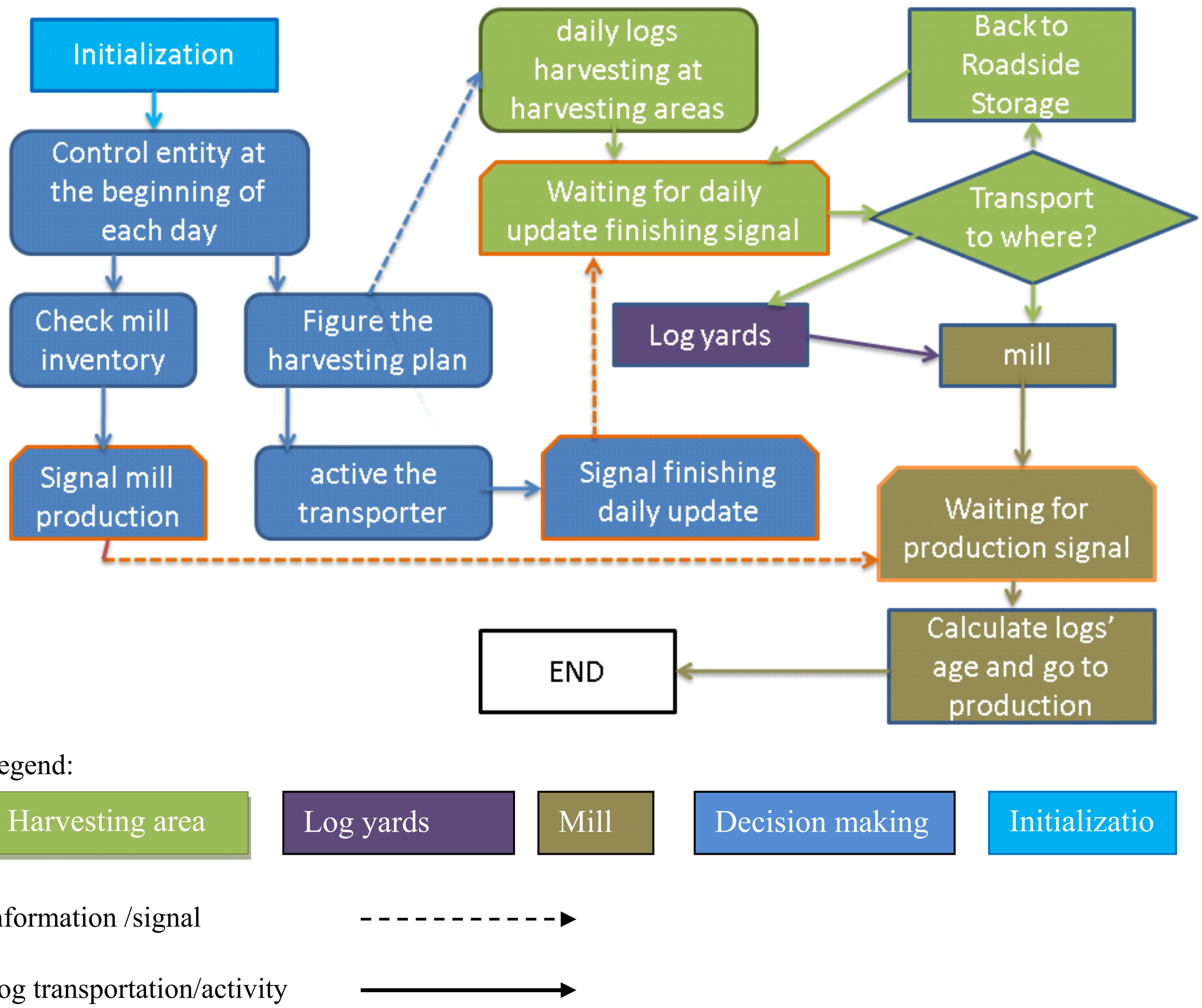


Figure 1: Logic of the supply chain model

Variables and Parameters

AdditionalCostTruckLoadingPerTon: named "possible additional load/unload routine" in the Graphical User Interface (GUI) which can be initialized by users at the beginning of the simulation, $/ton;

alconaerror: internal variables in Arena used to choose spring break up reading ways and scenarios;

AverageAge: recording daily average age of logs arriving at mill, in units of days;

AverageAgetoProcessed: recording average age of logs leaving mill for production, equals

TotalLogsAges / TotalLogstoProcessed;

CalculateDay: used to track the daily data;

CO2HarvestingPerTon: Emissions during harvesting, user-definable in Excel input file, units: kg GHG/ton;

CO2MachineryMillYardPerTon: Emissions from machinery in mill yard, user-definable in Excel input file, units: kg GHG/ton;

CO2MachineryRailYardPerTon: Emissions from machinery in rail yards, user-definable in Excel input file, units: kg GHG/ton;

CO2MachineryMillYardPerTon: Emissions from machinery in truck yards, user-definable in Excel input file, units: kg GHG/ton;

CO2TrucklowerPerMileTon: Emissions, log truck operation in L.P., user-definable in Excel input file, units: kg GHG/ton-mile;

CO2TruckupperPerMileTon: Emissions, log truck operation in U.P., user-definable in Excel input file, units: kg GHG/ton-mile;

CO2RailPerMileTon: Emissions, rail operation, user-definable in Excel input file, units: kg GHG/ton-mile;

CostHarvestingLogs(harvesting area#,eg.1-46): cost of logs produced at harvesting areas, variable in different time periods, user-definable in Excel input file, in units of $/ton;

CostRailPerMileTon: variable mileage cost, rail operation, user-definable in GUI, $/ton-mile;

CostTruckLoadingUnloadingPerTon: Fixed cost, log trucks including one load/unload routine, user-definable in GUI, $/ton;

CostTruckPerMileTon: variable mileage cost, log trucks, user-definable in GUI, $/ton-mile;

DaysOutofStock: number of days running out of stock in mill;

distributionparameter: internal variables in Arena used to determine the County Alcona's spring break up Start Day and End Day;

FixedRailCostPerTon: fixed cost, rail operation, user-definable in GUI, $/ton;

FuelHarvestingPerTon: Energy use, harvesting, user-definable in Excel input file, MJ/ton;

FuelRailPerMileTon: Energy use, rail operation, user-definable in Excel input file, in units of MJ/ton-mile;

FuelTrucklowerPerMileTon: Energy use, log truck operation in L.P., user-definable in Excel input file, in units of MJ/ton-mile;

FuelTruckupperPerMileTon: Energy use, log truck operation in U.P., user-definable in Excel input file, in units of MJ/ton-mile;

HarvestingInterval: the time based on which the harvesting plan/transportation plan is made. It is a week (7 days) in the current version;

InitialInventoryYardCount(yard#): the initial inventory at yards, reading from Excel file, initial inventory of truck yards is in the units of tons, initial inventory of rail yards is in the units of # of rail cars ;

InitialMillInventory: the initial inventory at mill yard, user definable in GUI, tons;

InventoryMillCount: the inventory at the mill, tons;

InventoryYardCount(yard#,eg.1-8): inventory at yard, 1-3 are truck yards, 4-8 are rail yards, unit of InventoryYardCount(4-8) is TruckCapacity, of InventoryYardCount(1-3) is TruckCapacityLower;

iOperater /iTest1 /iTest2 /iTest3 /iTest4: Arena internal variables;

LogsArriveYard(**yard#**): logs from harvesting areas to yard#, in units of TruckCapacity or TruckCapacityLower;

LogsBatchbyRail: number of rail trips to mill, tons;

LogsbyRail: logs to mill by rail, tons;

LogsbyTrucklowertoMill: logs to mill by log trucks in L.P., tons;

LogsbyTruckuppertoMill: logs to mill by log trucks in U.P., tons;

LogsbyTrucktoMill: sum of logs to mill by log trucks in both L.P. and U.P., tons;

LogsProduction(harvesting area#): Daily logs production at harvesting areas, tons/day;

LogstoMill(**harvesting area#**): logs to mill from harvesting areas, TruckCapacity;

LogstoYard(**harvesting area#**): logs to yard from harvesting areas, TruckCapacity;

MaxAge: daily maximum age of logs arriving at mill, days;

MaxAgeDaily: daily maximum age of logs leaving mill, days;

MillCapacity: the capacity of the mill, tons, user-definable in GUI;

PercentageToYard(**harvesting area#**): The percentage of logs from harvesting area to yard;

PercentageToYardSetting1(**harvesting area#**): The percentage of logs from harvesting area to yard, read in from spreadsheet for regular days;

PercentageToYardSetting2(**harvesting area#**): The percentage of logs from harvesting area to yard, read in from spreadsheet for the period before spring breakup.

PercentageToYardSetting3(**harvesting area#**): The percentage of logs from harvesting area to yard, read in from spreadsheet for the spring breakup period;

ProductionRequirement: Production requirement in mill which is 3200 tons; also user definable, in tons;

RailCap: number of rail cars dispatched per day, read from Excel file;

RailCapacity: rail car batch size, tons;

RailNetwork(1-2): two distances from each rail yard to mill, read from Excel file, in miles;

RailsArriveMill: number of trains arriving at mill;

RailSize: number of rail cars in a train;

RailstoMill(railyard#): trains from rail yard to mill;

RailUnit: used to decide which rail is activated every day;

Reorder level indicator at log yard(yard#): if the log yard inventory is equal to or less than the reorder level, it is set to 0; otherwise it is set to 1. It is used to decide when to order logs from harvesting areas to the log yard;

Reorder level indicator at mill yard: if the mill inventory is equal to or less than the reorder level, it is set to 0; otherwise it is set to 1. It is used to decide when to order logs to the mill;

ReorderLevelStockatMill: reorder level stock in mill, user-definable in GUI, tons;

ReorderLevelStockatYard(yard#): read from Excel file, reorder level inventory of truck yards is in the units of tons, reorder level inventory of rail yards is in the units of # of rail cars ;

Roadsideinitialage(harvesting area#): log's age for the initial inventory of roadside storage; user definable in Excel input file;

Roadsideinitialinventory(harvesting area#): initial inventory in the roadside storage; user definable in Excel input file, tons;

RoadsidestoragesCost(harvesting area#): the storage cost in roadside, reading from Excel input file, $/tons-day;

RoadNetworkYard#1-3(harvesting area#): distances between harvesting areas and log yard #(1-3), read from Excel file, miles;

RoadNetworkYard#4-6(harvesting area#) : distances between harvesting areas and log yard #(4-6) (which are also rail yards 1-3), read from Excel file, miles;

RoadToMillNetwork(harvesting area#): distances between harvesting areas with mill, read from Excel file, miles;

SBPeriod(harvesting area#): Length of the spring break up at harvesting areas; two ways to input; one is reading SBPeriod(eg.1-46) from Excel file, the other is asking the user to input the start day (SBStart(1)) and end day for Alcona in the GUI; the model would calculate the other counties' in VB program according to historic data, days;

SBProduction(harvesting area#): Logs Production during Spring break-up at each harvesting area, read from Excel file, tons;

SBStart(harvesting area#): spring breakup starting day at each harvesting area; two ways to input; one is reading SBStart(eg.1-46) from Excel file, and the other is asking the user to input start day (SBStart(1)) for Alcona in GUI; the model would the calculate the other 45 counties' in VB program according to historic data;

SBPeriodcalcu/ SBStartcalcu: The length/start day of the spring break up calculated by the GUI according to the relationship based on historical data from 2005 to 2010;

SBPeriodexcel/ SBStartexcel: The length/the start day of the spring break up, read from Excel input file,;SBPeriodexcel/SBStartexcel is the historical data of 2010, SBPeriodexcel2 /SBStartexcel2 is of 2009, SBPeriodexcel3 /SBStartexcel3 is of 2008, SBPeriodexcel4 /SBStartexcel4 is of 2007, and SBPeriodexcel5 /SBStartexcel5 is of 2006,; user can also change any of these to a new scenario;

Simulationstartday: the first day to start the simulation, can be selected by user in Arena->Run->Setup-> Start Date and Time;

Simulationendday: the variable used to check the last day for the simulation. The simulation continues when simulationendday=0, the simulation ends when simulationendday=1 which means the 365th day is finished;

Simulationstartyear: the first year for the simulation, determined automatically after user picks the simulationstartday;

StorageCostatMill: annual storage cost at mill, user-definable in GUI, $/ton-year;

StorageCostatYard(yard#): annual storage cost at log yards, user-definable in Excel file, $/ton-year;

Target inventory indicator at log yard: if the log yard inventory is less than the target, it is set to 0; otherwise it is 1.

Target inventory indicator at mill yard: inventory status at mill; if the mill inventory is less than the inventory, it is set to 0; otherwise it is 1.

TargetStockatMill: Target Stock at Mill, can be different before/during the Spring Breakup and the remaining period of "regular" days; initialized by user in GUI at the beginning of the simulation, tons;

TargetStockatMill1/2: TargetStockatMill1 is target level of mill for regular days; TargetStockatMill2 is for the period before/during Spring Break-up;

TargetStockatYard(yard#): Target Stock at the log yards, read in from Excel input file, target level inventory of truck yards is in the units of tons, target level inventory of rail yards is in the units of # of rail cars;

TotalLogsAges: used to calculate average age of logs to be processed in mill, in days;

TotalLogsAges1: used to calculate average age of logs arriving at mill, in days;

TotalLogstoProcessed: daily total logs to be processed in mill, in tons;

TruckCap: number of trucks dispatched per day, read from Excel file;

TruckCap1/2/3/4(#harvest area): the available trucks in each harvest area in different time period, would sum up to TruckCap during different time period;

TruckCapacity: truck's log load capacity in UP, tons;

TruckCapacityLower: truck's log load capacity in LP, tons;

TruckCountVal(Truck #): counter for Truck # in UP, records utility of each truck in UP;

TruckLowerCountVal(Truck #): counter for Truck # in LP;

TrucksArriveMill: number of trucks in UP arriving at mill;

TrucksLowerArriveMill: number of trucks in LP arriving at mill;

TruckstoMillfromYard(truckyard#,eg.1-3): number of trucks from truck yard # to mill;

TrucksUpperArriveMill: number of trucks in UP arriving at mill;

TruckTripsIndex: fraction deciding how many trucks can make double trips;

TruckUnit: used to decide which truck in UP is activated;

TruckLowerUnit: used to decide which truck in LP is activated;

TruckYardtomillNetwork(yard#): distance from yards to mill, miles, read in from Excel file;

YardInitiallogsageinstock(yard#): initial log inventory in yards, read in from Excel input file, tons;

YardsCapacity(yard#): the capacity of the yards, read in from Excel input file, truck yard capacity is in the units of tons, rail yard capacity is in the units of # of rail cars.

Simulation Model

Top-Level: Interface

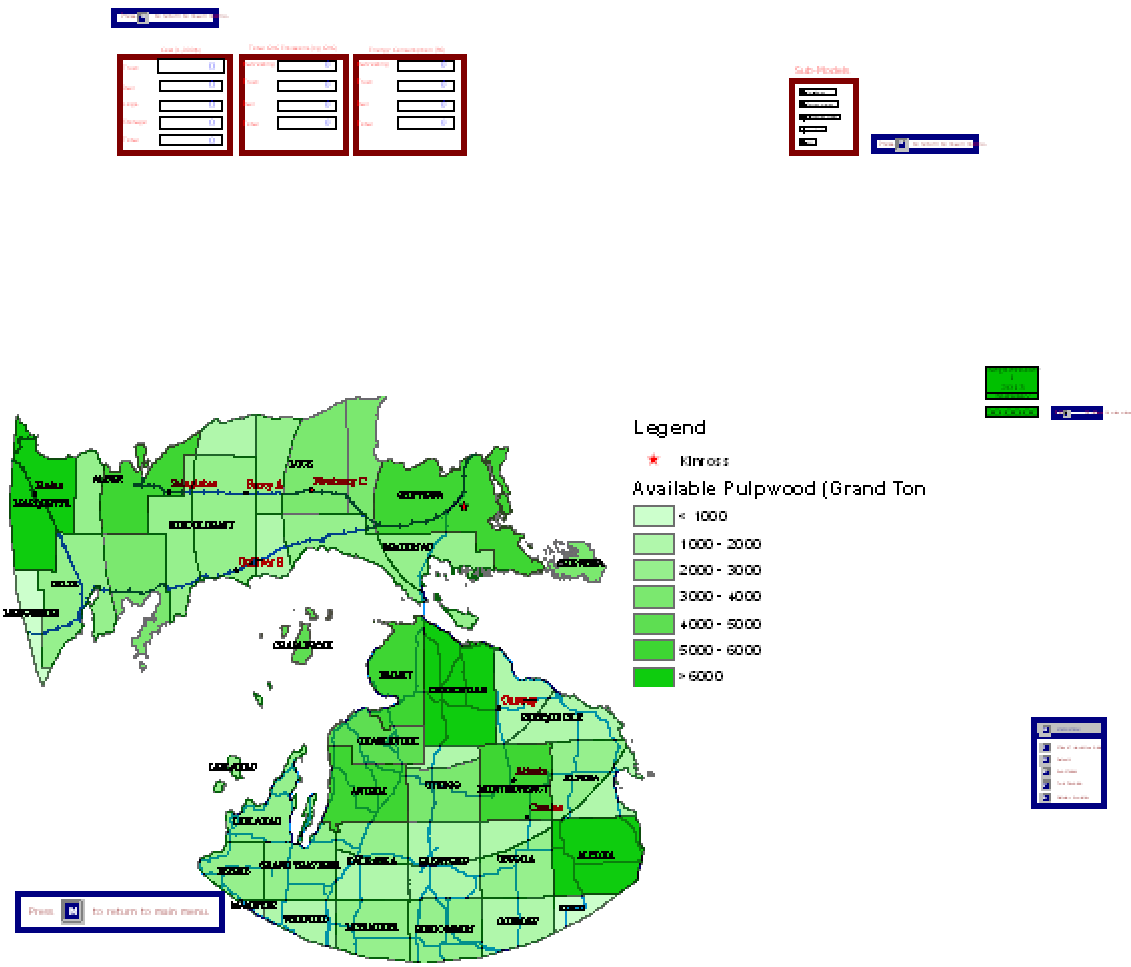


Figure 2: Interface of the supply chain simulation model.

Five Sub-models

- Harvesting Areas – 46 harvesting areas, according to counties and haul zones, plus three additional area for regions beyond 150 miles shipping by rail only;
- Log yards –5 available truck yards and 5 available rail yards, but 6 log yards are recommended to be selected for simulation, including 3 truck yards and 3 rail yards at rail spurs;
- Mill – with an onsite log yard;
- Initialization and Set-up – initialize the parameters, read simulation data from an Excel file;
- Decision-making

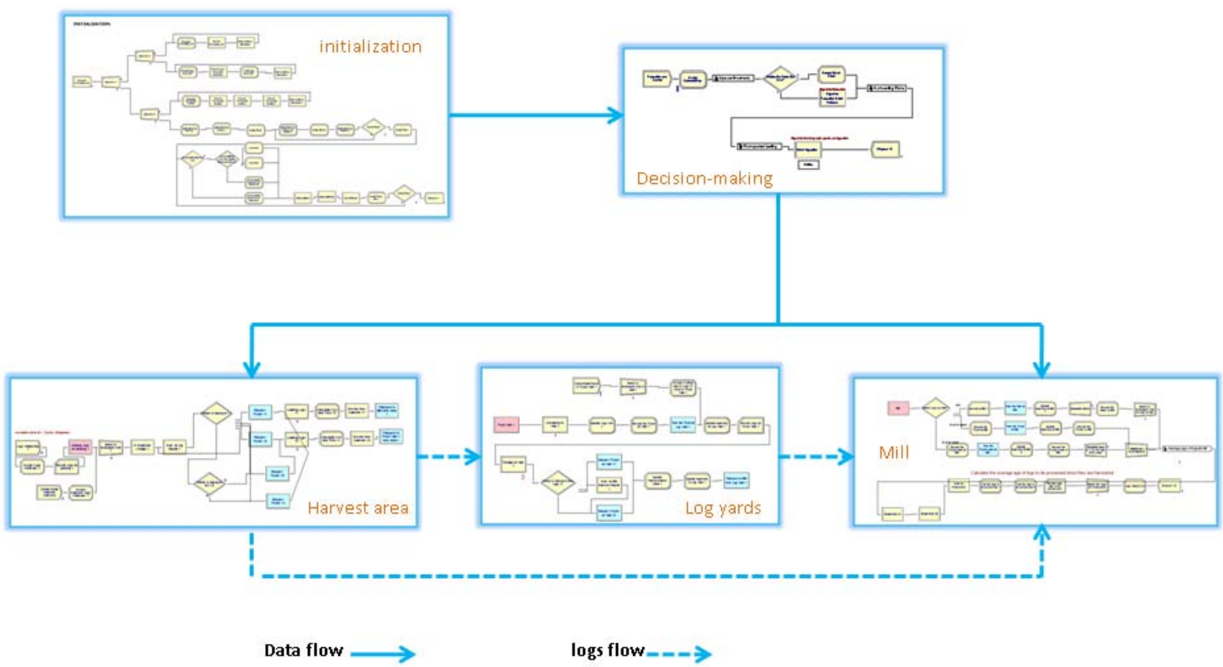


Figure 3: Five sub-models of the supply chain simulation model

Initialization and Set-up

The initial values of the following variables are read from the Excel file.

CostHarvestingLogs(Harvesting area#), InitialInventoryYardCount(Yard#), PercentageToYardSetting(Harvesting area#,1-3), RailCap, RailNetwork(railyard#), ReorderLevelStockatYard(Yard#), Roadsidecapacity(Harvesting area#), Roadsideinitialage(Harvesting area#), Roadsideinitialinventory(Harvesting area#), RoadsidestoragesCost(harvesting area#), RoadtoMillNetwork(harvesting area#),SBProduction(Harvesting area#), SBStart(Harvesting area#), SBPeriod(Harvesting area#), StorageCostatYard(Yard#), TargetStockatYard(Yard#), TruckCap, TruckLowerCap, TruckyardtomillNetwork(truck yard#), MillCapacity, YardInitiallogsageinstock(Yard#), YardCapacity(yard#) and emission and energy consumption data.

SBStart and SBPeriod could also be set from GUI. The statistical relationships used to calculate other counties' spring breakup data based on Alcona County.

An Excel file containing user specified data and an excel output file containing simulation results are connected to the ARENA software as shown in Figure 4.

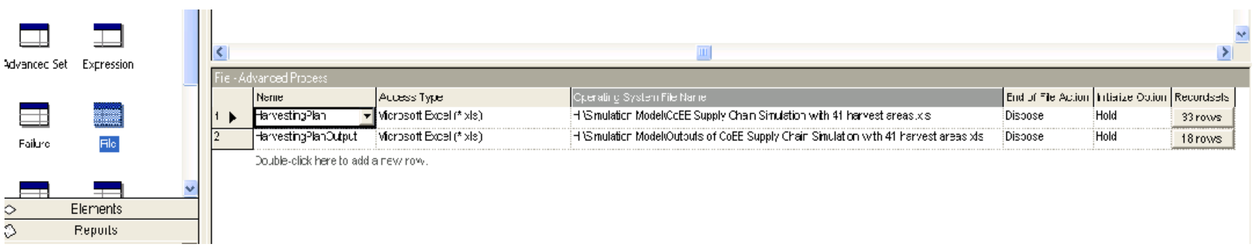


Figure 4: External file connected to the ARENA model (File – Advanced Process)

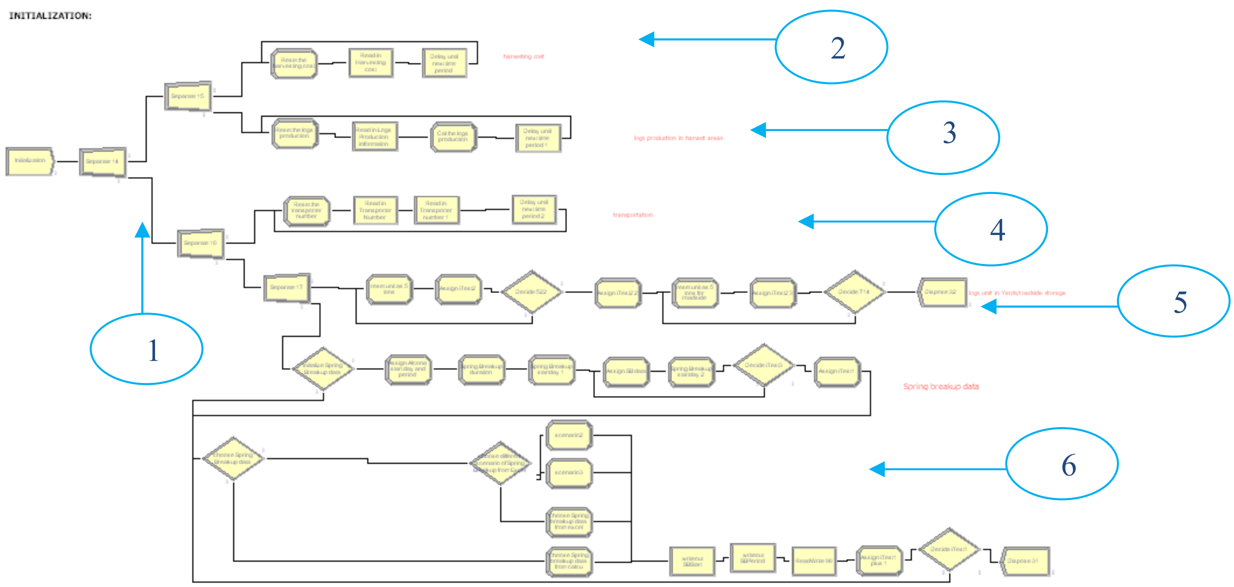


Figure 5: 'Initialization' sub-model

Description:

The sub-model in Figure 5 is Initialization. The critical module in this sub-model is the ReadWrite module, used to read in/write out data (Figure 6).

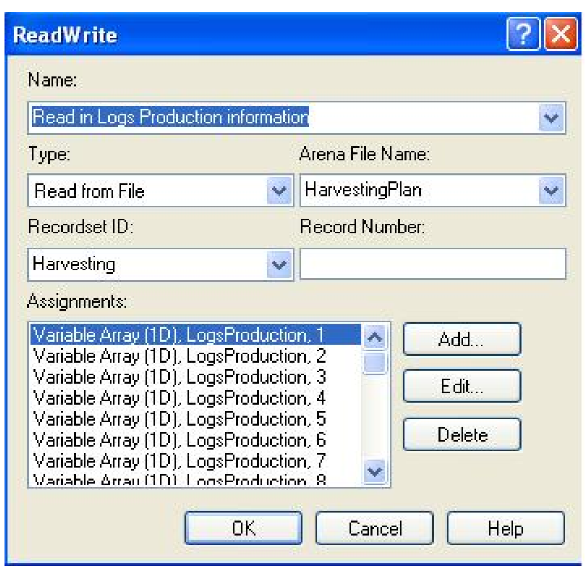
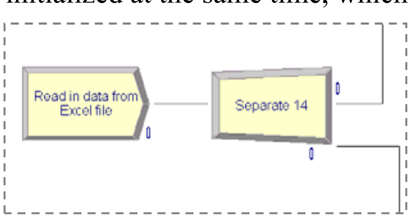


Figure 6: ReadWrite module

Sub-model Logic:

1. An entity is created at the beginning of each replication to read in data from an Excel file named "CoEE Supply Chain Simulation with 46 harvest areas.xls". The reason only one entity is created, and then duplicated to four instead of creating four entities initially, is to make sure all data would be initialized at the same time, which speeds up the simulation.

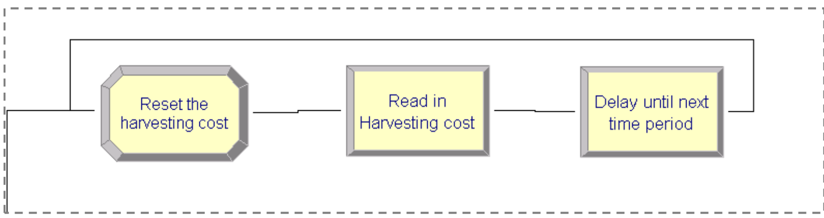


Module name: Read in data from Excel file;

Module type: CREATE from Basic Process;
Time between arrivals: Constant;
Value: 1 Day;
Entity per Arrival: 1;
Max Arrivals: 1;
First Creation: 0.0;

Module name: Separate 14;
Module type: SEPARATE from Basic Process;
Type: Duplicate Original;
# of Duplicates: 1;

2. The second section in Figure 6 is to read harvesting cost data for each harvesting area. Harvesting cost is set to zero before assigning it the value from the Excel file.



Module name: Reset the harvesting cost;
Module type: ASSIGN from Basic Process;

```
Module name: Read in Harvesting cost;
Module type: READWRITE from Advanced Process;
Type: Read from File;
Arena File Name: HarvestingPlan;
Recordset ID: HarvestingCost;
Assignments: Variable Array (1D), CostHarvestings, i
```

This module is used to read the harvesting cost data from ' HarvestingPlan' which is a file name in Arena. The actual file is "CoEE Supply Chain Simulation with 46 harvest areas.xls" as specified in Figure 5.

```
Module name: Delay until next time period;
Module type: DELAY from Basic Process;
Delay Time: HarvestingInterval;
Units: Days;
```

This module is used to delay the entity until next time period, then go back to "Reset the harvesting cost" module to read the data for next period.
Other parts work similarly to this one.

3. The third part in Figure 6 is to set up the daily harvesting plan for each harvesting area. Each entity "logs" in the Arena simulation represents 5 tons, so LogsProduction(i) equals LogsProduction(i) / HarvestingInterval*50/5, where 50 tons is the unit in the input file, representing the daily available logs in harvesting area i.

4. The fourth part in Figure 6 is to set up the daily transportation plan.

5. The fifth part in Figure 6 is to set up logs unit in logs yards and roadside storages, as the default unit for logs is 5 tons in simulation model and 1 ton in the input file. So this part changes unit of the reorder/target level and capacity of log yards and initial inventory in log yards and roadside storages to 5 tons.

6. The sixth part in Figure 6 is to set up spring breakup data.

Another way as reading in emission and fuel consumption data as shown in Figure 7 is to read them from the Excel file directly by Visual Basic.

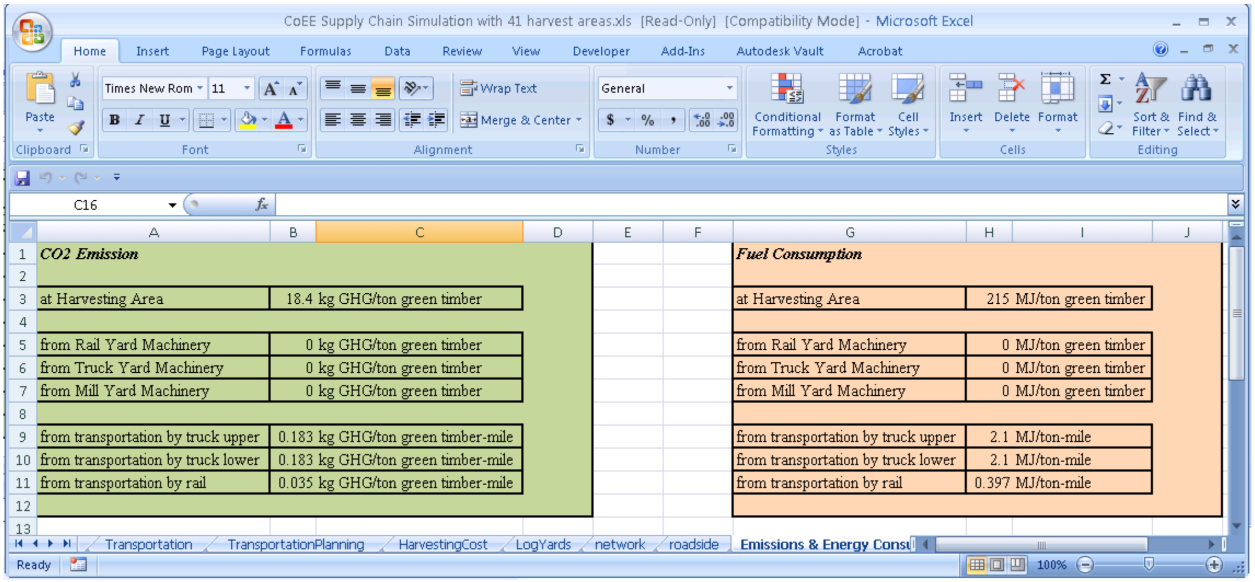


Figure 7: Emission and fuel consumption data in Excel input file

Other single-value parameter variables are initialized by the GUI, as shown in Figure 8.

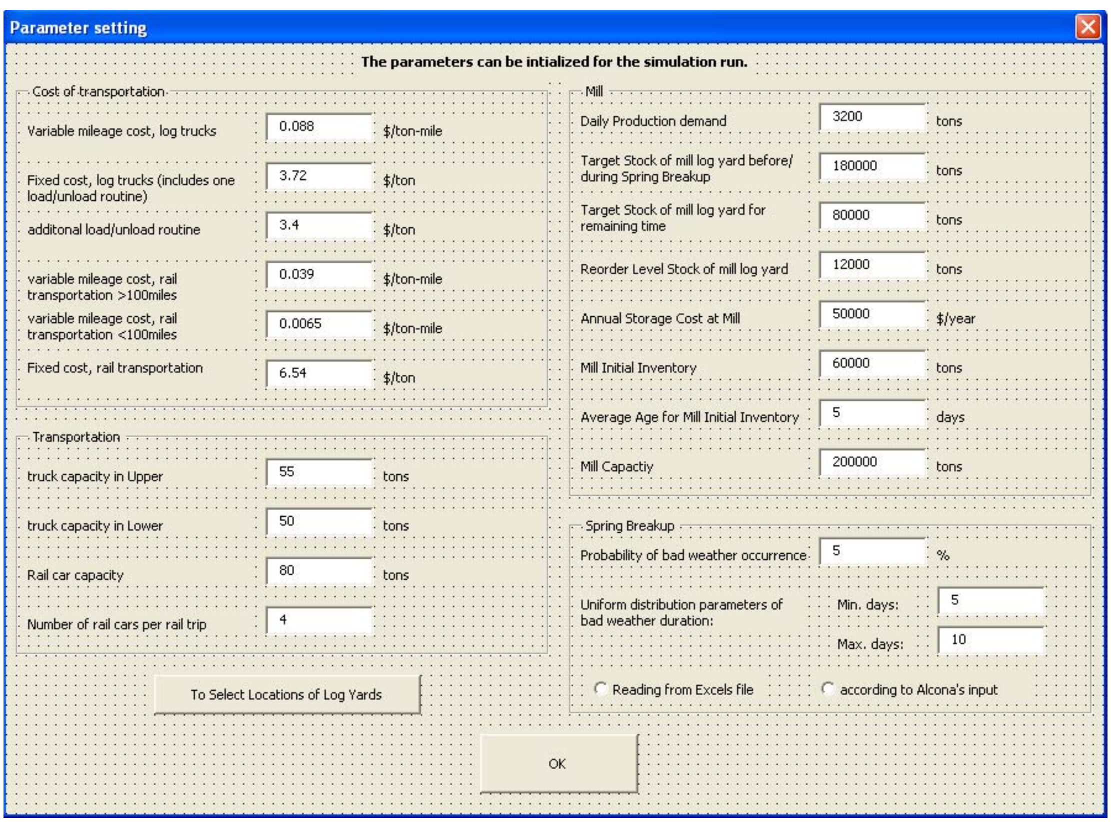
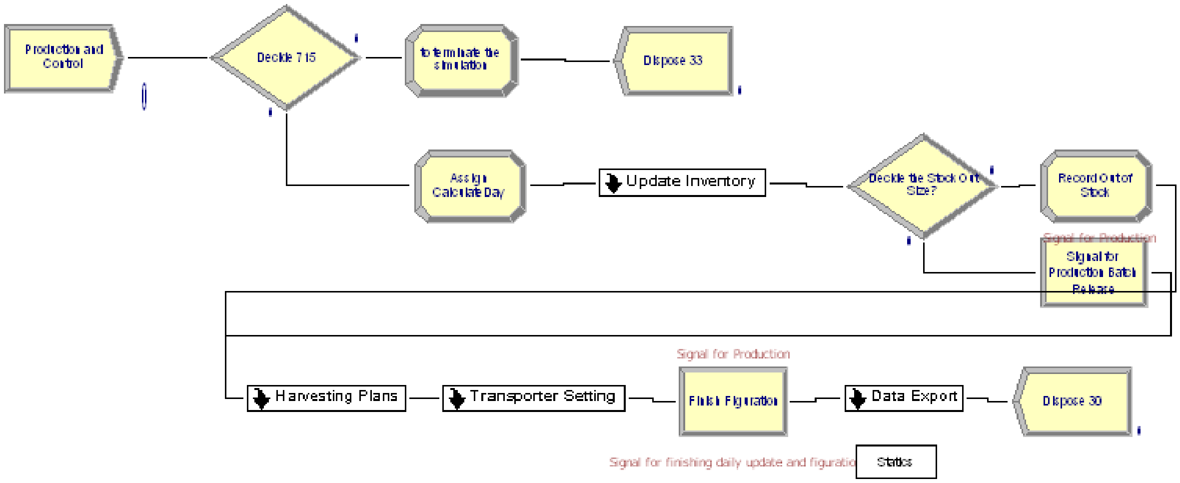


Figure 8: Graphical User Interface for setting parameter values.

Decision-making




```
Module name: Production and Control;
Time between arrivals: Constant;
Value: 1 Day;
Entity per Arrival: 1;
Max Arrivals: Infinite;
First Creation: 0.01;
```

This create module is used to create the entity "DailyControl" at the beginning of every day to update plans, to send a signal for production after checking the mill inventory, and to send signals to harvesting areas after transportation and harvesting plans are set. The delay of 0.01 in the first creation is set arbitrarily to make sure the initializations are finished before all the decisions are made.

```
Module name: Decide continue the simulation
Type: 2-way by condition;
Value: If CalculateDay==365;
```

This Decide module is used to check how long the simulation has been run. If it has run for one whole year, the simulation would end.

```
Module name: to terminate the simulation;
Assignment: simulationendday=1;
```

The simulationendday equals 0 when the simulation lasts for less than 1 year.

```
Module name: Dispose 33;
```

This module disposes the tracking entity when simulation lasts for 1 year.

```
Module name: Assign CalculateDay;
Assignment: CalculateDay=CalculateDay+1;
```

The tracking entity comes in this module when simulation lasts for less than 1 year. CalculateDay is used to track the daily data during simulation.

```
Module name: Decide the Stock Out Size? ;
Module Type: Decide in Basic Process;
Type: 2-way by condition;
```

```
Value: InventoryMillCount < ProductionRequirement * TruckCapacity;
```

This module is used to check the mill inventory to decide whether or not to send the signal for production.

```
Module name: Signal for Production Batch Release;
Module Type: Signal in Advance Process;
Signal Value: SigProduction;
Limit: ProductionRequirement;
```

The Signal module sends a signal value to each Hold module in the model set to "Wait for Signal," and releases the maximum specified number of entities, which is ProductionRequirement here.

Four modules in Decision-making are Update Inventory, Harvesting Plans, Transporter Setting and Data Export.

Module Update Inventory is to check the inventory information in mill, truck yards and rail yards totally.

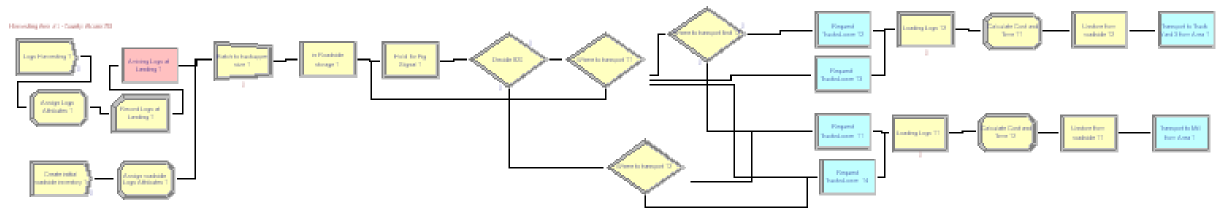
Module Harvesting Plans is to set different harvesting plans according to different time periods.

Module Transporter Setting is to activate certain quantity transporters according to transportation plan, read from the Excel input file.

Module Data Export is to record data in an Excel output file.

Harvesting area

A screen shot of the first harvesting areas is shown as below, and there are 45 other harvesting areas in this sub-model. Logs from most of the harvesting area are either going to mill or log yards depend on different situations like the one below, but there several special ones. Logs from two harvest areas, which are Chippewa 30 (#11) and Mackinac 30 (#25), are only able to go to mill directly. Logs from three harvest areas are only able to go to rail yards first. The three harvest areas are areas farther than 150 miles in UP (#44, #45 and #46).



The red text above the first module gives the information of which harvest area this flowchart represents, for instance, the first flowchart represents Harvesting Area #1 - County: Alcona150.

```
Module name: Logs Harvesting 1;
Module Type: CREATE in Basic Process
Entity type: Logs;
Time between arrivals: Constant;
Value: 1 Day;
Entity per Arrival: LogsProduction (1);
Max Arrivals: Infinite;
First Creation: 0.02;
```

This Create module is used to create "logs" at begin of every day according to harvesting plan. The delay of 0.02 in the first creation is set arbitrarily to make sure the initializations are finished and the decisions are made before the simulation of the day starts.

```
Module name: Assign Logs Attribute 1;
Module type: ASSIGN from Basic Process;
Assignments: FromLandingSite = 1;
             Cost = CostHarvestingLogs(1);
             Cutting Time = Entity.CreateTime;
             InitialAge = 0;
             Species = UNIF (1, 5);
```

```
Module name: Record Logs at Landing 1;
Module type: RECORD in Basic Process;
Type: count;
Value: 1;
Counter Name: Logs at Landing 1;
```

This Record module is used to record the entity statistic, which is the number of logs harvested from harvesting area here.

```
Module name: Arriving at Landing 1;
Module type: STATION in Advance Transfer;
Station Type: station;
Station Name: Landing Site 1;
```

The Station module defines a station (or a set of stations) corresponding to a physical or logical location where processing occurs.

```
Module name: Create initial roadside storage inventory;
```

```
Module name: Assign roadside Logs Attributes 1;
```

These two modules are used to simulate the initial inventory in roadside storage 1.

```
Module name: Batch to truckupper size 1;
Module Type: BATCH in Basic Process;
Type: Temporary;
Batch size: Truck Capacity;
Save Criterion: Last;
Rule: Any Entity;
Representative Entity Type: null;
```

This module is used to batch the logs for transportation. Batched logs are split later.

```
Module name: in roadside storage 1;
Module Type: STORE in Advanced Process;
Type: Storage;
Storage Name: Roadside Storage 1;
```

The Store module adds an entity to storage. When an entity arrives at the Store module, the storage specified is incremented, and the entity immediately moves to the next module in the model.

```
Module name: Hold for Fig Signal 1;
Module Type: HOLD in Advanced Process;
Type: Wait for Signal;
Wait for Value: SigFinishFig;
Queue Type: Queue;
Queue Name: Hold for Fig Signal 1.Queue;
```

This signal "SigFinishFig" here is sent by the sub-model “Decision Making”, meaning the parameters are all ready.

```
Module name: Decide 820;
Module Type: Decide in Basic Process;
Type: 2-way by Condition;
Value: If yardselectionindex(5)==1 &&
InventoryYardCount(5)*TruckCapacityLower<YardsCapacity(5),
then logs would go to log yard 5;
```

This module is used to identify which log yard is available for this harvest area.

```
Module name: Where to transport 11;
Module Type: Decide in Basic Process;
Type: N-way by condition;
Value: If InventoryMillCount<=TargetStockatMill && InventoryYardCount(5)<=
TargetStockatYard(5)/TruckCapacityLower, then logs go to both mill yard and log yard5;
else if InventoryYardCount(5) < YardsCapacity(5)/TruckCapacityLower, then logs go to
log yard5;
else if InventoryMillCount < MillCapacity, then logs go to mill yard;
else, logs stay in roadside storage.
```

This module is used to decide where logs go next and the priority of transporters they require.

```
Module name: Request Trucks 11;
Module Type: REQUEST in Advanced Transfer;
Transporter Name: Truck;
Selection Rule: Smallest Distance;
Save Attribute: Truck;
```

```
Priority: High(1);
Entity Location: Entity.Station;
Velocity: 40;
Units: Per hour;
Queue Type: Queue;
Queue Name: Request Trucks 11.Queue
```

The Request module assigns a truck to logs and moves the unit to the entity's location. When the entity arrives at the Request module, it is allocated a transporter when one is available. The entity remains at the Request module until the transporter unit has reached the entity's location. The entity then moves out of the Request module.

```
Module name: Request Trucks 12;
Module name: Request Trucks 13;
Module name: Request Trucks 14;
```

The three Request modules above work similarly to "Request Trucks 11".

```
Module name: Where to transport 12;
Module Type: Decide in Basic Process;
Type: 2-Way by Chance;
Percentage True: PercentageToYard(1);
```

This module is used to decide the percentage of logs going to yard and going to mill. The percentage is defined by user in Excel input file and initialized in Initialization Sub-model before simulation.

```
Module name: Loading Logs 11;
Module Type: PROCESS in Basic Process;
Type: standard;
Logic: delay;
Delay type: Normal, hours, value added, mean = 0.5, std dev = 0.05;
```

This module simulates the loading process. "Loading Logs 12" works similarly to this one.

```
Module name: Calculate cost and Time 12;
Module Type: ASSIGN in Basic Process;
Assignments: LogstoMill(1) = LogstoMill(1) + 1;
             Rail Tag=0;
```

LogstoMill(1) records the logs from harvesting area to mill. The attribute "Rail Tag" distinguishes how logs are transported to mill, with 2 indicated transport by truck in the U.P., 1 indicating transport by rail, and 0 indicating transport by truck in the L.P.. The module "Calculate cost and Time 11" works similarly to this one.

```
Module name: Unstore from roadside 11;
Module Type: UNSTORE in Advanced Process;
Type: Storage;
Storage Name: Roadside Storage 1;
```

The Unstore module is used to release the logs from roadside storage. "Unstore from roadside 12" is similar to this one.

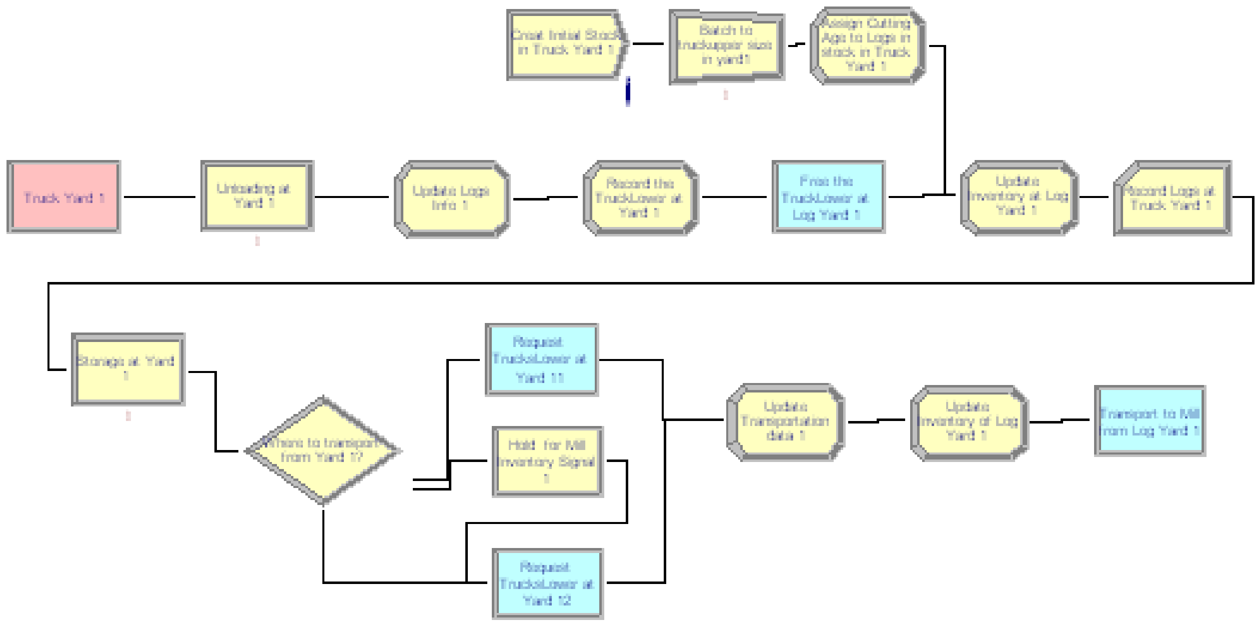
```
Module name: Transport to Mill from Area 1
Module Type: TRANSPORT in Advanced Transfer;
Transporter Name: Truck;
Unit Number: Truck #;
Entity Destination Type: Station;
```

```
Station Name: Mill;
Velocity: null;
Guided Tran Destination Type: Entity Destination;
```

This module is used to transfer logs to a destination station, which is the mill here. As the velocity is set to null here, it would use the default truck velocity defined in transporter which is 40 miles per hour. "Transport to Truck Yard 1 from Area 1" is similar to this one. The logic for the other 45 areas is the same as for this one.

Logs Yards

Truck Yards:



Logs transported from harvesting areas are stored at 5 truck yards and 5 rail yards, although 3 truck yards and 3 rail yards are recommended to be selected for simulation.
The screenshot above is of truck yard 1. The others are similar to this one.

```
Module name: Truck Yard 1;
Module type: STATION in Advance Transfer;
Station Type: station;
Station Name: Truck Yard 1;

Module name: Update Logs Info 1;
Module Type: PROCESS in Basic Process;
Type: standard;
Logic: delay;
Delay type: Normal, hours, value added, mean = 0.5, std dev = 0.05;
```

This module simulates the unloading process.

```
Module name: Unloading at Yard 1;
Module Type: ASSIGN in Basic Process;
Assignments: LogsArriveYard(1) = LogsArriveYard(1)+1;

Module name: Record the Truck at Yard 1;
Module Type: ASSIGN in Basic Process;
Assignments: TruckCountVal(Truck #) = TruckCountVal(Truck #) + 1;

Module name: Free the Truck at Log Yard 1;
Module Type: FREE in Advanced Transfer;
Transporter Name: Truck;
Unit Number: Truck #;
```

The Free module releases the transporter unit.

```
Module name: Create initial stock in Truck Yard 1;
Module name: Batch to truckupper size in yard 1;
Module name: Assign Cutting Age to Logs in stock in Truck Yard 1;
```

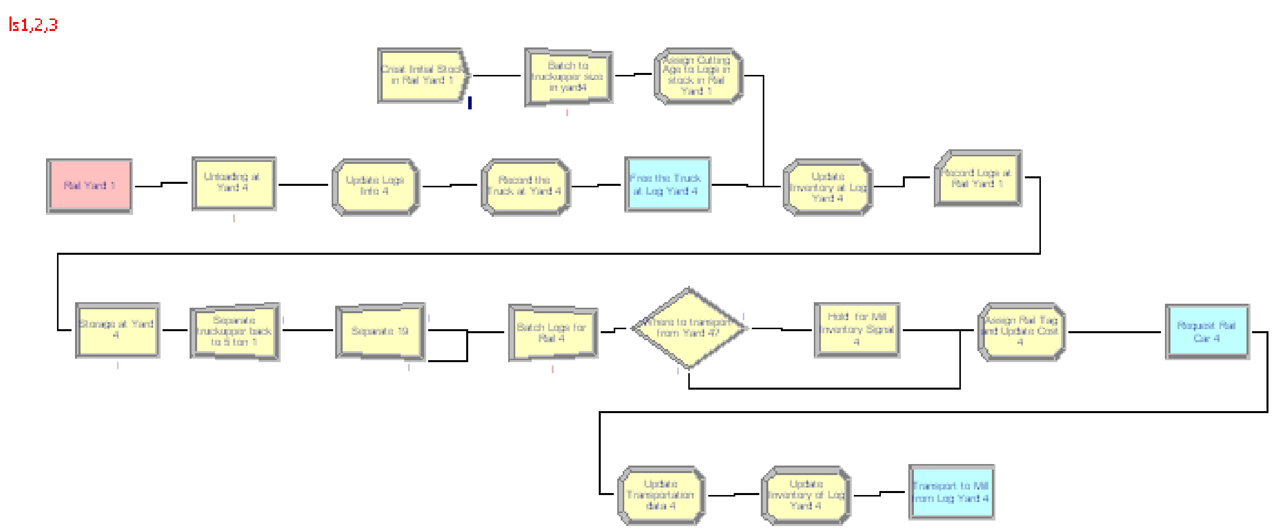
The above three modules simulate the initial inventory in truck yard 1.

```
Module name: update Inventory at Log Yard 1;
Module name: Record logs at truck Yard 1;
Module name: Storage at Yard 1;
Module name: Where to transport from Yard 1?;
Module name: Request Trucks at Yard 11;
Module name: Hold for Mill Inventory Signal;
Module name: Request Trucks at Yard 12;
Module name: Update Transportation data 1;
Module name: Update Inventory of Log Yard 1;
Module name: Transport to Mill from Log Yard 1;
```

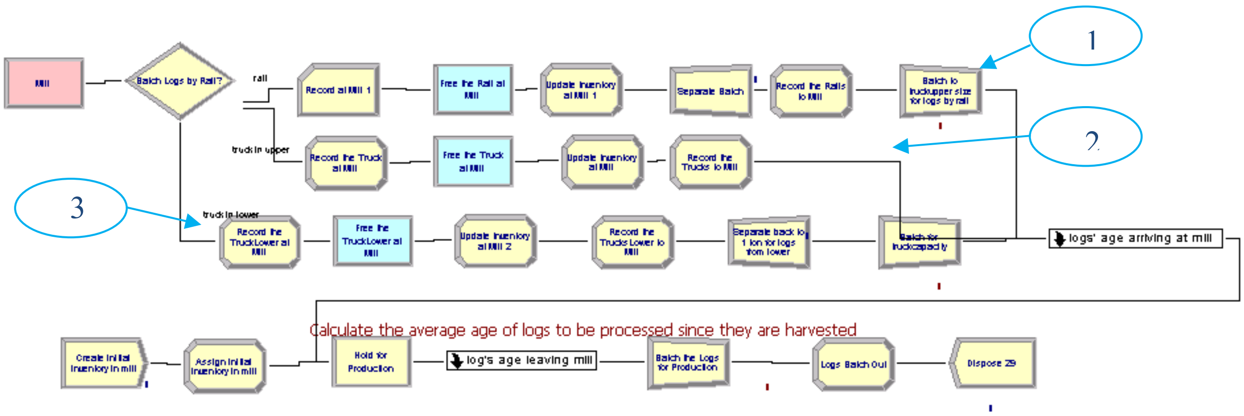
The truck yard 1 flowchart simulates the logs' process of arrival, storage, and departure from truck yard 1, and the inventory and transporter information are updated at the same time.

The logic of other truck yards is the same as this one. Rail yards have a similar logic, too.

Rail Yards:



Mill




```
Module name: Mill;
Module type: STATION in Advance Transfer;

Module name: Batch Logs by Rail?;
Module Type: Decide in Basic Process;
Type: N-way by condition;
Value: If Rail Tag=1, logs are transported here rail;
       Else if Rail Tag=2, logs are transported here truck in U.P.;
       Else, logs are transported here truck in L.P.
```

Modules in part 1:

```
Module Name: Record at Mill 1;
Type: Count;
Value: 1;
Counter Set Number: RailCount;
Set Index: Rail #;
```

This Record module records the rail used to transport logs to mill. Check "Record into Set" to specify that counter set would be used. The set "RailCount" records the number of rail cars used.

```
Module Name: Free the Rail at Mill
Transporter Name: Rail;
Unit Number: Rail #;
```

This Free module releases the rail unit.

```
Module Name: Update Inventory at Mill 1;
Assignments: RailsArriveMill = RailsArriveMill + 1
InventoryMillCount = InventoryMillCount + BatchSize;
```

This Assign module updates the inventory information.

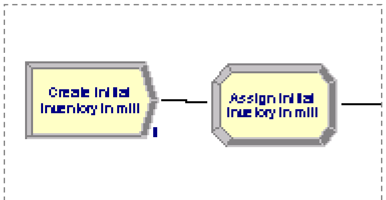
```
Module Name: Separate Batch
Type: Split Existing Batch
Member Attributes: Retain Original Entity Values

Module Name: Record the Rails to Mill

Module Name: Batch to truckupper size for logs by rail;
```

```
Type: Permanent;
Batch Size: TruckCapacity;
Save Criterion: last;
Rule: any entity;
```

The Separate and Batch modules above are used to re-batch the logs for production later.

The logic of part 2 and part 3 are similar to the logic of the part 1 above.

The Sub-Model log's age arriving at mill calculates the daily max age and average age of logs arriving at mill.




```
Module name: Create initial inventory in mill;
Module name: Assign initial inventory in mill;
```

These two modules in the left figure simulate the initial inventory in mill at the beginning of each replication.

```
Module name: Hold for Production;
```

The Hold module holds logs until the signal "SigProduction" is received.

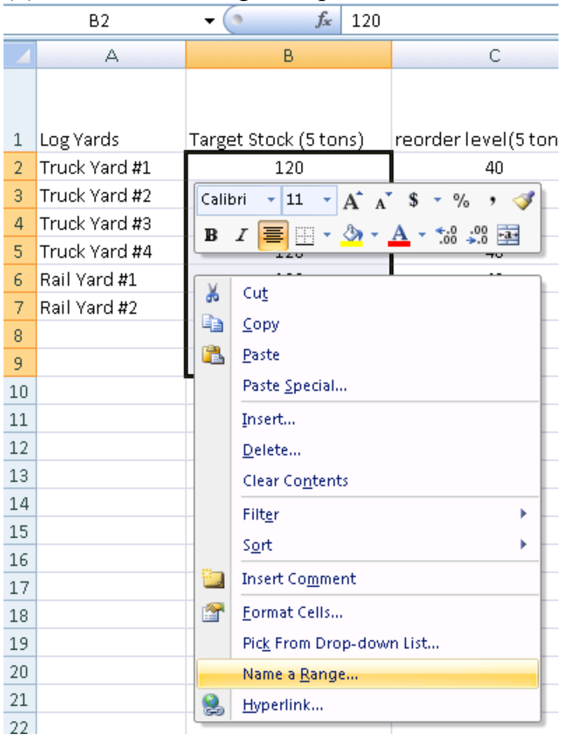
Sub-Model log's age leaving mill calculates the daily max age and average age of logs leaving the mill yard for production.

```
Module name: Batch the Logs for Production;
Module name: Logs Batch Out;
Module name: Dispose 29;
```

The logs are batched for production, and the mill inventory is updated at the same time. The "Dispose 29" module is the end of the simulation.

Steps to Read Data from Excel

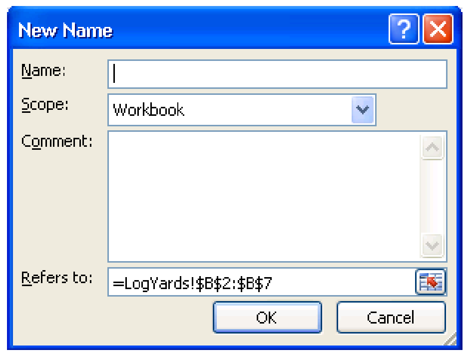
(1) Create name range in Spreadsheet:



a. Put data in Excel.

b. Choose target range; could be a single cell, or a range of multiple rows and columns.

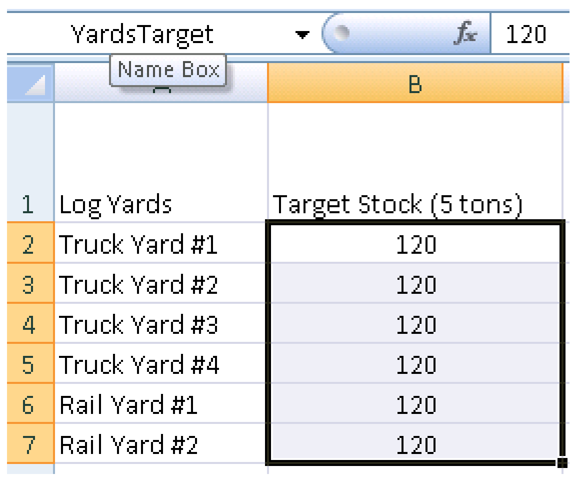
c. Right click on chosen range, then choose 'Name a Range…'.



d. Type in the name in the shown window.

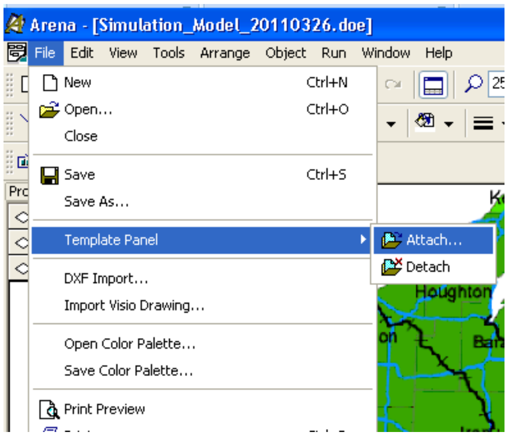
e. Users should avoid names that contain spaces.

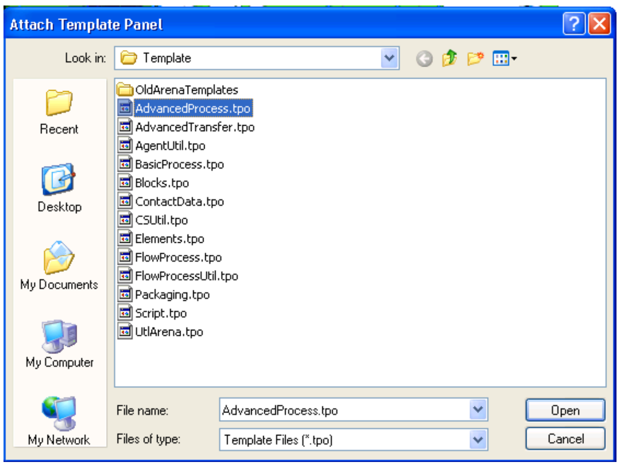
f. Then the typed name can be seen in the Name Box;



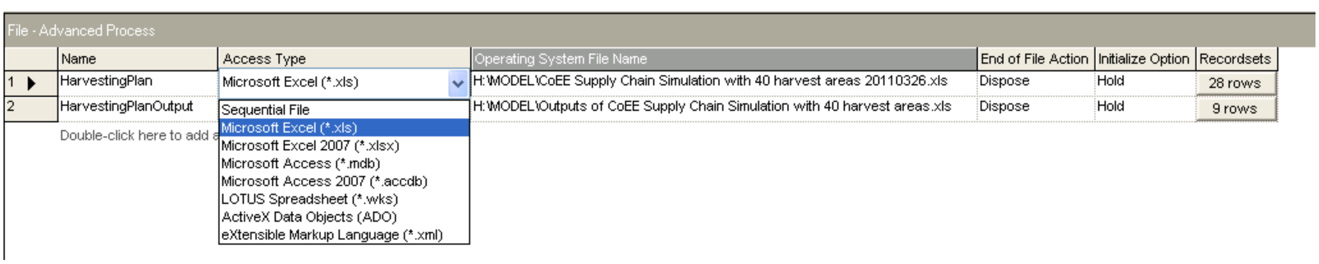
(2) Use File Module connecting to Spreadsheet and cell range:

a. Click on File Module in template Advanced Process. If the template is not under the project bar, attach 'AdvancedProcess.tpo' with 'Attach' under 'Template Panel' which is under the 'File' menu.

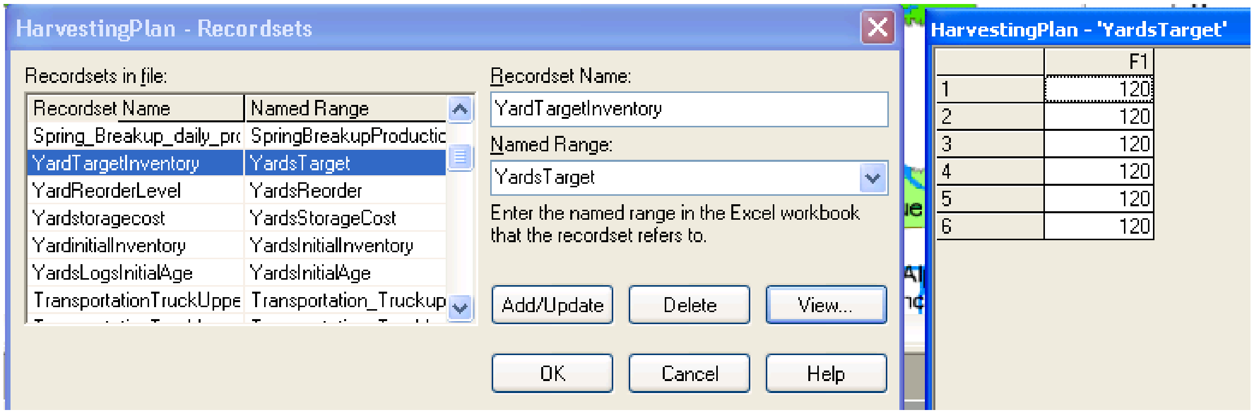




b. Under the file menu: 'Name'--the name of the file that is specified in the ReadWrite module later; 'Access Type'--choose the type of the file in which the input data is saved; 'Operating System File Name'--navigate to the file; 'Recordsets'--to access to the cell ranges in spreadsheet, click on it.

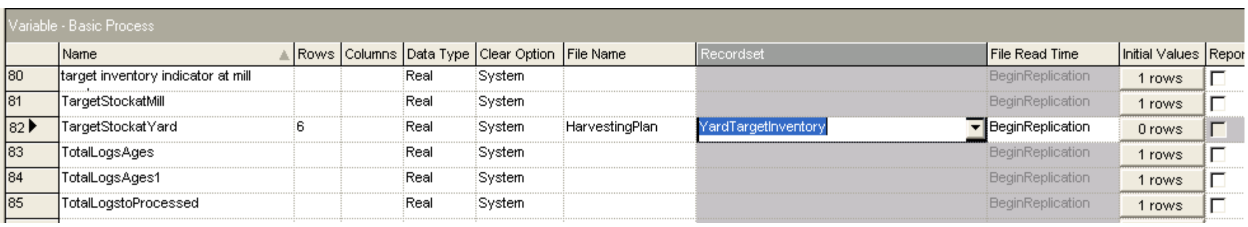


c. 'Recordset Name'--name used to identify the recordset in Arena, this name must be unique; 'Named Range'--the named range in the Excel workbook that was entered in step (1); click 'Add/Update' to add the recordset; click 'View' to see the data in Excel; then click OK to save the change. In this example, recordset 'YardTargetInventory' is directed to the cell range named 'YardsTarget' in spreadsheet.

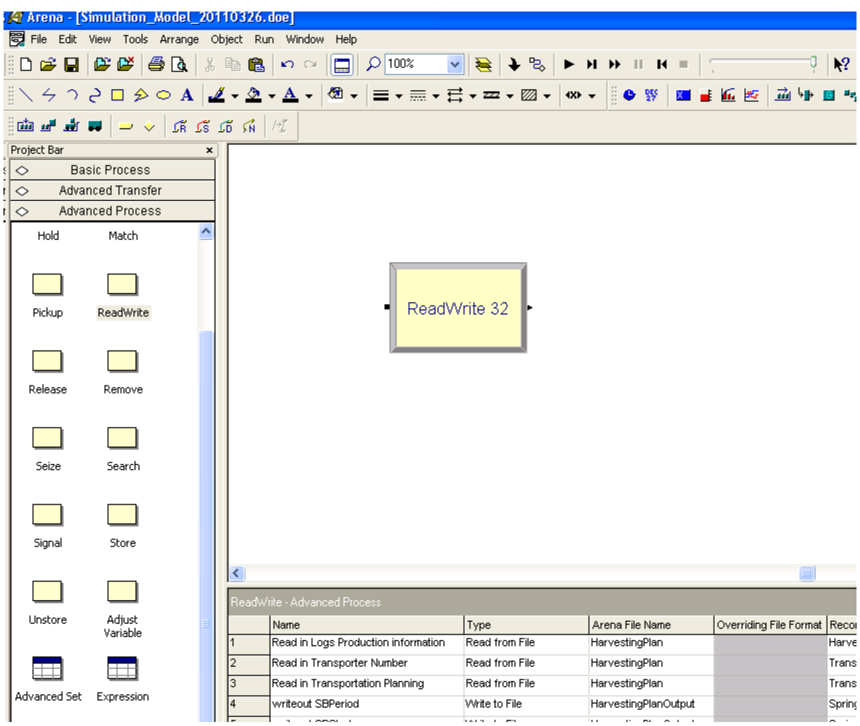


There are several modules that could use the recordset, such as ReadWrite, Variable.
(3) Use the Variable module to read the data:

a. Click on Variable Module in template Basic Process; to direct the variable 'TargetStockatYard' to the cell range 'YardsTarget' in Excel, put the right file name and recordset entered in step (2);



(4) Use ReadWrite module to read the data:



a. Drag ReadWrite module from template Advance Process to model window.

b. Double click on it, and a window called ReadWrite shows up.

c. Type refers the method of reading or writing used. Choose Read from File.

d. Type in the file name and Recordset.

e. Click on Add besides Assignments window, and add the value of first cell in the range of spreadsheet to variable TargetStockatYard(1), the second to TargetStockatYard(2), and so on.

The steps of writing data out to Excel are similar to the steps for reading data from Excel: create cell range in output file, use File module connect to that range, then use ReadWrite module to write out to the file. The only difference here is to choose "Write to File" in the Type of ReadWrite instead of "Read from File".