

ECONOMIC MODELING OF AGRICULTURAL PRODUCTION IN NORTH
DAKOTA USING TRANSPORTATION ANALYSIS AND FORECASTING

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Title

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DOCTOR OF PHILOSOPHY

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ABSTRACT

Agricultural industry is crucial for the economy; agricultural transportation is an integrated part of that industry. Optimization of the transportation and logistics costs is an important part of the transportation economics. This study focuses on the minimization of the total cost of transportation logistics. Sugar-beet is one of the important crops in the state of North Dakota and there has been sporadic research in the sugar-beet transportation economic modeling. Therefore, this research focuses on the transportation economic modeling of the sugar-beet including yield forecasting to reduce the uncertainty in this process.

This study begins with developing a yield forecasting model which is presented as a way to sustain the agricultural transportation under stochastic environments. The stochastic environment includes variation in weather conditions, precipitation, soil type, and randomness of natural disasters. The yield forecasting model developed uses Normalized Difference Vegetation Index (NDVI), Geographical Information System (GIS), and statistical analysis.

The second part of this study focuses on economic model to calculate the total cost associated with the sugar-beet transportation. This model utilizes the GIS analysis to calculate the distances travelled from member coop farms during harvest and transport to processing facilities in various locations. This model sheds light on the critical cost factors associated with the total economic analysis of sugar-beet harvest, transportation, and production.

Since the sugar-beet yield varies significantly based on different factors, it provides for a variable optimal harvesting time based on the plant maturity and sugar content. Sub-optimized piers location result in the high transportation and utilization costs.

The third part of this research focuses on minimizing the sum of transportation costs to and from piers and the piler utilization cost. A two-step algorithm, based on the GIS with global

optimization method, is used to solve this problem. In conclusion, this research will provide a primary stepping stone for farmers, planners, and engineers to develop a data driven analytical tool which will help to minimize the total logistics cost of the sugar-beet crop while at the same time keeping the sugar content intact and predict the sugar yield and truck volume.

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DEDICATION

This dissertation is dedicated to my grandmother Shalini Deshpande, my mother Nilima Dharmadhikari, my wife Roopa Dharap, my father Laxmikant Dharmadhikari and my grandfather Ramchandra Deshpande. Their support and encouragement helped me to keep working and guided me to achieve this milestone.

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CHAPTER 1. INTRODUCTION

Background and Motivation

Agricultural industry is crucial for the economy in North Dakota and many other states in the United States. Agricultural industry share in Gross State Product (GSP) of North Dakota was 7.9 percent in year 2000. This is one of the highest in the United States (Leistriz, Lambert and Coon 2002). North Dakota ranks first in production of numerous crops in United States. The important crops statistics in North Dakota for crop year 2018 published by National Agricultural Statistical Service are presented in Table 1.

Table 1. North Dakota Crop Statistics (2018).

U.S. Rank	Commodity	Number	Unit	Percent of U.S. Total
1	Beans, dry, edible	12,392,000	cwt.	35%
1	Beans, navy	1,648,000	cwt.	40%
1	Beans, pinto	8,409,000	cwt.	61%
1	Canola	2,542,800,000	pounds	82%
1	Flaxseed	3,435,000	bushels	90%
1	Peas, dry, edible	7,380,000	cwt.	52%
1	Wheat, Durum	28,920,000	bushels	53%
1	Wheat, spring	207,870,000	bushels	50%
2	Lentil	2,175,000	cwt.	29%

Table 1. North Dakota Crop Statistics (2018) (continued).

U.S. Rank	Commodity	Number	Unit	Percent of U.S. Total
2	Sunflower, all,	696,900,000	pounds	32%
2	Sunflower, non-oil	70,980,000	pounds	23%
2	Sunflower, oil	625,920,000	pounds	34%
2	Wheat, all	238,085,000	bushels	14%
3	Sugar beet	6,445,000	tons	18%
3	Oat	4,640,000	bushels	9%
3	Barley	24,885,000	bushels	18 %
6	Safflower	4,836,000	pounds	3%
4	Potato	25,160,000	cwt.	6%
9	Soybean	239,700,000	bushels	6%

The crop statistics provide insight on the importance of the agricultural products in North Dakota. Agricultural industry is crucial for the economy in the state. According to the North Dakota Policy Council, gross domestic product of agriculture and related industries in 2008 was \$2,468 million while the mining (including oil) industry's contribution was \$441 million. Also, the farm employment in 2008 was 32,225 compared to employment in mining was 8,434 (Thorning and Wilber 2010).

North Dakota is important in production of a large number of agricultural commodities, and the transportation economics of the state and the nation are affected by these commodities. Agricultural transportation research studies the agricultural commodities movements and evaluates highway, railroad, and waterways systems needed for moving, storing, and distributing of these commodities. Transportation economics covers a wide variety of economic research in the field of transportation. Transportation economics of the North Dakota is largely dependent on the commodity transportation within and without the state. This research analyzes agricultural commodities in the state of North Dakota alone. The analysis is based on the transportation and logistical needs of the said commodities. This is further expanded with yield forecasting to perceive factor changes in the transportation economics both on the micro and macro level.

North Dakota is a large agricultural state; and there are many areas which focus on a variety of crops. For the purpose of this research, the economy of the sugar transportation and production as one of the most important crops in the state is considered. Geographically the Red River Valley, in the eastern part of North Dakota, is the hub for sugar beet production. This thesis is a one of the earliest building blocks of the sugar-beet transportation and logistics research. This crop is transported exclusively by semi-trucks to the sugar processing facilities from the farm after harvest. The processed sugar is packaged and transported with other means of supply chain. Sometimes the sugar is shipped through railways and other times the processed sugar is transported through trucks. This process collectively uses all forms of transportation available in North Dakota.

The transportation economic model for an agricultural commodity includes five stages: harvesting, loading, front haul, unloading, and finally backhaul. This process is depicted in Figure 1. The harvesting stage consists of the use of combine or any other form of equipment to

harvest the final produce or grains. The sugar beet is loaded in the primary transportation mode, such as semi-truck, as it is harvested to be transported to the storage facility. The front haul stage includes the transportation from farm to the storage or processing facility. The unloading stage is where the harvested commodity is unloaded at the facility. Finally, the backhaul is usually staged where the empty truck returns to the farm for the next loading trip.

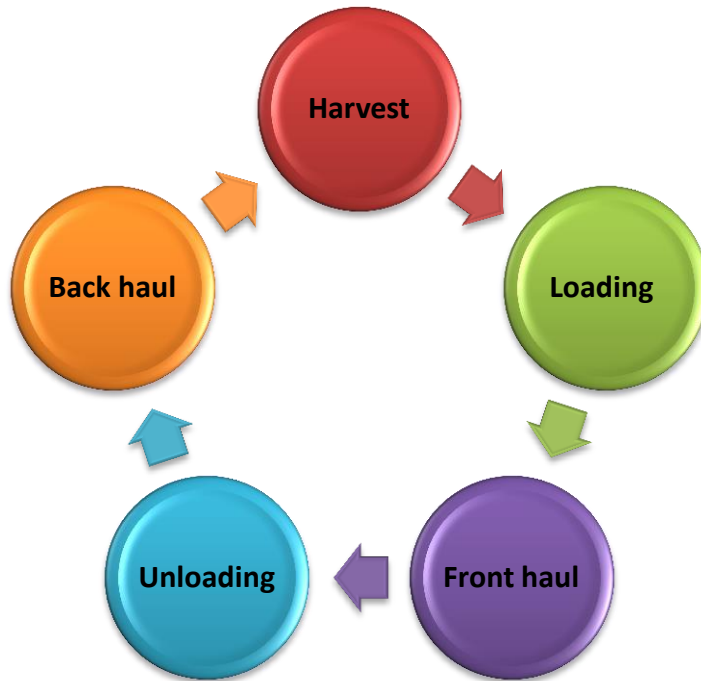


Figure 1. Transportation Economic Model for Agricultural Commodity.

There are different costs associated with different steps in the transportation model. The total cost is equal to the summation of the costs of loading the commodity, front haul to storage or processing facilities, cost of unloading, and backhaul to the farm. This cost is represented in terms of product of distance, truckloads of commodity, and an average fuel cost factor based on the distance. The uncertainty in this process can be reduced with the help of yield forecasting.

Yield forecasting is a process which uses satellite imagery to forecast the yield of the commodity at the end of the harvest season. There are different methods of yield forecasting.

These methods are discussed in details in the literature review section. This study uses yield forecasting with the help of satellite imaging and GIS. GIS is further used in the transportation model building. It aids to predict to and from distance travelled by truck carrying commodity. These distances are used in the optimization study. This study will be useful for the transportation planners and researchers in optimizing distance travelled and minimizing cost along with planning for crop transportation based on harvest forecast. This can further be developed as a data driven decision system model to provide insights to farmers and logistics systems operators.

Research Objectives

Optimization of the transportation and logistics costs is an important part of the transportation economics. This study focuses on the problem of minimization of the total cost of transportation. Furthermore, it is important to have a good understanding of the sugar beet transportation requirements and various steps, to develop an accurate economic model for this important commodity for the state of North Dakota. This type of research works in two ways. It is useful for farmers, as well as planners and engineers, who are involved in various stages of transportation and production. Farmers will be able to save on the transportation costs at same time maximizing their sugar output. At the same time, planners and engineers will have the data for the transportation volumes and the demand on the rural roads as far as truck traffic and tons of products moved. This data will be important for the future expansion and maintenance of the roads.

Therefore a crucial data driven approach to combine the yield forecasting with the optimization process is developed. This approach is depicted in Figure 2. This approach includes the yield forecasting with the help of satellite imagery, transportation cost estimation, and total

logistic cost optimization. Outputs from each step can be used individually or can be combined to generate a final optimized solution of the transportation economic model. This approach is tested for the sugar-beet crop and can be replicated for other crops.

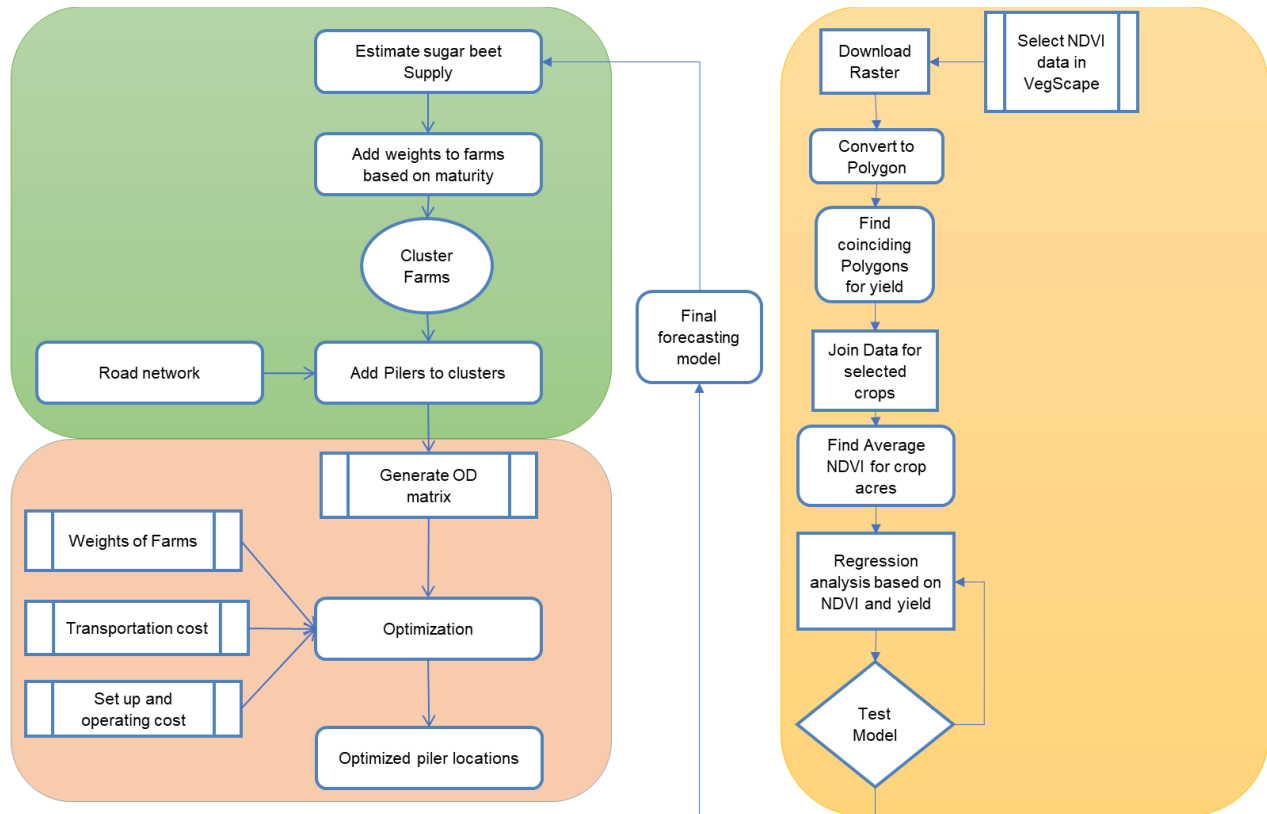


Figure 2. Data Driven Approach Combining Yield Forecasting with Optimization.

Research Contribution and Structure

To complete this data driven approach for sugar-beet transportation economic model, three journal articles have been completed and published. These three articles will be my original contribution to the study of transportation economic modeling. These three articles are as follows:

Yield Forecasting to Sustain the Agricultural Transportation under Stochastic Environment will provide a forecasting methodology for the sugar-beet yield. This approach is

developed with the help of Normalized Difference Vegetation Index (NDVI) values derived from the Vegetation Condition Explorer (VegScape) developed by the National Agricultural Statistics Service (NASS). This study answers following questions:

1. What are the most useful yield forecasting techniques?
2. How can we use easily available data such as NDVI data for yield forecasting?
3. What will be the data driven approach for yield forecasting?

Significance:

This research is the first study in the field of yield forecasting for the sugar-beet farming. This study provides a data driven technique to forecast yield of the agricultural commodity using easily available data such as NDVI. This article is published in the International Journal of Research in Engineering and Science.

Analysis of Transportation Economics of Sugar-Beet in the Red River Valley of North Dakota and Minnesota Using Geographical Information System will provide a detailed model of the transportation economics analysis for sugar-beet crop. This study will answer following research questions:

1. How to calculate total transportation cost for sugar-beet crop?
2. How to use GIS to estimate the total miles travelled by sugar-beet trucks?
3. How to track the trends in the transportation cost model?

Significance:

This research is one of the first studies in the sugar-beet transportation field. The transportation cost model developed here is useful for performing economic analysis. This model can also be replicated for other commodities. This article was published in the Journal of Renewable Agricultural.

Piling Centers Location Optimization for Sugar Beets under Supply Variation will address the issue of the location optimization and its importance in the transportation economic model. This article talks about the minimization model for the total logistics cost which includes set up cost, storage cost, yield loss cost, and transportation cost. This article expands the research from the previous article and uses transportation economic analysis in the optimization model. This article provides answers to following research questions:

1. How to address supply variation in the sugar-beet transportation?
2. How to improve sugar content by providing optimal harvesting time and reduce yield loss cost?
3. What is the data driven algorithm to optimize the sugar-beet piler (piling center) locations?

Significance:

This study presents a data driven optimization algorithm for sugar-beet transportation. This algorithm is important to minimize the total logistics cost at the same time keep the optimum sugar content, thus maximizing the returns to the farmers. The outputs from first two articles can be used as the input for this study and combined study can be used to present the detailed transportation economic model of sugar-beet crop. This article is accepted for presentation at 2019 Transportation Research Board (TRB) Annual Meeting.

This dissertation is organized as follows: Chapter 2 reviews the literature in the field of yield forecasting, economic modeling, and agricultural transportation and supply chain. Chapter 3 presents the research in the field of yield forecasting. Chapter 4 presents the transportation economic study of sugar-beet production. Chapter 5 presents the optimization model for sugar-

beet transportation. Chapter 6 presents the discussions based on this research. And Chapter 7 presents the conclusions and future research.

CHAPTER 2. LITERATURE REVIEW

Yield and Yield Forecasting

Yield of can be defined as the full amount of agricultural product. Yield is measured in different systems. Senay and Verdin (2003) use ton/hectars (t/ha) unit to measure the yield in Ethiopia. They provide yield as ratio between production in tones and planted area in hectars. Agricultural reports in United States use bushels as a unit of agricultural yield. Murphy (1993) provides the weights per bushels of different crops on University of Missouri Extension website. According to the data wheat weighs 60 pounds per bushel and corn weighs 56 pounds per bushel.

In the research of the agricultural production it is important to study different efforts of yield forecasting. Yield forecasting is used to estimate the yield in one season or one year. The results of the yield forecasting are useful for transportation and economic decision making and providing policy changes. Yield forecasting is carried out with the help of different techniques. This research concentrates on the techniques using GIS and other mathematical work. Following section reviews different efforts of yield forecasting.

Donatelli et al. (2010) develop the APES: Agricultural Production and Externalities Simulator. This simulator consists of different modules starting from soil, water, and crop with diseases and chemicals.

A new combined model for biomass growth and crop yield forecasting from low cost NOAA–AVHRR measurements has been developed and calibrated for the conditions in Pakistan. Advance very high resolution radiometer, coarse resolution - pixel size 1.1 km. (Bastiaanssen and Ali 2003)

The spatial structure of the relationship between rainfall and groundnut yield has been explored using empirical orthogonal function (EOF) analysis. They finally use district level scale

which is highly correlated ($R_{sq} = 0.96$). Their experiment studies different spatial scales to use in the forecasting. (CHALLINOR, et al. 2003)

Cantelaube and Terres (2005) present a model with two parts: 1) Crop growth simulation 2) Regression analysis. Data used is the weather data from DEMETER climate models. They observed use of climatic forecast in crop yield modeling provides better predictions. Net primary productivity (NPP) was estimated using PAR and NDVI. They use NPP equation by Goward and Huemmrich (1992). Results of the study show that it is possible to monitor crop growth and assess grain yield on a large scale through the integration of satellite imagery, field data, and growth modeling. (Baez-Gonzalez, et al. 2002)

Louhichi et al. (2010) develop the Farm System Simulator (FSSIM) which helps to present a bio-economic modeling to provide insight to complex agriculture structure of Europe. Senay and Verdin (2003) connect the yield reduction in Ethiopia with the water balance using GIS based model. They use the water requirement satisfaction index (WRSI) and data acquired by GIS to find interrelationship between yield of maize, sorghum and teff. They suggest this WRSI based estimates can be used as a warning system for different crops.

Liu (2009) in his research about crops prepares a GIS tool for modeling the relation between crops and water. He connected a GIS part with EPIC model (Environmental Policy Integrated Climate) to simulate dynamics of soil–crop–atmosphere–management system. He also enlists different available models for the food production. He categorizes them in categories such as physical model, economic model, physical-economic model, time series model, regression analysis model, and integrated model. He uses an integrated model. This model adds the crop growth model and soil evaporation model with the help of GIS to simulate the plant growth. In the case study this GEPIC (GIS and EPIC) model estimated the crop water productivity (CWP)

for three major cereal crops. CWP is ratio of crop yield to crop evapotranspiration which is an important indicator to measure relation between crop yield and water consumption.

Liu et al. (2009) continued their research with EPIC model for agricultural and environmental studies provide a new model for the regions where daily weather data is not available. They develop a MODAWEC (MOntly to DAily WEather Converter) model to generate the daily precipitation and maximum and minimum temperature. They use monthly precipitation, maximum and minimum temperature, and number of wet days to generate daily values. They generate this reliable data to simulate the crop yield and crop weather use, their main objectives. With the help of case study they show that the quality of generated daily weather data is good enough to use in simulation of crop yield.

Chavas et al. (2009) try to study the effect of the climate change on the productivity of major crops in China. They determine domain wide trends and also detect the regions which are vulnerable to future climate change and change in productivity is 10% increase or decrease. They use simulation modeling to assess the region wide changes in long term. They test the scenarios of the greenhouse gas emission and CO₂ farming. In this study they combine regional climate model output (RegCM3) over the domain, a global soil database (WISE), a county-level cropland database (UNH), and Chinese farm management data with the EPIC agro-ecosystem simulation model. They conclude that if the CO₂ enrichment is used, it will increase the productivity. In absence of this enrichment climate change will affect negatively on the productivity.

Mo et al. (2005) developed a process based crop growth model. This model predicts regional crop growth, water consumption and water use efficiency (WUE). They use remote sensing data from North China Plain (NCP) which includes GIS, land use maps, digital elevation

model (DEM) and soil texture with leaf area index (LAI). They receive their data from National Oceanic and Atmospheric Administration (NOAA)–Advanced Very High Resolution Radiometer (AVHRR) data. They simulate the winter wheat and summer maize yields in 1992 and 1993 and compare them with county level data. They state that to improve accuracy and reliability of crop yield prediction higher resolution satellite images such as MODIS should be cheaply available, preferably free on-line access, globally.

Ewert et al. (2009) state the Integrated Assessment and Modeling (IAM) for the agricultural production can provide impacts on policy changes. They try to provide a flexible IA model which will allow solution of range of issues and not focus on just one problem. They propose a framework SEAMLESS-IF which integrates relationship and processes across disciplines and scales and combines quantitative analysis.

Economic Modeling

Economic modeling is a way to simplify the complex processes to explain the proposed changes and predictions. Howitt (1995) presents a method to calibrate Constant Elasticity of Substitution (CES) production functions in agricultural production models. This method uses minimum dataset that usually restricts the modeler to a linear program. This approach has some characteristics of econometric and programming models which makes it more flexible production specification than linear or quadratic programming models. The resulting models are shown to satisfy the standard microeconomic conditions. Fraser, McInnes and Russell (1997) build their research on the work of Howitt. They study reform in the Europe and UK sugar industry and trade. They provide an econometrics model for efficient UK sugar-beet production. They present a method to test the alternative allocation procedure in sugar-beet farming in UK.

Kameyama (n.d.) introduced the primary model framework for regional agricultural production model, focusing on land use by crops and to apply for assessing the impact of climate change. They used positive mathematical programming (PMP) for calibrating the land allocation in Adana province. They considered the impact of climate change only as the yield change (reduction) of crops. Konyar and Howitt (2000) study the effects of Kyoto protocol on the US crop production. They analyze the carbon trading and projected climb in energy prices. They develop a mathematical programming model with an objective function representing domestic and foreign customers and producer welfare. They further develop the input substitution for this model. Their model captures the flexibility in the crop production using the input substitution analysis of farmers' behavior and price changes due to energy market changes.

Adenäuer and Heckelei (2005) examine two alternative behavioral models, expected profit maximization and utility maximization. They test to ability of those models to contribute to an explanation of observed supply behavior and consequently for a more realistic simulation responses to policy changes than previous approaches. They suggest as low yield can lead to considerable income losses if production quotas are not filled, the yield uncertainty plays an important role under the framework of production quotas. Bangsund, Hodur and Leistritz (2012) provide expenditure information by sugar-beet processing and marketing cooperatives. They estimate economic impacts using input-output analysis for production in Minnesota and North Dakota entities in fiscal 2011. They also provide direct and secondary impact of sugar-beet with tax revenue assessment. They conclude that even though sugar-beet industry in North Dakota and Minnesota is small in acreage, it has a vast contribution in the local and regional economies.

Brookes and Blume (2012) discover the economic and environmental impacts of genetically modified (GM) technology in Ukraine. They state that there are no legally permitted GM crops in Ukraine. They argue adoption of GM technology offers considerable potential for the arable cropping sector in the Ukraine to make rapid technological and productivity advances.

El Benni and Finger (2012) apply variance decomposition approach using data to quantify the direct and indirect effects of yields, prices and costs on net revenue variability at the farm level. Furthermore they investigate relevance of different risk sources across crops and the influence of farm characteristics on their risk profile. The results show that costs play only a minor role in determining income variability but price and yield risks are of outmost importance and very crop specific.

May (2012) developed a multivariate model considering economic and social-psychological variables to explain farmers' behavior and to study farmers' cropping decisions. This model can be used to graphically identify behavioral patterns across farmers. The aim was to predict the crop allocations made by sugar-beet growers in response to the Sugar Regime reform introduced in 20th February 2006. The multivariate model integrates a number of different approaches into a single framework to study economic and non-economic drivers that influence farmers' strategic cropping decisions.

Wisner, et al. (2001) wrote about use of the baseline projection from large agricultural economic models as the long-range forecast. They contest that this method of using projections as forecast for major investment decisions is harmful. They state these models were created to analyze impacts of U.S. and global impact based on agricultural policies and changes. They conclude that there is a large need of funding to convert these models in to the forecasting models.

Transportation and Supply Chain

The economic modeling highlights the importance of the study of transportation system and supply chain involved in the agricultural production. There are different types of studies of supply chain of the sugar industries. Majority of these studies are for the sugar cane transportation and production. Deshmukh et al. (2012) started with the comparison of the sugar industries in the world. They study world sugar export and further establish extensive statistics about Indian sugar industry. They mention problems for inbound supply chain and transportation of sugar cane in India. They also comment on the low sugar yield in India. Their research explains the economics of sugar in world and in India. Le Gal, et al. (2009) use simulation to study the sugar cane supply chain. They try to combine a tactical supply planning model with a daily logistics model to explore the relationships between these supply components. They study Supply chain models for the seasonal short term planning, using ARENA® to simulate the logistics process.

Gaucher, Le Gal and Soler (2003) use two model structure based on simulation to explain relationship between stakeholders and sugar mills. They use a strategic model and a logistics model and track the daily management of the sugar cane flow. Their first model compares weekly and total seasonal sugar production while second model focuses on simulation of supply chain which evaluates impact of technology changes on daily harvest and logistic capacities. Grunow, Günther and Westinner (2007) study the situation where they keep the supply constant while minimize associated costs. They use optimization with hierarchical method involving Cultivation Planning, harvest planning, and crew and equipment dispatching.

Ioannou (2005) study the Hellenic Sugar Industry (HSI), the single sugar-quota producer in Greece and the largest agricultural company. They state that the production of the beets is seasonal therefore the sugar production is also seasonal. The goal of this research was to reduce the 3.5 million US\$ transportation cost, which constituted almost 40% of the field operating expenses. They develop an appropriate transportation model and optimize sugar supply chain. They try to minimize the overall transportation cost between all the nodes of the distribution network and assumes that this cost is a linear function of the distance traveled and the per unit distance travel cost.

Kostin, et al. (2011) presented a new method to solve the supply chain problems with less computational effort. They propose rolling horizon algorithm to solve the supply chain problem with integer programming for sugar industry. They test their method with a case study of sugar cane industry in Argentina. They determine the number and type of production and storage facilities to be built in each region of the country to fulfill the sugar and ethanol demand is fulfilled with maximization of the economic performance. Laudien, Bareth and Doluschitz (2004) use multispectral or hyperspectral vegetation indices to find if the diseases will yield lower sugar-beet. Mele, et al. (2011) presented a quantitative tool to support supply chain decision making. They formulate a multi-objective linear programming problem and try to simultaneously optimize economic and environmental performance of the supply chain. They provide the algorithm of the solution with the case study of the sugar cane industry in Argentina. They suggest that their approach proceeds towards a sustainable supply chain.

Pathumnakul, et al. (2012) took into account different maturing times of sugar cane to solve the location allocation problem for sugar cane loading stations. They modify the “fuzzy c-means” (FCM) method, which takes into account both the cane supply and the different cane

maturity periods. Their method states the objective of minimization of the sum of the transportation and station utilization costs. Scarpari and Beauclair (2010) use GAMS to develop a linear programming tool to develop an optimized planning model for sugarcane farming. Their objective is to maximize the profit harvesting time schedule optimization in the sugar mill. Thuankaewsing, Pathumnakul and Piewthongngam (2011) use artificial neural network to forecast sugar cane yield and use these values with linear programming to find the optimized harvesting schedule. The objective function in the mathematical model ensures maximization of sugar cane yield while harvesting scheduling maintains equality within farmer groups.

Grain supply chain differs a lot from sugar-beet and sugar cane supply chain. The modes used for transportation (trucks, rails) are similar though there is a significant change in the handling and equipment use. Typical North Dakota grains are transported from farms to the elevators by trucks and then by railroad to the intended market. Vachal, Berwick and Benson (2010) track the wheat transportation in North Dakota. They study the competitive position of the wheat growers and the market. They highlight the importance of the logistics studies in the wheat market. They try to focus on market flows and transportation rates to primary domestic markets and export market gateways. They also try to understand trends and shifts in transportation related factors to assess future investment and policies.

Ahumada and Villalobos (2009) provide a comprehensive review of literature regarding the supply chain of agricultural products. They categorize the reviewed papers in deterministic and stochastic modeling. They classify successfully implemented models in the fields of production and distribution planning for agri-foods based on agricultural crops. They focus on type of crops modeled and the scope of the plans. They review literature based on both non-perishable and fresh products. Bessler and Fuller (2000) study the railroad wheat waybill data.

They use time series method to carry out their analysis. Their results suggest that rate-setting in a particular region is in part a function of the dominant railroads management and its aggressiveness, an expected outcome in an oligopolistic market.

Ferguson (2001), in his thesis, considers the problem of the organic wheat supply chain. They compare selling to large and small grain companies, selling through producer-owned firms (POFs) and selling directly to processors. Increased coordination between producer and marketer through a POF can be advantageous for the producer, but not necessarily for the marketer, due to the difference in the distribution of rents. Johnson and Mennem (1976) develop market area concentration tool for competitive and non-competitive. They use the market area sensitivity tool in market structure analysis.

Babcock and Bunch (2003) study the structural changes in the grain transportation in Kansas based on the increased use of the trucks and reduced short line railroads. These objectives were achieved with the method of interviewing and questionnaire analysis. They conclude that the increase in the farmer-owned truck is the most important reason of this change. Also they predict the need of study for the abandonment of the short line and its effects on deterioration of roads in Kansas. Babcock, et al. (2003) continue their research on the abandonment of the short line railroads and its effects on the transportation. They study the case of wheat transportation in Kansas. They simulate the case of the abandonment of the railroad using GIS and a truck routing algorithm. They conclude that total transportation cost is not much different in both scenarios but the handling cost makes a huge difference.

Choudhury, Bouman and Singh (2007) compare the raised beds for rice and wheat. Their research suggests there is little or no help for increasing yield by using raised beds. This research is useful to forecast the yield based on the input parameters. Jha and Jha (1995) base their study

on the farm level data and focus on the small farm constraints. They study diversifications and risks associated with it. Kandhai, Booi and der Fels-Klerx (2011) study Delphi-based method for mycotoxin contamination in wheat supply chain. They use the survey method for this study. They involve persons from all three stages of the supply chain - production, transportation and storage. Ladha, et al. (2003) studied yield and yield decline in wheat and rice in long term experiments. They predict the causes of the decline are mostly location-specific but most prominent one is soil depletion.

Li, et al. (2012) study the wheat straw production and supply chain (lifecycle analysis). The study quantified the environmental impact of producing wheat straw pellets in terms of global warming potential, acidification, eutrophication, ozone layer depletion, abiotic depletion, human toxicity, photochemical oxidation, fresh water aquatic Eco toxicity, and terrestrial Eco toxicity. Magnan (2011) traces the wheat supply chain between Canadian growers and UK based bakers. He studies the identity-preserved sourcing relationship that ties contracted prairie wheat growers to consumers of premium bread in the United Kingdom. He touches the social aspects of this supply chain relationship. This is an old study from 1969 when the railroads were dominant in the agricultural transportation (Rust and St. George 1969). Authors study the respective position of the Montana, away from the market centers and they suggest the importance of the transportation system in Montana.

CHAPTER 3. YIELD FORECASTING TO SUSTAIN THE AGRICULTURAL TRANSPORTATION UNDER STOCHASTIC ENVIRONMENT¹

Introduction

Agricultural transportation is a major part of the United States' freight transportation and overall transportation systems. Agricultural commodities such as Cereal Grains represent one of the top ten commodities by weight originating in United States as shown in Table 2. (U.S. Department of Transportation 2015). It involves several stages of the transportation activities namely 1) from farm to storage, 2) from storage to production facility, and 3) from production facility to market. Farmers are involved in the first step 'from farm to storage.' Logistical costs for this step are accrued by farmers. This step is incorporated of different modes of transportation like roads, railways, or waterways. The logistical costs are dependent on the yield of the crop, shipping distance, and the harvest time of the year. Though distance and the time of the year are fairly similar each year, yield of the crop can change drastically year to year. The yield of agricultural commodities is dependent on stochastic environments such as weather conditions, precipitation, soil type, and natural disasters. This consideration of stochastic environment is important for the freight transportation modeling as trip origins are seasonal and yield of the commodity is varying. Transportation models are forecasting models which consist of a series of mathematical equations that are used to represent how people travel (Beimborn 2006). The freight transportation models substitute people with different commodities and forecast how freight travels and how it affects the transportation network. Thus, it is important for farmers and

¹ Published as 'Yield Forecasting to Sustain the Agricultural Transportation Under Stochastic Environment' in International Journal of Research in Engineering and Science.

freight models to have a yield forecasting model to predict logistical needs for the agricultural transportation.

Table 2. Top 10 Commodities in U.S. for year 2013.

#	Commodity	Weight (millions of Tons)
1	Gravel	2,427
2	Cereal grains	1,665
3	Non-metallic mineral products	1,514
4	Waste/scrap	1,441
5	Natural Gas, coke, asphalt	1,403
6	Coal	1,263
7	Gasoline	1,029
8	Crude Petroleum	839
9	Fuel Oils	757
10	Natural Sands	620

Yield can be defined as the harvested amount of agricultural product. Yield is measured in different unit systems. Senay and Verdin (2003) use ton/hectars (t/ha) unit to measure the yield in Ethiopia. They provide yield as ratio between production in tones and planted area in hectars. Agricultural reports in United States use bushels as a unit of agricultural yield. Murphy (1993) provides the weights per bushels of different crops on University of Missouri Extension website. According to the data, wheat weighs 60 pounds per bushel and corn weighs 56 pounds per bushel. Agricultural transportation becomes a stochastic process as it is dependent on the

yield of the commodity. The yield of the commodity is not constant. It is dependent on weather conditions, rainfall, soil type, and other factors Figure 3.

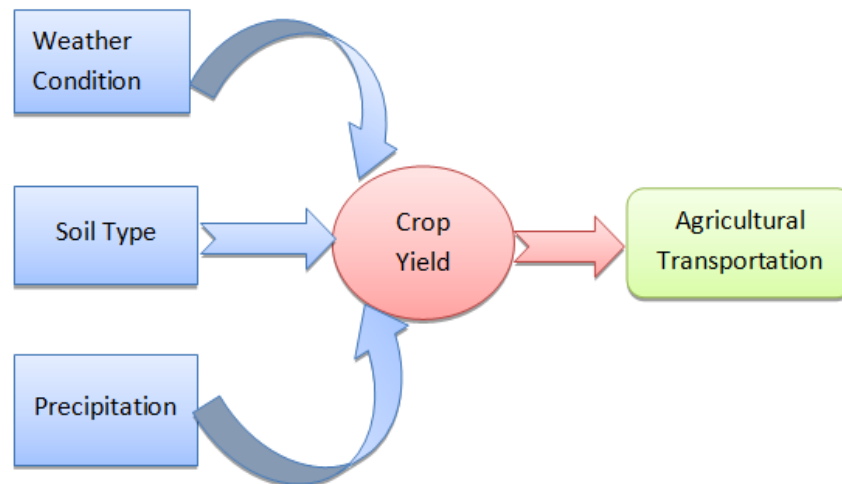


Figure 3. Agricultural Transportation Process.

This paper presents a study of yield forecasting with the help of satellite imaging and geographic information system (GIS). This research can be useful for farmers, transportation professionals, and logistical operators. Models and algorithm developed in this study can be replicated for different crops and harvest times. The paper is organized as follows: Section 2 reviews current and past literature about relevant yield forecasting techniques, Section 3 demonstrates the method used in the study and proposes the variables and data required for the analysis, Section 4 presents the data analysis part with results, and Section 5 discusses insights gained from this study and future research avenues.

Literature Review

In the research and production of the agricultural products it is important to study different efforts of yield forecasting. Yield forecasting is used to estimate the yield in one season or one year. The results of the yield forecasting are useful for transportation and economic

decision making and providing policy changes. Yield forecasting is carried out with the help of different techniques. This research concentrates on the techniques using Geographical Information System (GIS) and other mathematical algorithms to determine and forecast agricultural yield. Following section reviews different efforts of yield forecasting in the literature.

Donatelli et al. (2010) developed the agricultural production and externalities simulator (APES). This simulator consists of different modules starting from soil, water, and crop with diseases and chemicals. A new combined model for biomass growth and crop yield forecasting from low cost measurements has been developed and calibrated for the conditions in Pakistan. Advance very high resolution radiometer, coarse resolution - pixel size 1.1 km (Bastiaanssen and Ali 2003). The spatial structure of the relationship between rainfall and groundnut yield has been explored using empirical orthogonal function (EOF) analysis. They finally use district level scale which is highly correlated ($R^2 = 0.96$). Their experiment studied different spatial scales to use in the forecasting (Challinor, et al. 2003) Cantelaube and Terres (2005) present a model with two parts: 1) Crop growth simulation and 2) Regression analysis. Data used is the weather data from DEMETER climate models. They observed use of climatic forecast in crop yield modeling provides better predictions. Net primary productivity (NPP) was estimated using PAR and NDVI. They use NPP equation by Goward and Huemmrich (1992). Results of the study show that it is possible to monitor crop growth and assess grain yield on a large scale through the integration of satellite imagery, field data, and growth modeling. (Baez-Gonzalez, et al. 2002)

Louhichi et al. (2010) developed the Farm System Simulator (FSSIM), which helps to present a bio-economic modeling to provide insight to complex agriculture structure of Europe. Senay and Verdin (2003) connect the yield reduction in Ethiopia with the water balance using a

GIS based model. Then, they use the water requirement satisfaction index (WRSI) and data acquired by GIS to find interrelationship between yield of maize, sorghum and teff. They suggest this WRSI based estimates can be used as a warning system for different crops.

Liu (2009) in his research about crops prepares a GIS tool for modeling the relation between crops and water. He connected a GIS part with Environmental Policy Integrated Climate (EPIC) model to simulate dynamics of soil–crop–atmosphere-management system. He also enlists different available models for the food production. He categorizes them in Physical model, Economic model, Physical-economic model, Time series model, Regression analysis model, and integrated model. He uses an integrated model. This model adds the crop growth model and soil evaporation model with the help of GIS to simulate the plant growth. In the case study this GEPIC (GIS and EPIC) model estimated the crop water productivity (CWP) for three major cereal crops. The CWP is ratio of crop yield to crop evapotranspiration which is an important indicator to measure relation between crop yield and water consumption.

Liu et al. (2009) continued their research with EPIC model for agricultural and environmental studies provide a new model for the regions where daily weather data is not available. They develop a MODAWEC (MOnthly to DAilyWEather Converter) model to generate the daily precipitation and maximum and minimum temperature. They use monthly precipitation, maximum and minimum temperature, and number of wet days to generate daily values. They generate this reliable data to simulate the crop yield and crop weather use, their main objectives. With the help of case study they show that the quality of generated daily weather data is good enough to use in simulation of crop yield.

Chavas et al. (2009) try to study the effect of the climate change on the productivity of major crops in China. They determine domain wide trends and also detect the regions which are

vulnerable to future climate change and change in productivity is 10% increase or decrease. They use simulation modeling to assess the region wide changes in long term. They test the scenarios of the greenhouse gas emission and CO₂ farming. In this study, they combine regional climate model output (RegCM3) over the domain, a global soil database (or WISE), a county-level cropland database, and Chinese farm management data with the EPIC agro-ecosystem simulation model. They conclude that if the CO₂ enrichment is used, it will increase the productivity. In absence of this enrichment climate change will affect negatively on the productivity.

Mo et al. (2005) developed a process based crop growth model. This model predicts regional crop growth, water consumption and water use efficiency (WUE). They use remote sensing data from North China Plain (NCP) which includes GIS, land use maps, digital elevation model (DEM) and soil texture with leaf area index (LAI). They receive their data from National Oceanic and Atmospheric Administration (NOAA) – Advanced Very High Resolution Radiometer (AVHRR) data. They simulate the winter wheat and summer maize yields in 1992 and 1993 and compare them with county level data. They state that to improve accuracy and reliability of crop yield prediction higher resolution satellite images such as MODIS should be cheaply available, preferably free on-line access, globally.

Ewert et al. (2009) state the Integrated Assessment and Modeling (IAM) for the agricultural production can provide impacts on policy changes. They try to provide a flexible IA model which will allow solution of range of issues and not focus on just one problem. They propose a framework SEAMLESS-IF which integrates relationship and processes across disciplines and scales and combines quantitative analysis.

Methodology

From the literature review, the study found that a variety of ways are proposed for the yield forecasting out of which we choose yield forecasting using vegetation index method for this research. These vegetation indices are obtained from the satellite images. Raw or unprocessed satellite images have different issues such as cloud cover which make them difficult to use in the analysis. National Agricultural Statistics Service (NASS) has created a Vegetation Condition Explorer (VegScape) to provide simplified vegetation data as a raster image by simplifying satellite images (National Agricultural Statistic Service 2016). Different vegetation indices available at VegScape are as follows: 1) Normalized Difference Vegetation Index (NDVI) Products, 2) Vegetation Condition Index (VCI), 3) Ratio of current NDVI to previous year for the same periods (RVCI), 4) Ratio of current NDVI to the median of previous years since 2000 for the same periods (RMVCI), and 5) Deviation of the vegetation to "normal" vegetation or multiple-year mean (MVCI). This research uses NDVI as the primary vegetation index for the yield forecasting model. NDVI is calculated from different satellite images with the equation 1. It is calculated with the help of visible and near-infrared light reflected by vegetation. Healthy vegetation absorbs most of visible light and reflects large near-infrared light thus NDVI is one of the most useful indices for yield forecasting (Propastin and Kappas 2008).

$$NDVI = \frac{NIR-Red}{NIR+Red} \quad (1)$$

Where,

NIR = near-infrared spectral reflectance measurement

Red = red spectral reflectance measurement

The methodology follows the algorithm shown in Figure 4. It begins with the VegScape. The raster datasets for intended area are downloaded. These datasets are available in daily,

weekly, or biweekly timelines. Based on the computing power available and the accuracy of the analysis required one of the dataset can be selected. The raster dataset is then converted in to the polygons with each polygon having individual values for NDVI. The polygons coinciding with the yield data from desired farms are selected based on location. This gives data set of desired NDVI values for a time interval based on farm locations. This analysis is performed with the help of geographical information system (GIS). The localized NDVI values are used to perform the regression analysis to generate the forecasting model. The validation and verification tests are performed on this model. Once the tests are done the final model is presented. This is an ongoing process and there is a different model for each season.

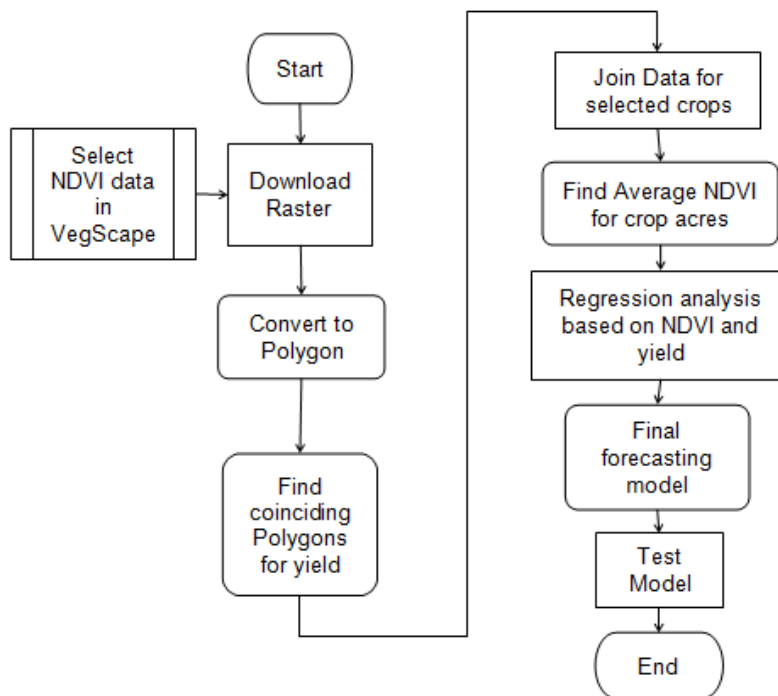


Figure 4. Algorithm for Yield Forecasting Method using NDVI.

Relationship between yield and NDVI was derived using regression analysis. As this model performs regression analysis on location data it can be considered as a geospatial

regression model. A lineal regression model similar to Equation 2 is used as a sample model for analysis. It represents yield as a function of the NDVI at a given time period ($n-i$) until n time period for i time windows. ε is the deviation from the regression line. For the best fit regression, we try to minimize $\sum \varepsilon^2$.

$$Yield = NDVI_{n-i}x_{n-i} + \dots + NDVI_nx_n + \varepsilon \quad (2)$$

This study connects the simplified satellite data available to the geographical regression modeling. This is important for farmers as well as modelers as they will have a simple tool to perform yield forecasting without carrying out an elaborate remote sensing and image processing. This will also help to make the logistical decisions at the end of the harvest season. Analysis section presents the data analysis part with the case study. The logistical cost of the sugar beet processing can be further calculated in the research article by Farahmand, Dharmadhikari and Khiabani (2013).

Analysis

Analysis is performed with the help of GIS and statistical analysis. Sugar beet crop from North Dakota's Cass County is chosen for the analysis step. Sugar beet production in Cass County is a co-op operation which is managed by American Crystal Sugar Company (ACSC) (Farahmand, Khiabani, et al., Economic Model Evaluation of Largest Sugar-beet Production in U.S. States of North Dakota and Minnesota 2013). The location and yield data for the sugar beet farms were received from the company. The analysis is carried out in three steps. First step is of NDVI data collection with GIS analysis. Second step consists of statistical analysis using regression modeling. Third and final step tests the model developed in the second step.

Step 1: NDVI data collection with GIS analysis

The NDVI data collection is carried out with the GIS analysis. Using location based NDVI data helps with the geographical regression process. The sugar beet locations are added in the GIS document. The locations are shown in Figure 5. NDVI data is downloaded from VegScape website. Cass County is selected as the area of interest as shown in Figure 6. The information for the area of interest is entered as weekly NDVI data for selected year. The ranges of dates were selected based on the plant time and harvest period of the sugar beet crop.

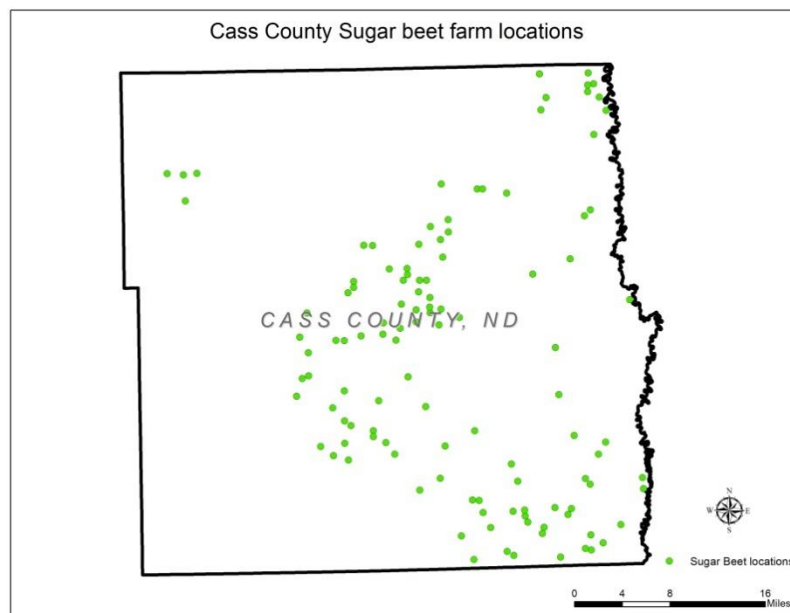


Figure 5. Sugar Beet Locations in Cass County of North Dakota.

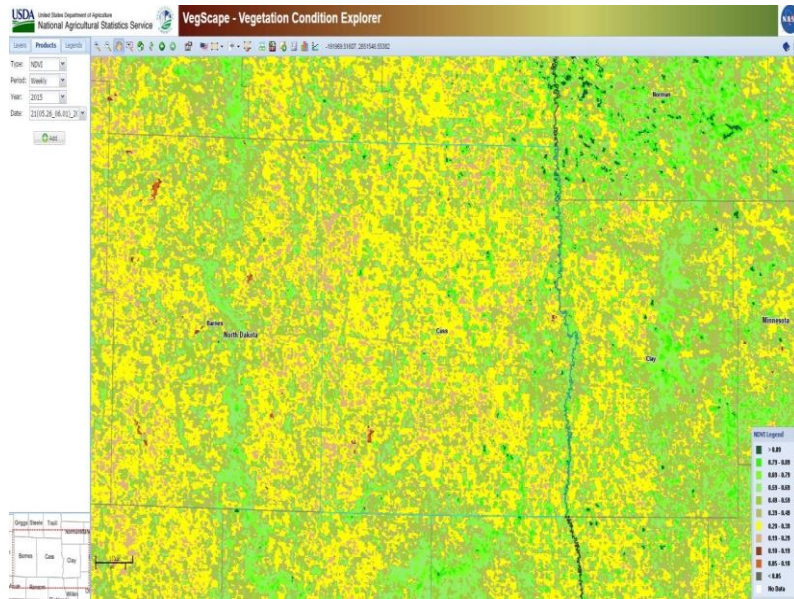


Figure 6. Screen Shot of the Area of Interest in VegScope (National Agricultural Statistics Service 2016).

The downloaded data comes in the raster form. The raster data is converted into polygons. A polygon in GIS is a vector object which can be considered as the boundary of each field in this case. These polygons are used to attach the locations to the NDVI values. The polygons are created using ArcGIS software and 'raster to polygon' tool. The polygons are further joined with the locations of the sugar beet farms. This gives timely NDVI data for the sugar beet farm locations. This process can be seen in Figures 7, 8, and 9. The NDVI values from the polygons are joined to the farm location datasets. The NDVI values are collected for the months in which sugar beet farming takes place. They are collected twice for each month. For example, the NDVI values in early September are *N9A*. These values are then added with the dataset of previous records of the yield from the respective farms. This provides a big dataset for regression analysis.

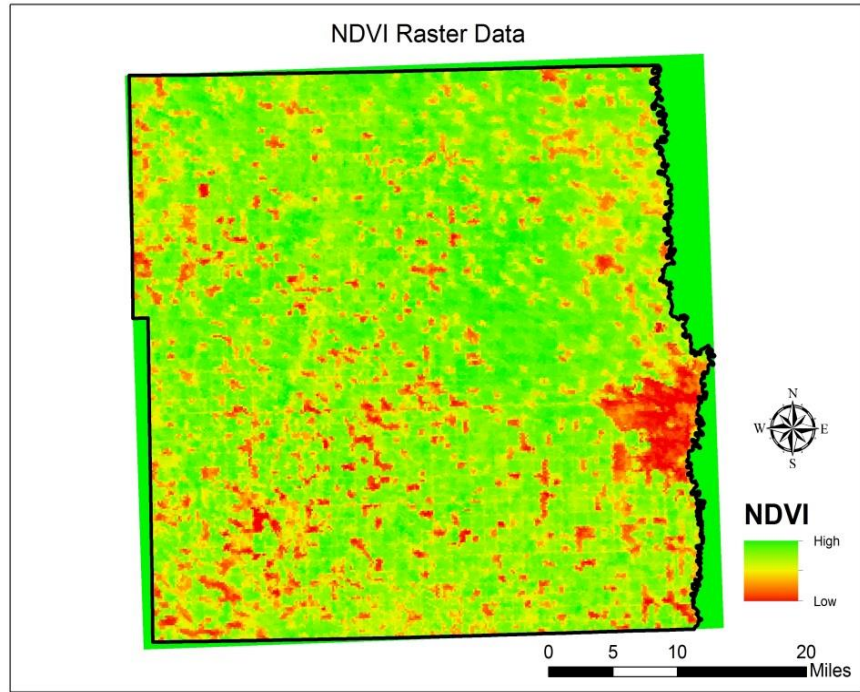


Figure 7. NDVI Data in Raster Form.

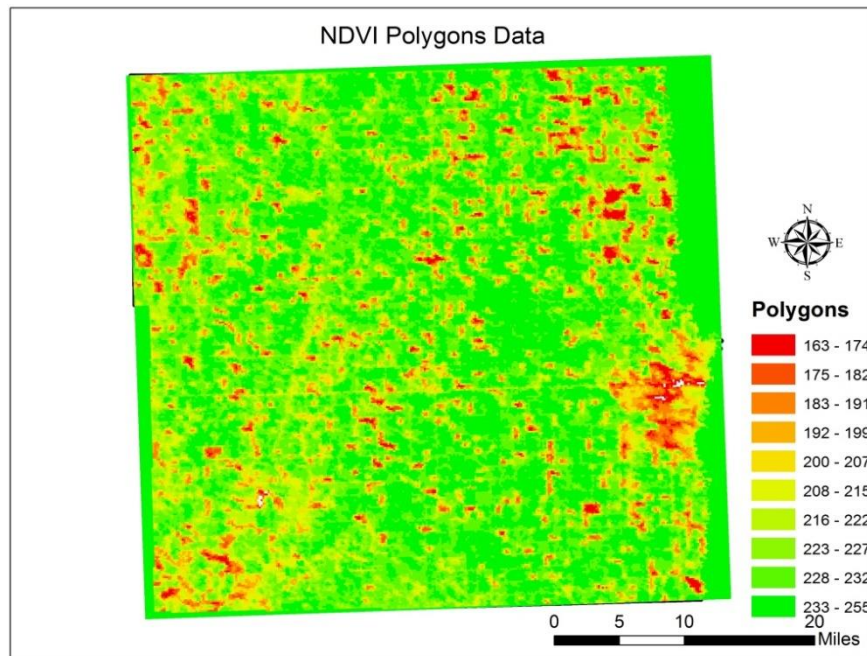


Figure 8. NDVI Data in Polygon Form.

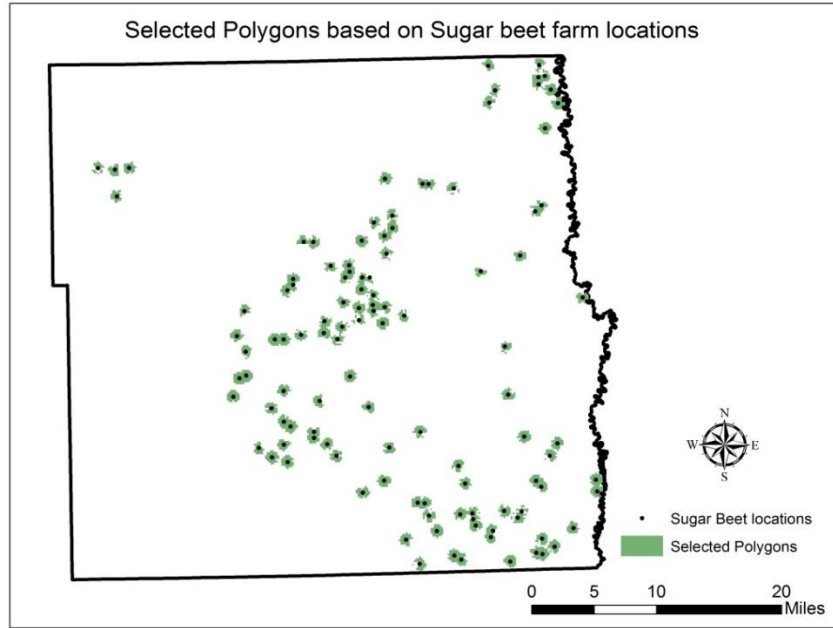


Figure 9. Selected Polygons Based on Locations of Sugar Beet Farms.

Step 2: Regression analysis

As mentioned in the methodology we use linear regression model for performing this analysis. Regression model is similar to the model shown in Equation 2. SAS® Enterprise Guide software is used to perform the regression analysis. The results of regression analysis are presented in Table 3.

Table 3. Preliminary Results from Regression Analysis

Number of Observations Read				4180	
Number of Observations Used				3585	
Number of Observations with Missing Values				595	
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	69113	23038	2027.79	<.0001
Error	3581	40684	11.36095		
Corrected Total	3584	109797			
Root MSE	3.37060		R-Square	0.6295	
Dependent Mean	20.75227		Adj R-Sq	0.6292	
CoeffVar	16.24208				
Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	1	-27.41441	0.69801	-39.28	<.0001
N8A_mean	1	32.53307	1.07348	30.31	<.0001
N9_mean	1	9.63945	0.57729	16.70	<.0001
N8B_mean	1	24.70714	1.37598	17.96	<.0001

The adjusted R-square value of 0.6292 is within the acceptable range. Also, residual plot in Figure 10 shows the distribution of residuals for yield is normal. Using the parameter estimates from Table 3 a preliminary regression for forecasting can be developed. Equation 3 represents the forecasting equation for yield for each farm. This regression equation can be used to forecast the yield at the farm in different years. The validation of this equation is important. The step 3 is the validation process.

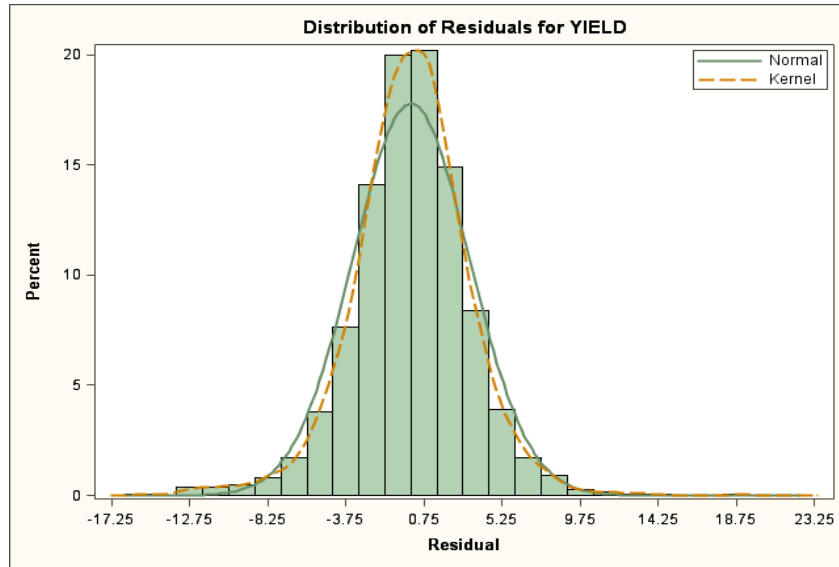


Figure 10. Distribution of Residuals (ϵ) for Yield

Preliminary equation:

$$\widehat{yield} = -27.41 + 32.53(N8A) + 9.63(N9) + 24.70(N8B) \quad (3)$$

Where,

yield: Yield at a farm.

N8A: NDVI Value reading at that farm for early August

N9: NDVI Value averaged for month of September

N8B: NDVI Value reading at that farm for late August

Step 3: Validation

The validation process includes forecasting and comparison parts. A different year's NDVI data is collected similar to previous process. This data is added for similar farms as earlier year's farms. The Equation 3 is used to forecast the yield using NDVI data. This yield population is compared with the actual yield numbers. We assume that the difference between two

populations is small. The t-test results for comparing two samples are presented in Table 4. In the table, Y_{Orig} is the actual yield and Y_{Cal_1} is the yield calculated based on model.

Table 4. t-Test Results

	Y_{Orig}	Y_{Cal_1}
Mean	24.90600445	23.00976276
Variance	14.00129181	4.882805396
Observations	1349	1349
Pearson Correlation	0.226423724	
Hypothesized Mean Difference	2	
df	1348	
t Stat	-0.979419744	
P(T<=t) one-tail	0.163774183	
t Critical one-tail	1.645984801	
P(T<=t) two-tail	0.327548366	
t Critical two-tail	1.961725384	

P-value is 0.3275 thus we can't reject the null hypothesis. Plots in Figure 11 depicts that the distribution of difference is normal. We can say that the difference between two populations may be small. Thus it can be said that the forecasting equation provides results closer to the actual yield. These results can be used in the making of logistical decisions in the future to reduce the logistical costs.

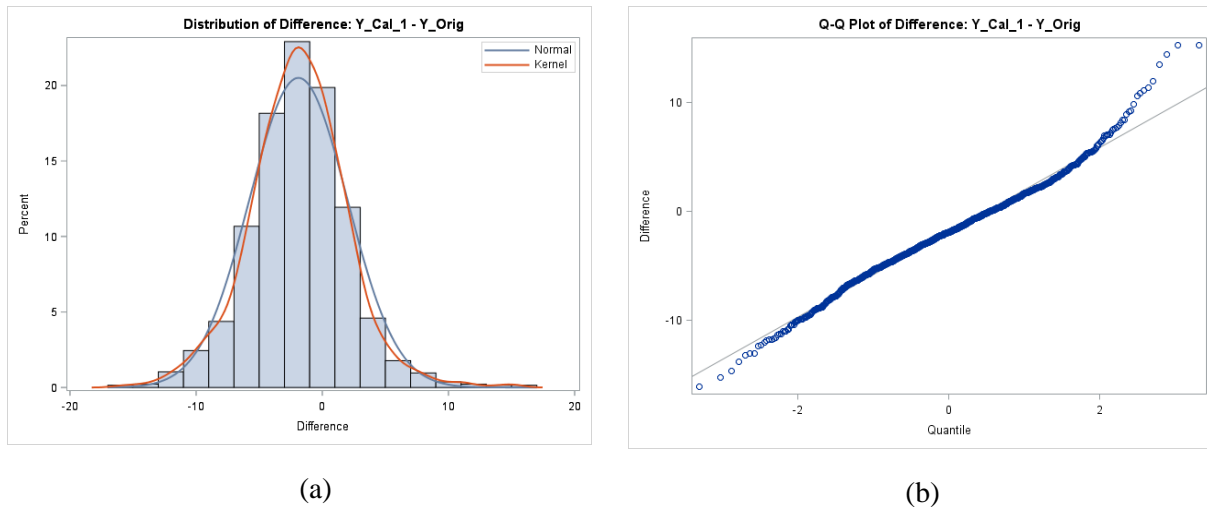


Figure 11. Normality Test using (a) Distribution of Difference and (b) Q-Q Plot of Difference.

Conclusion and Future Research

This paper provides insight about using yield forecasting techniques to sustain agricultural transportation. Yield forecasting can be carried out with the help of GIS and statistical analysis. USDA's VegScape product can be effectively used to acquire NDVI data. The analysis part shows that the yield NDVI data can be successfully used to predict the yield. This yield prediction is important for the logistical operations. If the yield is predicted with some part of certainty, the logistical operational decisions at the harvest season can be made with the ease. This will help to reduce the logistical cost. The forecasted data can be used in demand analysis as disaggregated or aggregated based on township or county. The methodology developed in this paper can be used by farmers, co-operatives, logistical operators, or producers. This methodology is based on the free data which is available readily from USDA.

The model tested here is an ordinary least squares (OLS) regression model. As the accuracy and precision of the data gathered increases, the forecasted model can be improved. Addition of other variables such as soil type, fertilizer with the VegScape NDVI data can help the model to perform better. Other analysis such as crop mix analysis and crop rotation analysis can be used to provide insights to the model. Drones or unmanned aerial vehicles (UAV) can be used to gather different data that can be used in such model. This will help to fine tune the model and generate more useful and timely results. The results from this model can be used in the optimization model which can optimize the total logistical cost based on planting, fertilizing, and harvesting cost, in addition to transportation and storage cost.

CHAPTER 4. ANALYSIS OF TRANSPORTATION ECONOMICS OF SUGAR-BEET IN THE RED RIVER VALLEY OF NORTH DAKOTA AND MINNESOTA USING GEOGRAPHICAL INFORMATION SYSTEM²

Introduction

Sugar-beet is one of the most important crops in the Red River valley for both social and economic reasons. According to Bangsund and Leistritz (1998) agricultural industries in smaller rural areas are generally overlooked. However, considering that the area under sugar-beet cultivation in the Red River valley of North Dakota and Minnesota is comparatively smaller than corn and other crops lands, it generates a large economic activity in local and regional level with a greater impact on jobs and stimulation of agriculture, transportation, and farm economy. It is also important to mention that the sugar-beet industry in Red river valley as it is owned by about 2800 shareholders who raise nearly 40% of the nation's sugar-beet acreage and produces about 17% of America's sugar (ACSC 2011). This is a very good example of well-functioning agricultural cooperative. This operation is managed by American Crystal Sugar Company (ACSC) which has five sugar processing facilities in the Red River valley. Zeuli and Deller (2007) propose a model to measure the economic impacts of cooperatives on communities. They mention that there are differences in the engagements of cooperatives with the improvements of communities. Their work could also be applied to the sugar-beet cooperative in the Red river valley.

² Published as 'Analysis of transportation economics of sugar-beet production in the Red River Valley of North Dakota and Minnesota using Geographical Information System' in Journal of Renewable Agriculture

ACSC report presents that the five facilities produced 26 million hundredweight of sugar and 602,000 tons of agri-products from September 8, 2011 to May 5, 2012. In 2011, ultimately 452,000 acres were planted with the last acres seeded on June 20. Pre-pile harvest began on September 6 and was followed by full stockpile harvest on October 1. The 2011 crop averaged 20.7 tons per acre with 18.0 percent sugar content. Total tons delivered equaled 9.2 million from 443,000 acres (ACSC 2012). This highlights the economic importance of the sugar-beet industry in Red river valley. There are a total of 10 million plantable acres for all crops in the red river valley. The Sugar-beet crop is regulated by the ACSC and the shareholders based on storage and processing capacity. For each share of stock members can grow 0.88 acres (0.88 acres/share of ACSC). ACSC employs 24 agronomists who travel to farm and work with growers and collect data. The boundaries of the growing region are from South of Kent, MN to Canadian border and from east to west in the Red River valley.

The sugar-beet processing can be divided in to three parts as shown in Figure 12. The first part is sugar-beet harvesting, second part is transportation and storage, and the third part is final processing in the production facilities. Growers are responsible for choosing the seed they plant, tilling, planting, growing, harvesting, and delivering the crop to the receiving stations. ACSC has 105 receiving stations (pilers) for growers to deliver the load to and five processing factories. Beets get unloaded at receiving station in piles and the responsibility shifts from grower to the ACSC. At pilers, the sugar-beet is cleaned and is piled 30' tall x 240' long for long term storage through the winter. The beets need to stay cold and frozen for long term storage or otherwise they will rot. From these piles sugar-beet is sent for further processing to the five facilities. In this paper we will concentrate on the transportation phase of this process.

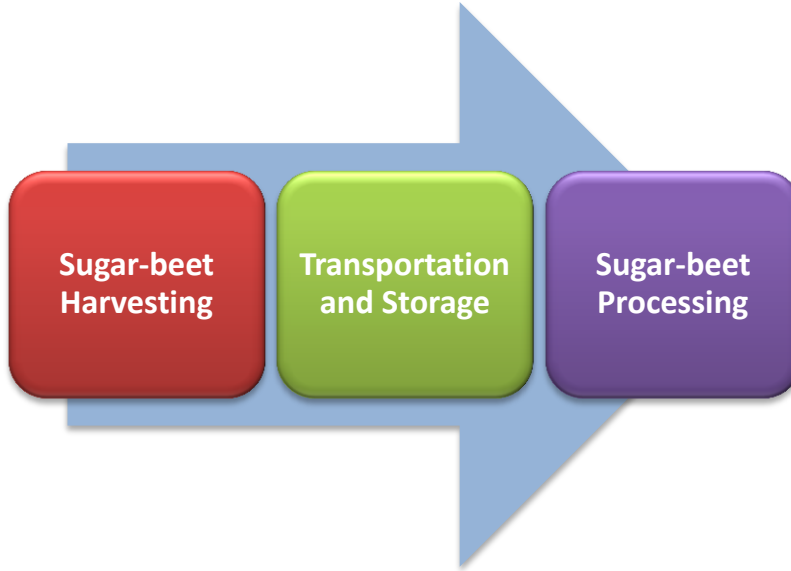


Figure 12. Sugar-beet Production Process Flow Chart.

Several attempts have been made to study and estimate the transportation demand for the agricultural commodities. Miklius, Casavant and Garrod (1976) used a logit model applied to apple and cherry shipments to study elasticity. Their model significantly explains the choice of transport method. Johnson (1981) studies the competitive advantages in the interregional competitions and its effects on the agricultural transportation. He proposes to consider the market supply and demand relationship to better address issues related to the agricultural transportation. He tells that the structure of market is always changing and economists should cope with this change in their models. Liu and Zhang (2008) used data mining techniques to improve modern agricultural logistics management. They explain how data mining techniques are becoming important in agricultural logistics decision making. These data mining techniques are important in certain part of this research too. The large data related to farms and locations are involved in this research and certain part of data mining is used to handle large data.

Apart from articles concentrating on transportation, there are various efforts to study the economics of sugar-beet in different parts of the world. Howitt (1995) proposes a method to

calibrate nonlinear Constant Elasticity of Substitution (CES) functions in agricultural production models using a minimum data set that usually restricts the modeler to a linear program. The resulting models are shown to satisfy the standard microeconomic conditions. Fraser, McInnes and Russell (1997) build their research on the work of Howitt. They study reform in the Europe and UK sugar industry and trade. They present a method to test the alternative allocation procedure in sugar-beet farming in UK. Bangsund, Hodur and Leistriz (2012) provided expenditure information by sugar-beet processing and marketing cooperatives. They estimate economic impacts using input-output analysis for production in Minnesota and North Dakota entities in fiscal 2011.

The use of precision agriculture techniques is becoming increasingly common in the US. For example, some of the growers of farm products of sugar-beets and dry beans depend on global positioning system (GPS) or infrared images captured by aerial photography to see from space what they cannot see from the ground. GPS, satellite imagery, sensor technologies combined with meteorological information provides enhanced capability for improving farm practices and productivity. At the same time this poses the challenges of effectively analyzing the data and converting it to information that can be used by potential users.

This information can be collectively used with Geographical information system (GIS) tools to predict different flows of the crop growth, transportation, and economics. In this paper we use GIS tools to predict the sugar-beet transportation flows from farms to the processing facilities and analyze the economics related to it.

The rest of the paper is organized as follows. After the introduction we propose a process flow model for sugar-beet transportation. Different costs associated with various phases are added to the model. Further we develop a closest facility method to connect farms with facilities

based on the impedance. This method is used with the GIS data to map the actual flow of sugar-beets and the costs associated with this flow are calculated. We analyze these costs and map the results. These results are validated with the data from ACSC. A conclusion section talks about the findings from this research and future avenues to explore.

Transportation Process Flow

The transportation of sugar-beet crop from the farm to the plant and/or to piles is an important phase of the sugar-beet harvest. ACSC has facilities located in five locations in Red river valley. They are located at Crookston, East Grand Forks, and Moorhead in Minnesota and Drayton, and Hillsboro in North Dakota. The sugar-beet producing farms are located in both Minnesota and North Dakota in the Red River valley (Bangsund, Hodur and Leistritz 2012). As all the sugar-beet reach the processing facilities at the end of transportation phase we focus our attention to mapping travel distances and flows from farms to facilities. The transportation process is divided in four phases. These phases are loading, front haul, unloading, and backhaul. This process can be depicted as shown in a flow chart in Figure 13.

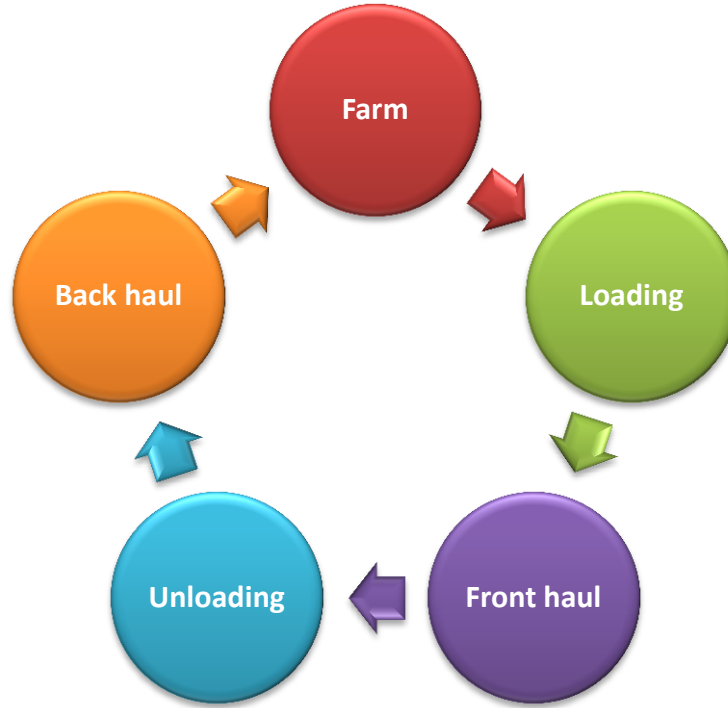


Figure 13. Sugar-beet Transportation Flow Chart.

There are different costs associated with different steps in the transportation flow. Equation 1 is used to calculate the total cost encountered. This equation suggests that the total cost is equal to the summation of the costs of loading the sugar-beets, front haul to facilities and piles, cost of unloading, and back haul to the farm. This cost is represented in terms of product of distance, truckloads of sugar-beets, and an average fuel cost factor based on the distance.

$$C_T = \sum_{i=1}^n \sum_{j=1}^m \sum_{k=1}^l (dl_i \times x \times y_i) + (df_{ik} \times x \times y_{ik}) + (df_{ij} \times x \times y_{ij}) + (du_k \times x \times y_k) + (du_j \times x \times y_j) + (db_{ki} \times x \times y_{ki}) + (db_{ji} \times x \times y_{ji}) \quad (4)$$

Where

- C_T = Total transportation cost
- i = Index for Farm
- j = Index for Processing facility
- k = Index for Pile
- x = Average fuel cost factor per mile of distance
- y = Truckloads of Sugar-beet
- dl = Distance of loading at farm

- df = Distance travelled in Front haul from farm to pile/facility
- du = Distance of unloading at pile/facility
- db = Distance travelled in back haul from pile/facility to farm

The cost associated with the transportation is used in the economic analysis. The GIS data is used to calculate the cumulative cost of transporting the annual yield from farms to the processing facilities. Locations of farms producing sugar-beet were acquired from ACSC raw data. The data provided locations with latitude and longitude and yield information. Latitude and longitudes are then projected in GIS to produce the maps of sugar-beet farms. Locations of farms in the Red river valley for five years (2008-2012) are detailed in Figure 14.

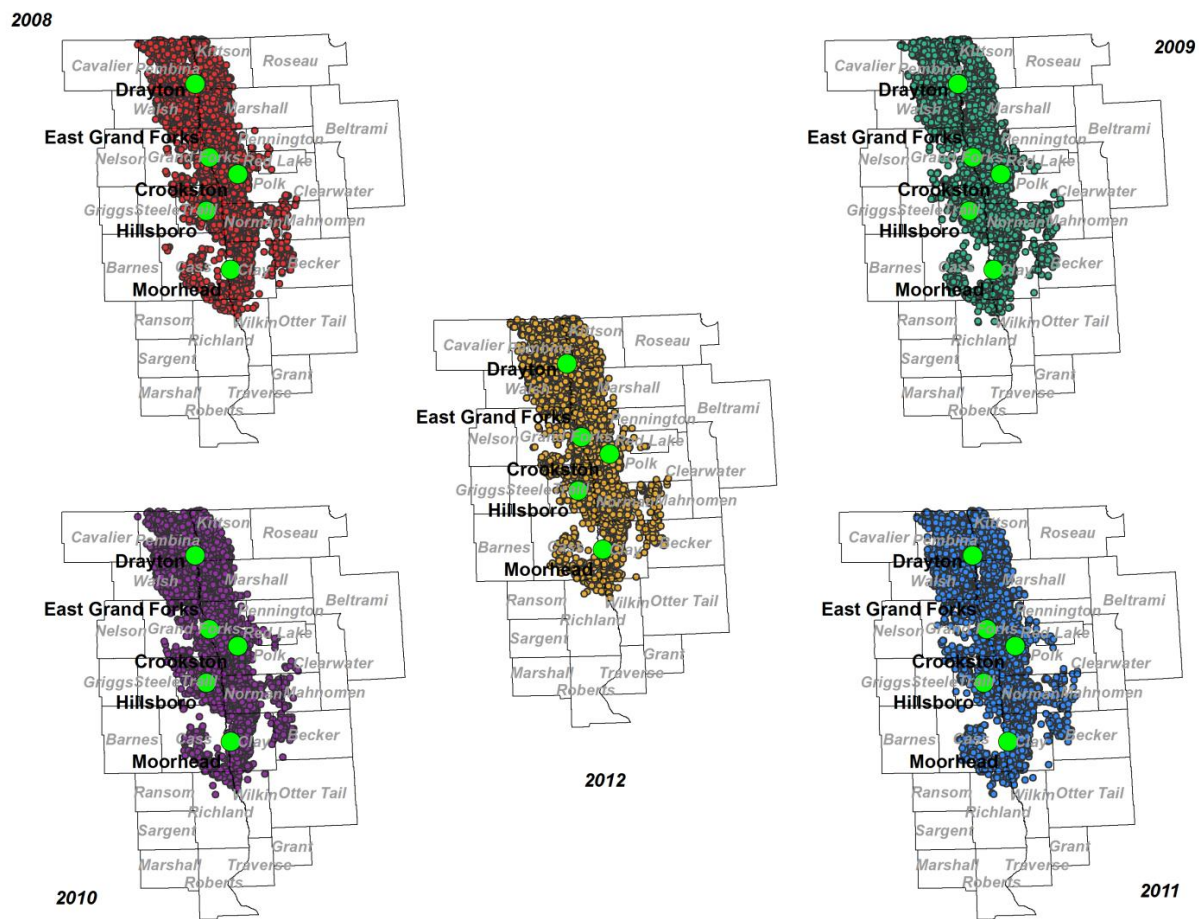


Figure 14. Sugar-beet Farm Locations in the Red River Valley.

Analysis

The distances between the farm and the processing facility are calculated using the closest facility analysis method from ArcGIS software from ESRI®. This method uses Dijkstra's algorithm. Dijkstra (1959) in his original research solves two problems of the graph theory based on pairing of points (nodes). He solves a problem of constructing a tree of minimum total length connecting all n nodes and a second problem of finding a path of minimum length between two given nodes. The software uses the algorithm of the second problem solving in the closest facility method. The algorithm was used to find the path of minimum length between a farm and a facility. This length was then used to find the total paths connecting different farms to different processing facilities.

The data used in this process is mostly GIS shapefile data. These shapefiles are taken from different public and private sources. The farm location data is given by ACSC as explained earlier. The road network in the Red River valley is constructed using shapefiles from American Census Bureau Tiger shapefile data. This network consists of county roads with state and federal highways. The network from North Dakota and Minnesota is fixed with connecting links using bridges on the Red river. This network connectivity is crosschecked with the help of dummy loads and connecting them with dummy links. Locations of the facilities are found from the website of ACSC. This location is pinpointed using the Google earth. The facilities and fixed network is shown in the Figure 15.

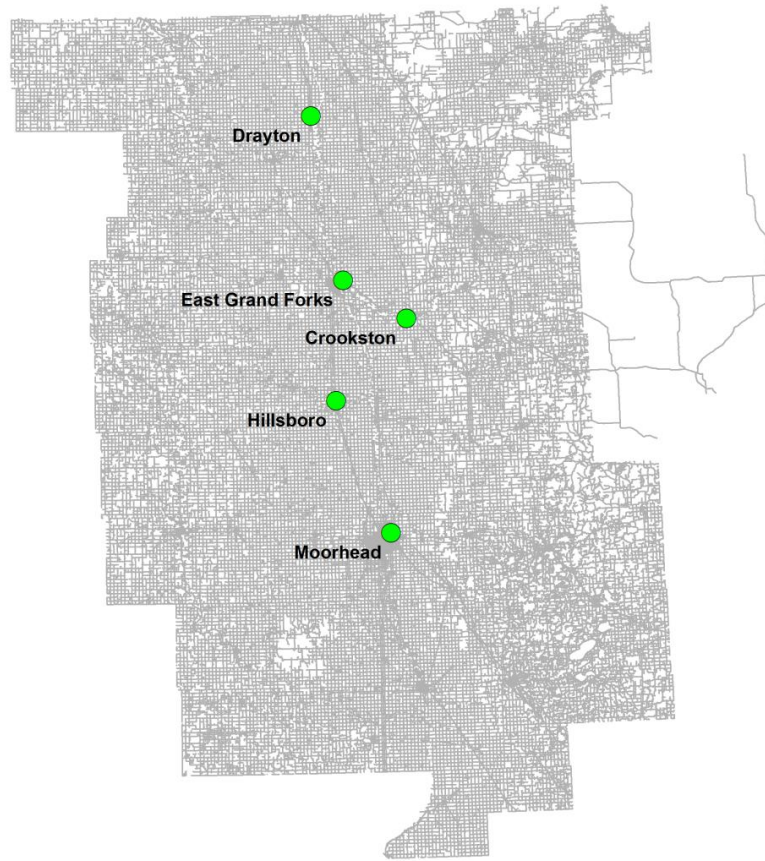


Figure 15. Road Network with Sugar-beet Processing Facilities.

For the solution of the closest facility problem the distance in miles was used as the impedance. After the GIS problem was solved, the network is developed based on the least distance between particular farm and the connected facility. This network gives a database for the farms, facilities, and connecting length. This length is further used in calculating the total cost utilizing Equation 1. The sugar-beet processing, as displayed in Figure 16 can be explained in details using the values associated with Red River valley. Trucks start loading the yield from the farm and the average loading time is assumed to be 30 minutes. The average speed for the loaded truck from farm to the facility is assumed to be 50 miles per hour. However in the data analysis, the combined loading time is determined using an average travel speed of 45 miles per

hour to include the loading time in the calculations. Average unloading time for the sugar-beet is assumed to be 20 minutes at the facility/plant. The empty truck can then travel faster from facility to the farm therefore the average speed of 55 miles per hour is used.

Trucks in average can carry 30 Tons of sugar-beet and therefore the number of trips from the farm to the plant is determined by dividing the total yield by 30. The yield data were reported in Tons per acre from an individual farm to the facility. Therefore, to calculate the total yield, one would need to multiply the yield in Tons per acre by the acreage of the farm. Dividing the total yield by 30 will provide the total number of truckloads from the farm to the facility. The factor of the average fuel cost per gallon is calculated based on the data from U.S. energy information administration web site. This is done by averaging the national weekly diesel prices for the months August- November per year (US EIA 2012).

Other costs involved in the average fuel factor are different overhead costs such as labor cost and maintenance cost. The distance between farm and facility is transformed from mileage to minutes in order to be able to add loading and unloading times. The resulting time in minutes is transformed to hours to calculate driver cost and then multiplied by 20, which is the assumed average payment per hour to the driver. The maintenance cost is assumed to be 7 miles per gallon. To calculate Fuel plus maintenance costs, the distance in mileage from the farm to facility is multiplied by 2 (round trip) then divided by 7 and the resulted value is multiplied by the average cost of diesel per gallon for the related year. Adding all the costs will result in the total transportation cost calculated.

Results and Discussions

The solution of the closest facility problem yields a database of network connecting farms with facilities as discussed in earlier section. The solution was used to generate maps for

different years representing solved paths. These paths are depicted in Figure 16. Furthermore, these results are analyzed by plotting graphs comparing different aspects of sugar-beet transportation. Facility ID 5 stands for Moorhead, 4 stands for Hillsboro, 3 stands for East Grand Forks, 2 stands for Drayton and 1 stands for Crookston.

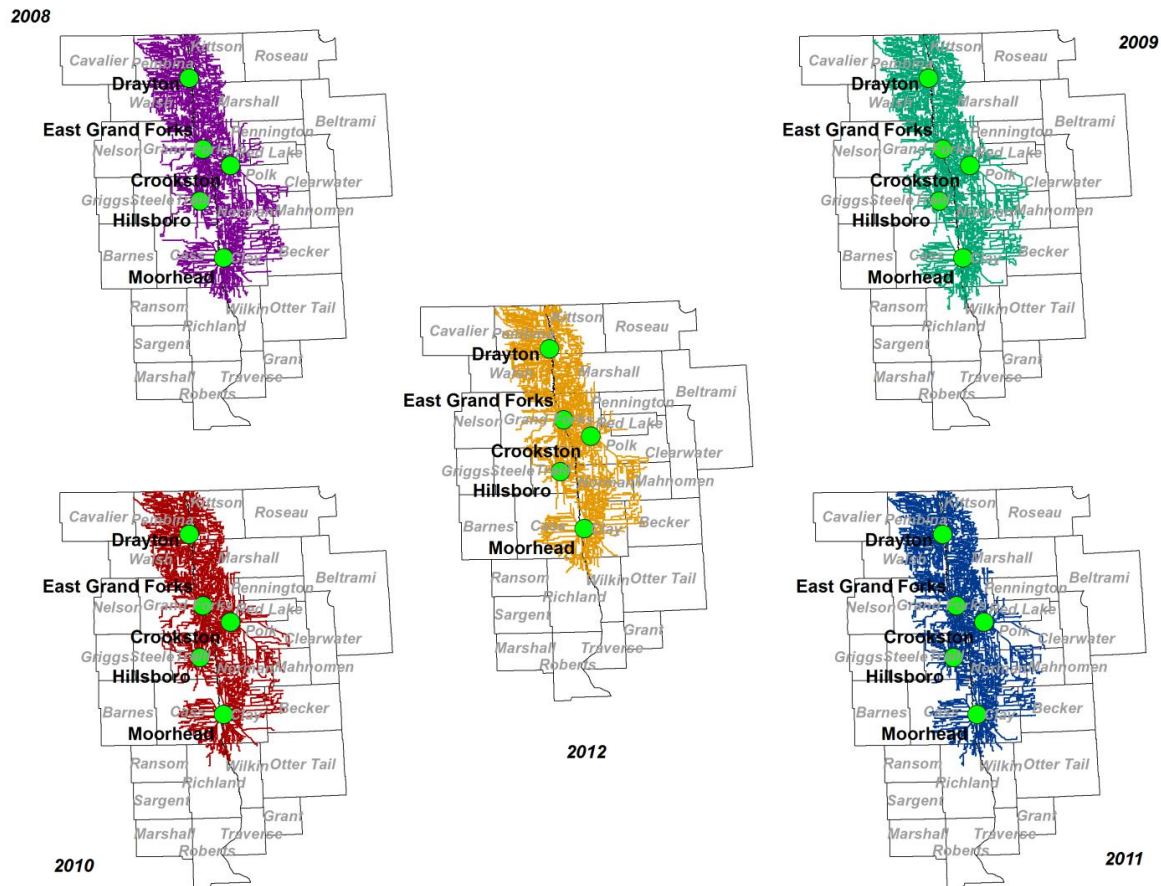


Figure 16. Routes from Sugar-beet Farms to the Facilities.

Average mileage, cost, and yield are represented for five facilities in Figures 17 (a - d). These figures show changes in the costs, mileage, and yield based on facility location for four years from 2008 to 2011. Figure 18 depicts a yearly comparison of costs. Based on data shown in this figure the year 2009 reaches the lowest average cost of transportation per facility per farm for the most regions. The reason for this is not only the amount of yield which is less than

average yearly yield expected as shown in Figure 17 (2009 has the least average yield) but also the Average diesel cost per gallon was above \$3 dollars for all years except the year 2009 where the cost of fuel averaged out to be \$2.68 per gallon. Analyzing the figures shows increased cost of transportation for facility 2 (Drayton) in 2008 which is due to the increase in yields for farms transporting (close) to Drayton.

It is important to validate and verify the GIS model presented in this study. These results are validated and verified using ACSC data. Total yield per year was compared with the yield per year in ACSC 2012 annual report. Of course the slight discrepancy is due to not having a complete set of data for all farms for analysis. However the results were close enough to confirm the results.

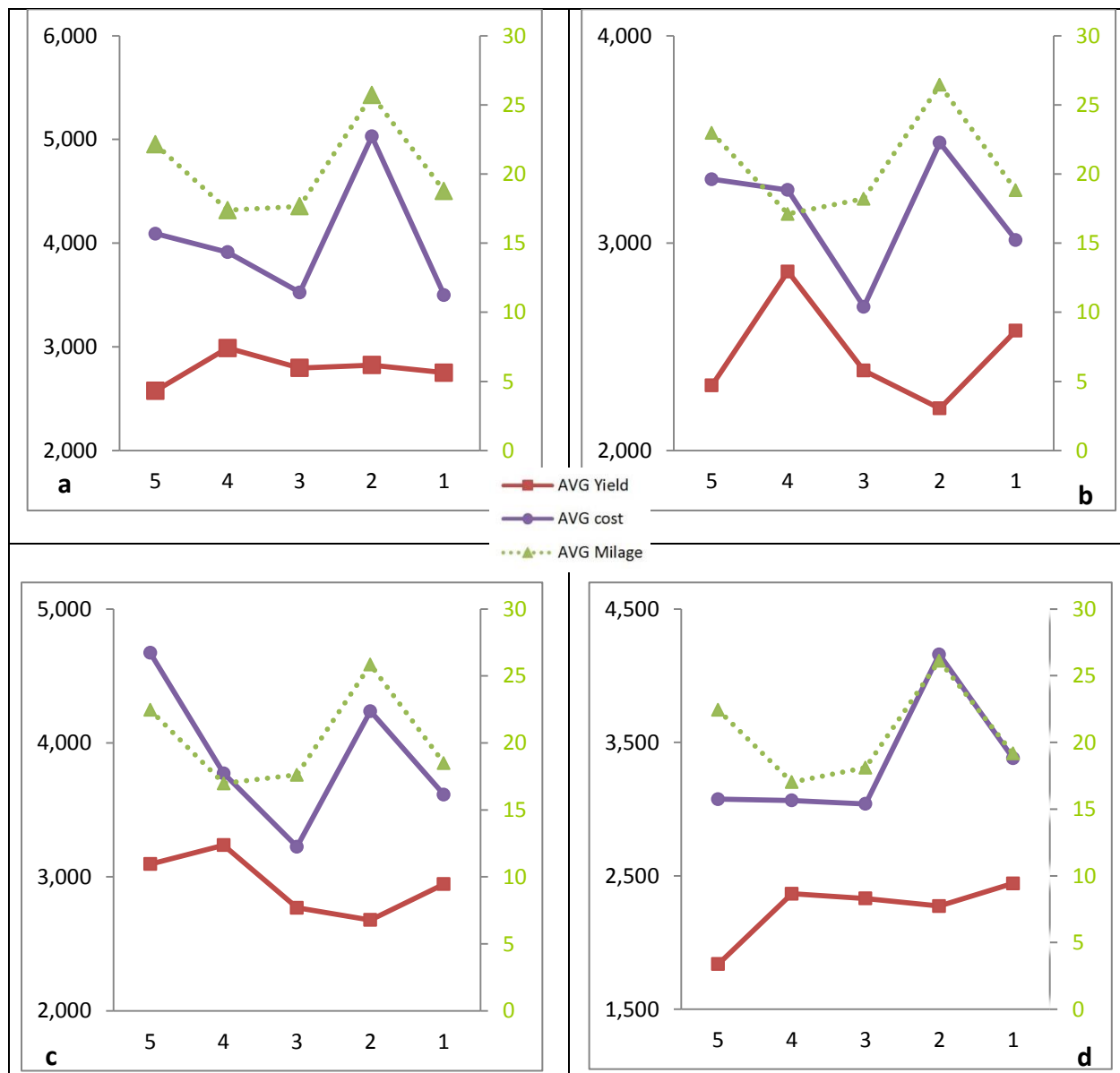


Figure 17. Graphs of Average Yield, Cost, and Mileage (a - 2008, b - 2009, c - 2010, d - 2011).

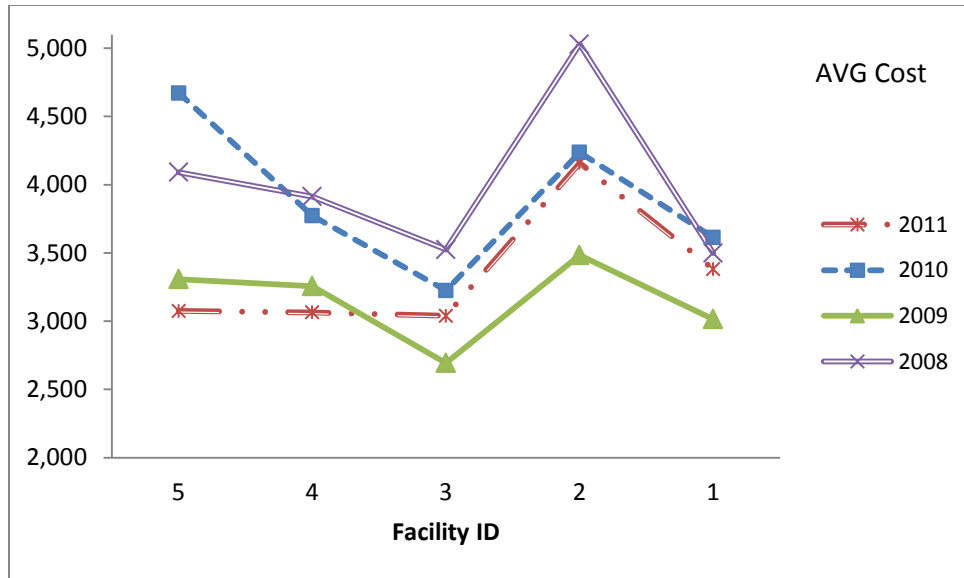


Figure 18. Sugar-beet Yearly Average Transportation Cost.

Conclusions

We provide a starting model to analyze sugar-beet transportation in the Red River valley in U.S. states of North Dakota and Minnesota. Transportation costs are a major part of economic model of sugar-beet processing. This model provides a basic structure to calculate the transportation costs associated with the sugar-beet processing. It is an important step in economic modeling. This model can be used as a part of a data-driven decision support system incorporating sensor data, satellite images, and weather information to allow farmers to improve the productivity of farm lands while reducing the needed resources for growing their crops. This model is easily transferable and with minor modifications could be used for analyzing other crops. With a future yield forecasting it can be used to maximize the profit by minimizing transportation cost.

CHAPTER 5. PILING CENTERS LOCATION OPTIMIZATION FOR SUGAR BEETS UNDER SUPPLY VARIATION³

Introduction

The sugar beet is considered as one of the most important crops in Red River Valley of North Dakota and Minnesota in the United States. According to Farahmand et al. (2013) this sugar beet co-op operation is the largest sugar beet producer in the United States. The co-op is owned by about 2,800 shareholders who raise nearly 40% of the nation's sugar beet acreage. There were around 452,000 acres planted in 2011 (Farahmand, Dharmadhikari and Khiabani 2013). They also mentioned that the last seeding usually takes place on June 20 while full stockpile harvest starts on October 1st. This explains the seasonal nature of sugar beet harvesting. American Crystal Sugar Company (ACSC) manages this co-op. ACSC has five processing facilities in the Red River Valley as shown in Figure 19.

³ Accepted for the presentation at 2019 Transportation Research Board (TRB) Annual meeting.

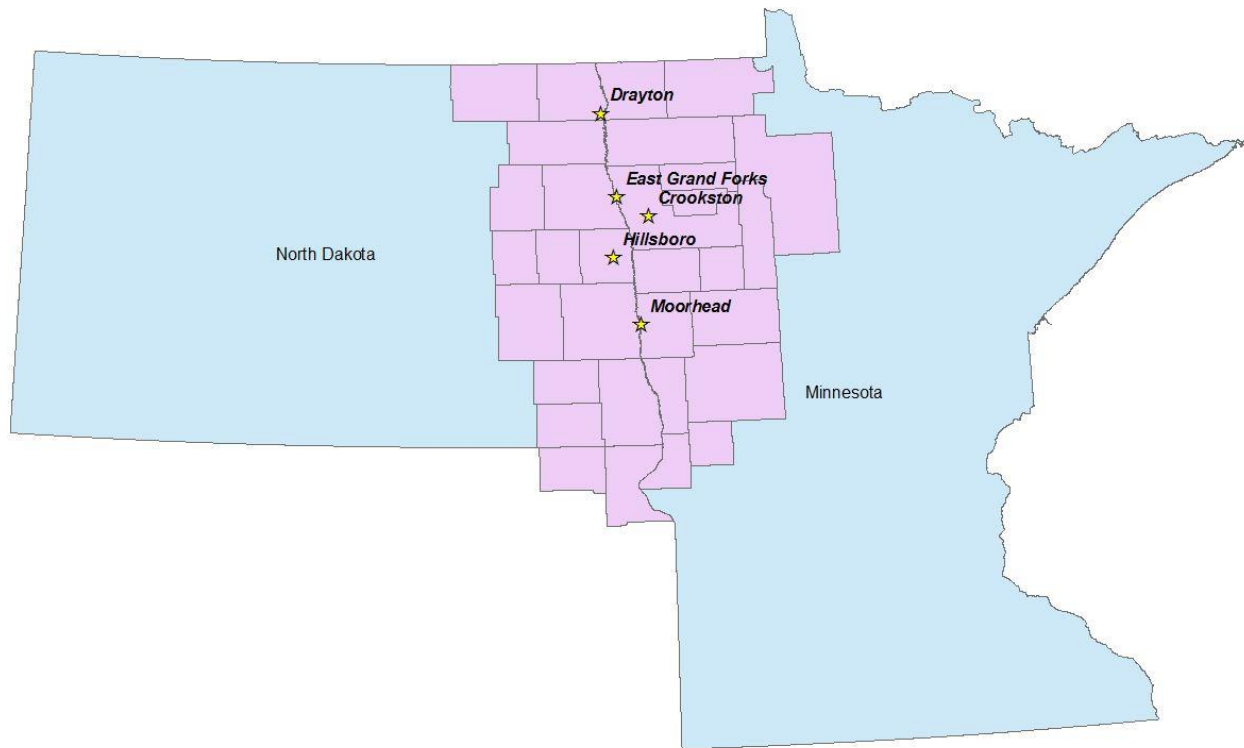


Figure 19. Sugar Beet Region and Processing Facilities in North Dakota and Minnesota.

Growers are responsible for delivering the crop to the piling centers. ACSC operates the piling centers for growers to deliver the load to five processing factories. Beets get unloaded at the piling center (piler) in piles and the responsibility shifts from grower to the ACSC. At the pilers, sugar beets are cleaned and are piled 30' tall x 240' long for long term storage through the winter. The beets need to stay cold and frozen for long term storage or otherwise they will rot. At processing time, these beets are loaded on the truck using conveyors. Once the truck is full, a new truck takes over loading the beets. The loaded trucks drive to the nearest sugar beet processing plant or receiving station. Figure 20 depicts this logistics system of sugar beet transportation from farms to processing plants.

Some beets are directly transported to the processing plants without storing them. This process is dependent on different factors. Farmers and ACSC decide whether to store beets or to take them to processing plant directly. This decision is mainly based on the maturity of the beets. The mature beet has the highest sugar content. The payment received by the farmer is based on sugar content thus farmers want to keep the beets in the ground to maximize sugar content. ACSC desires to start the harvest at an optimal time to ensure the processing plants are busy and remain at capacity throughout the season. This balance is important based on the planting time and harvesting time in order to minimize cost and maximize profit to the growers.

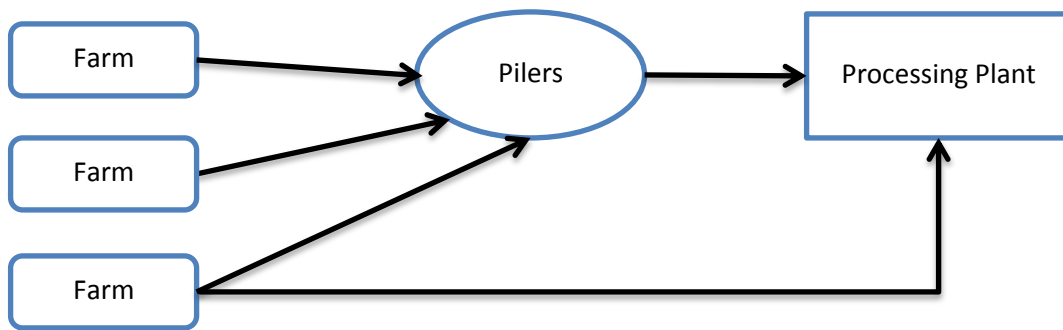


Figure 20. Sugar Beet Processing.

Pilers are considered as natural refrigerators to save beets from rotting. The colder temperatures in Red River Valley in winter help the beets to stay at pilers for a longer time after harvest. Sugar beet roots should be cleaned from excessive dirt, and properly defoliated and cleaned from weed or leaves to allow for proper ventilation while stored in piles. Sugar beets may be stored up to 4 months, and during this storage period the roots will decay and ferment. As a result, the sugar beet roots will heat up and the respiration leads to around 70% loss of sucrose. Decay and fermentation during storage could also cause sucrose loss of up to 10% and 20%. Some of the sucrose losses caused by the storage have been reduced through the utilization

of forced-air ventilation, cooling in hotter areas and subsequent freezing of storage piles after mid-December in colder areas. Ensuring the root temperature never reaches 55° F will keep the roots from decay. During harvest, if air temperature is rising and the root temperature increases past 55° F, the harvest will stop, and no sugar beets will be accepted at the pilers. This will prevent storage rot. Cold weather and frost could also damage the roots. Foliage and leaves have proven to provide a natural barrier to frost conditions thus protecting the roots and the crown area. Exposed roots during a frost shutdown, experience a higher degree of frost damage.

This situation is ideal for a location allocation problem. The locations of the pilers are to be optimized to minimize the transportation and storage cost. This article is organized as follows. Section 2 studies the literature available for location allocation problems in agriculture and other settings. Section 3 describes the methodology and algorithm used for solution. Section 4 discusses a case study. Section 5 presents sensitivity analysis. Section 6 presents conclusions along with the path to future research

Literature Review

Kondor (1966) presented the initial problem of the sugar beet transportation. They tried to find the economic optimum results using the mathematical modeling of the problem. They established the relation between the processor starting date and the scheduling of the beet arrival. They provide the case study of Hungary. Scarpari & de Beauclair (2010) developed a liner programming model for sugarcane farm planning. Their model delivered profit maximization and harvest time schedule optimization. They used GAMS® programming language to solve the problem. They solve this problem based on the case study of sugarcane farming in Brazil.

The location problem in a different setting is solved by Esnaf & Küçükdeniz (2009). They presented the multi-facility location problem (mflp) in logistical network. Their objective is

to optimally serve set of customers by locating facilities. They studied the fuzzy clustering method and developed a hybrid method. Their method is a two-step method in which the first step uses fuzzy clustering for mflp and the second step further determines the optimum location using single facility location problem (sflp). The fuzzy clustering step uses MATLAB® for geographical clustering based on plant customer assignment. They compared their method with other clustering methods. Costs generated by the hybrid method are less than other methods. Zhang, Johnson, & Sutherland (2011) presented a two-step method to find the optimum location for biofuel production. Step one uses Geographical Information System (GIS) to identify feasible facility locations and step two employs total transportation cost model to select the preferred location. They presented a sensitivity analysis of location study in the Upper Peninsula of Michigan.

Houck, Joines, & Kay (1996) present the location allocation problem and its solution methodologies. They examine the applications of genetic algorithm to solve the problem. They propose that these problems are difficult to solve by traditional optimization techniques thus requiring the use of heuristic methods. Zhou & Liu (2003) propose different stochastic models for the capacitated location allocation problem. They also propose a hybrid algorithm which integrates network simplex algorithm, stochastic simulation and genetic algorithm. They test the effectiveness of this algorithm with numerical examples. In the further research Zhou & Liu (2007) study the location allocation problem with fuzzy demands. They model this problem in three different minimization models. They propose another hybrid algorithm to solve these models.

Lucas & Chhajer (2004) provided a detailed review of literature in the field of location allocation involving agricultural problems. They express that there are a lot of location allocation

problem solutions available but there is a lack of application-based research articles. They study six real world examples. Pathumnakul et al. (2012) considered the different maturity times of sugarcane to find the optimal locations of the loading stations. They modify the fuzzy c-means method to consider cane maturity time as well as cane supply. Their objective is to minimize the total transportation and utilization cost. They compare the performance of their method with traditional fuzzy c-means method to conclude their method provides better solution for the problem. They test these methods with the help of a case study in sugarcane farming in Thailand.

Another location problem of sugarcane loading stations is studied by Khamjan, Khamjan, & Pathumnakul (2013). They compare the solution times of the mathematical model and the heuristic algorithm. Their objective function includes minimization of various costs such as investment cost, transportation cost, and cost of the sugarcane yield loss. They also applied their model to a case study to solve the industrial problem. In a recent study Kittilertpaisan & Pathumnakul (2017) present a multiple year crop routing decision problem. Their model includes heuristic algorithm for a three years period of sugarcane harvesting. They solve their problem to design the planting and routing such as sugarcane becomes mature in three years for harvesting.

This literature study shows that there are very few articles about sugar production and location problems and there are nearly zero articles about sugar beet harvesting and location problems involved in it. As the numbers of sugar beet fields are large, optimization algorithms suggested in some of the articles are not applicable in this situation. Also, there are very few articles studying the seasonal nature of the sugar beet harvest. Based on these problems this article tries to solve the location allocation problem for the sugar beet harvesting using a two-stage geographical information system (GIS) based Multi Facility Fuzzy Clustering (MFFC) algorithm.

Methodology

As stated earlier we use a two-stage method to solve a sugar beet piler location allocation problem. It involves stage one of GIS analysis with clustering and stage two of optimization. The solution algorithm is depicted in Figure 21.

Stage 1: GIS analysis with clustering

Stage 1 involves GIS analysis. As stated by Pathumnakul (2012) clustering of farms is carried out in this stage. The goal of this stage is to generate an Origin – Destination (O-D) matrix. A GIS dataset is created with different shapefiles. The farm location shapefile is then added in the dataset. Along with the location of farms, this shapefile also has data about planting dates at each farm, weather conditions, and yield. Weights are assigned to the locations of the farms based on the different harvest times due to different planting dates and weather conditions. The farms are clustered in the groups of four based on these assigned weights. These clustered farms are origins. The locations of pilers are also added to this dataset which is designated as the destinations.

Finally, the road network is added in the dataset. The road network needs to have distances of each segment in miles, speed limits or observed speed over these segments, and time taken to travel the distance of each segment (travel time). The GIS software uses a shortest path algorithm to create the O-D matrix. This method is similar to the method in Dharmadhikari, Lee, & Kayabas (2016). The O-D matrix can be generated in two ways – 1) distance in miles or 2) travel time between O-D pair. For this process we prefer to use shortest distance in miles which will be used as one of the inputs for optimization stage.

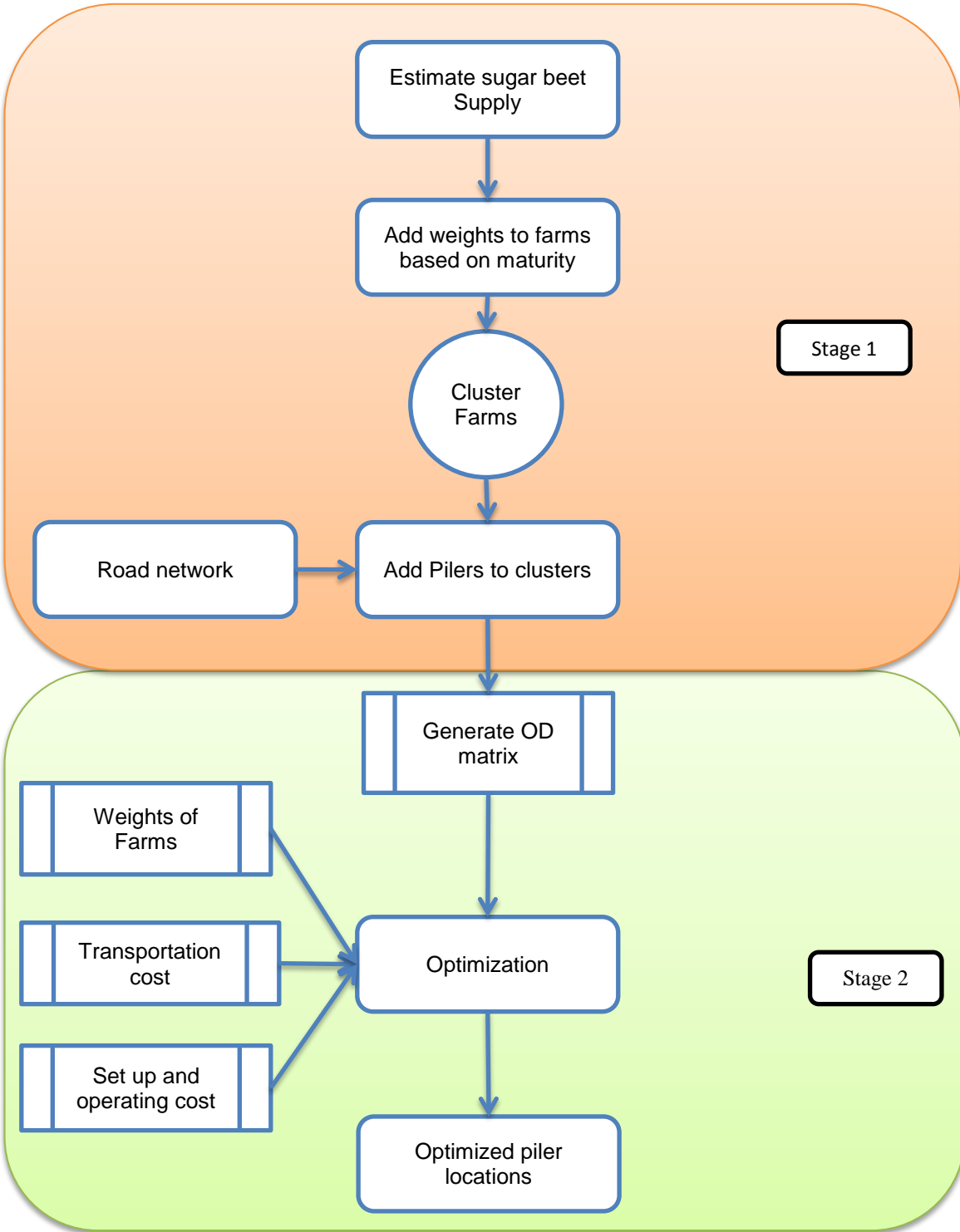


Figure 21. Solution Algorithm.

Stage 2: Optimization

The aim of the Stage two is to perform the optimization to find the pair of operating pilers and farms at the given harvest times. This will be a cost optimization process. The objective of the optimization function is to minimize the cost of logistics. Following are the important inputs for this process:

1. O-D matrix generated in Stage 1
2. Weights of farms from Stage 1
3. Transportation cost of sugar beets
4. Set up and operating cost of piler

The optimization is performed based on following assumptions:

1. Sum of all shipments should not exceed the total yield at farms
2. Piler is either open or closed at any given time
3. Quantity of sugar beets harvested should not be greater than piler capacity
4. Each sugar beet farm is assigned to one piler only
5. All pilers have the same capacity

The cost of logistics is expressed in terms of addition of different costs involved in the process such as the cost of transportation, the cost of yield loss if not harvested at the right time, and the cost of piler operation. These costs are further simplified in terms of the tangible variables which are easy to measure. These variables are piler set up cost, storage cost, distance, number of trucks, cost per mile for the truck, and yield loss cost. This gives us Equation 5 for the cost of logistics.

$$\text{Cost of logistics} = (\text{set up cost}) + (\text{storage cost}) + (\text{distance} \times \text{number of trucks} \times \text{cost per mile}) + (\text{yield loss cost}) \quad (5)$$

The objective function is represented in Equation 6. The objective function states the minimization of the cost of logistics. It is subject to the sum of all shipments being less than the total yield at farms (Equation 7); A Piler can be open or closed (Equation 8); number of trucks should be greater than or equal to zero (Equation 9); yield at the given farm should be greater than or equal to zero (Equation 10); and quantity of sugar beets harvested should not be greater than total piler capacity (Equation 11). The explanation of data sources is presented in the case study section.

$$\text{Minimize } C_l = \text{Minimize } \sum_{i=1}^n \sum_{j=1}^m \sum_{k=1}^4 ((S_{uj} \times P_j) + (S_{tj} \times P_j) + S_{yi} + (X_{ijk} \times T_{ij} \times C_d)) \quad (6)$$

Subject to:

$$\sum_{i=1}^n \sum_{j=1}^m (T_{ij} \times P_j \times t) \leq Y \quad (7)$$

$$P_j \in \{0,1\} \forall j \quad (8)$$

$$T_{ij} \geq 0 \forall i, j \quad (9)$$

$$y_i \geq 0 \forall i \quad (10)$$

$$\sum_{j=1}^m I_j \times P_j \geq Y \quad (11)$$

Where,

X_{ijk} = Distance (miles)

i = number of farms (1, 2, ... n)

j = number of pilers (1, 2, ... m)

k = number of distance (1, 2, 3, 4)

y_i = yield at farm 'i' (tons)

$Y =$ total yield from all farms $= \sum y_i$

$t =$ sugar beet truck capacity (tons)

$T_{ij} =$ number of trucks from farm i to piler $j = y_i/t$

$C_d =$ Cost per mile

$I_j =$ Capacity of the piler

$S_{uj} =$ Set up cost of piler j

$S_{ij} =$ Storage cost at piler j

$S_{yi} =$ yield loss cost at farm i

$P_j = 0$ or $1 =$ Piler is used or not used

$C_l =$ Cost of logistics

Case Study

Red River Valley of North Dakota and Minnesota is the study area. This area involves sugar beet production in nearly 30 counties as depicted in Figure 19. The sugar beet processing is handled by American Crystal Sugar Company (ACSC). They have five processing plants at locations Moorhead, Hillsboro, Crookston, East Grand Forks, and Drayton. As explained earlier, sugar beets are transported first to the piler locations by farmers for storage until ACSC transports them to one of the five processing plants. These piler locations are shown in the Figure 22 with the road network.

Data sources

ACSC provided locations of the plants, pilers, and farms. These are the most important locations for the GIS analysis. ACSC also provided data related to the plant dates, costs, and yields at each farm. The road network was built upon using TIGER shapefiles from American Census Bureau (United States Census Bureau 2018). Two shapefiles for road networks in North

Dakota and Minnesota are downloaded. The road networks are then combined and cleaned. The boundary between these two states is defined by the Red River. There are numerous bridges on the river. The cleanup process involved finding locations of the bridges and connecting the road network where an existing bridge is present. This helps to provide a combined network to use in the GIS analysis. The process followed in this step is similar to the process in Farahmand, Dharmadhikari, & Khiabani (2013). Sugar beet truck fuel efficiency is assumed to be 10 miles per gallon and average fuel cost is assumed to be \$3.00 per gallon for the study period.

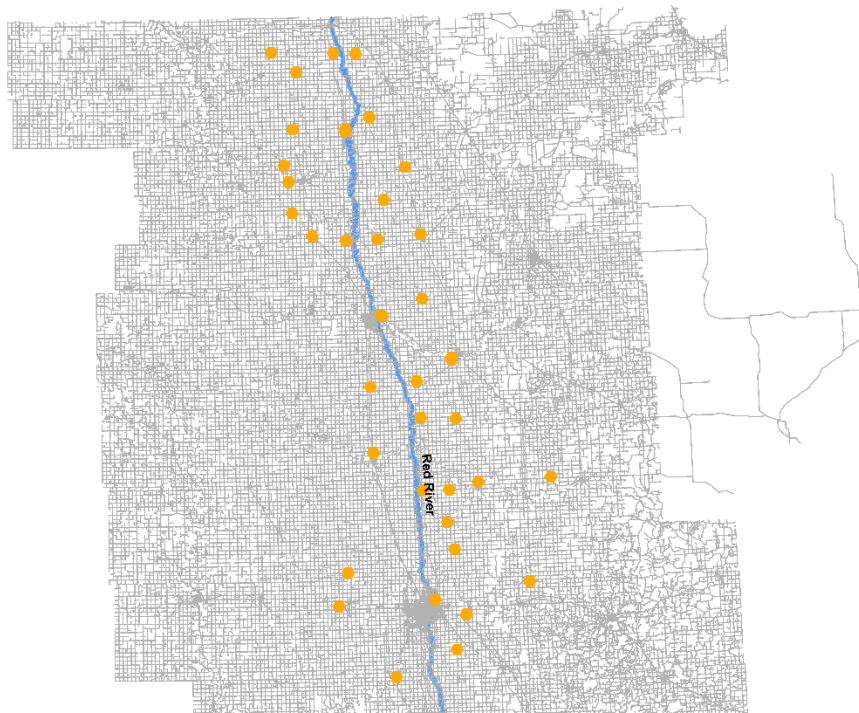


Figure 22. Red River Valley Road Network and Piler Locations.

GIS Analysis

Following the algorithm shown in Figure 21, GIS analysis is the first part of the study. This analysis involves combining all data sources and performing a clustering model with the goal of generating origin – destination (O-D) matrix. The road network of Red River Valley is added in the database. This road network is cleaned and combined as stated in data sources section. The road network contains attributes such as name, road type, and distance in miles

which are important for the GIS analysis. Distance in miles is used in creation of the network dataset.

Clustering

The sugar beet harvest starts late in months of September and October. Thus, clustering of farms is carried out based on the harvest days. Harvest weeks are divided into four groups. These weeks are shown in Table 5. The farms are selected based on the harvest days falling within these four categories. Four separate clusters are formed for farms. These clusters are shown in Figure 23. By visual inspection, week group 2 and week group 3 have the largest number of farms in the cluster. The locations of the pilers are also added in this database.

Table 5. Week Group Division.

Harvest Weeks	Days of Year
Week Group 1	Less than or equal to 280
Week Group 2	281-287
Week Group 3	288-294
Week Group 4	More than 294

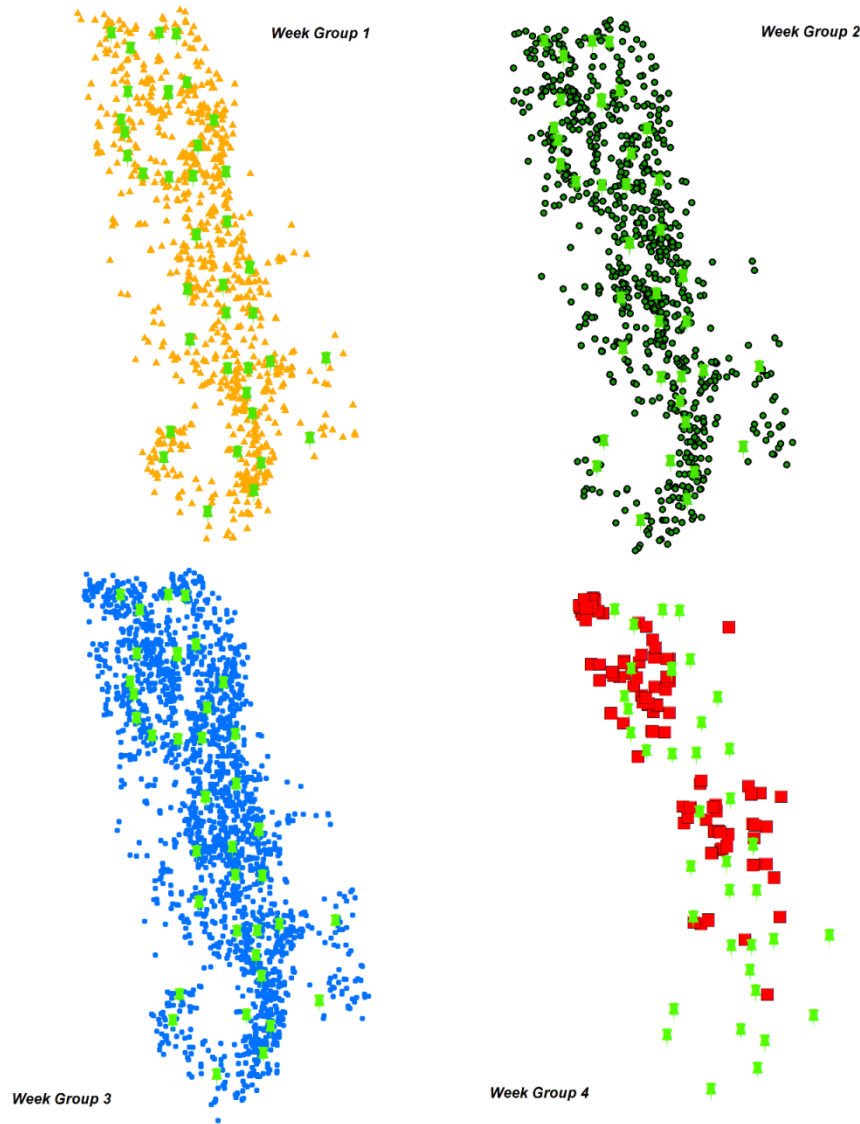


Figure 23. Sugar Beet Farm Clusters Based on Week Groups.

Closest facility

As stated in the methodology section, the clustered farms are connected to the pilers using closest facility method from ArcGIS®. This method uses the road network prepared in the data sources section. The cost of travelling for this analysis is based on the distance in miles between farm (incident) and piler (facility). This method finds the closest piler to any farm. A total of four closest pilers are found for each farm to generate origin-destination cost matrix. This

gives us four distances in miles for each farm. The closest facility solution routes are shown in Figure 24. This cost matrix initially consists of distances in miles, which is later converted in the transportation cost matrix. The transportation cost is calculated using method from Farahmand, Dharmadhikari, & Khiabani (2013). This method states that the maintenance cost is assumed as seven miles per gallon. The total fuel plus maintenance cost is calculated by multiplying O-D distance matrix by two (for truck roundtrips) and then divided by seven to get gallons of fuel used. The resulting value is multiplied by average cost of diesel per gallon for the related year. These costs are added for all four-week groups.



Figure 24. Closest Facility Solution Routes.

For further analysis, piler capacity is calculated from the ACSC data (American Crystal Sugar Company 2018). It states that Hillsboro factory has seven piler locations. Total beets produced in the catchment area of the Hillsboro factory are 1,402,421 tons per year. This is divided by seven to get the capacity of each piler. This comes to around 200,346 tons. We assume capacity of each piler as 200,000 tons.

Piler set up cost and storage cost are calculated from Farahmand et al. (2013). The set-up cost is calculated with the help of overhead expenses. It is calculated with the addition of machinery lease cost, building lease cost, utilities per acre, and labor and management charges. The set-up cost comes to nearly \$120 per acre. The Hillsboro pilers have an area of around 35 acres. Total Set up cost is calculated by multiplying area by the per acre cost, which comes to \$4,200. This set up cost is assumed to be the same for all pilers. The storage cost is assumed to be \$0.01 per ton of sugar beets. A piler capacity is 200,000 tons so storage cost of a piler is \$2,000. Sensitivity analysis is performed based on set up cost and storage cost.

Optimization Results

After the GIS analysis, the following are the variables known:

1. Shortest distances from each farm to nearest 4 pilers. This gives a distance matrix for each farm location.
2. Plant date
3. Yield
4. Storage cost
5. Set up cost

For performing the optimization, the distance matrix is converted into the cost matrix by multiplying the distances with the cost of fuel. In this case, we assume cost of the diesel fuel as

\$3.00 per gallon (Farahmand, Dharmadhikari and Khiabani 2013). The optimization model is developed in the LINGO software from LINDO systems. The optimization results are presented in Table 6. It shows that the number of pilers required to be open in week 1, 2, and 3 are 41. The number of pilers needed to be open in week 4 are 16. This is depicted in Figure 25. It is also observed that for week 1 to 3, the total cost is increasing but as week 4 has less sugar beet to harvest, the total cost is then greatly reduced. The validation of the model is carried out by testing Week 1. One or Two pilers in Week 1 are termed closed in the input data. It is expected that the model will not supply any volume to these pilers. Model performed as expected and it did not supply any volume to closed pilers while increasing the total cost.

Table 6. Optimization Results.

Week	Open Pilers	Total Cost
Week 1	41	1,624,895
Week 2	41	3,696,831
Week 3	41	6,662,072
Week 4	16	304,630

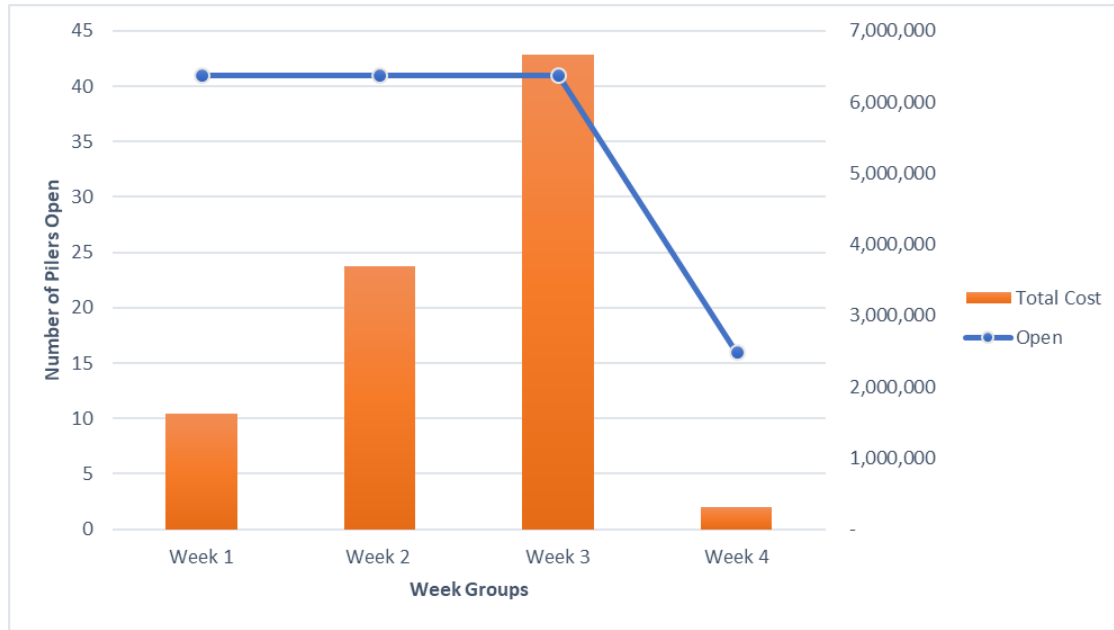


Figure 25. Optimization Results.

Sensitivity Analysis

The sensitivity analysis is carried out to check if the model is performing as expected. It is also important to examine the assumed values and how they perform. Week 4 model is used to perform two types of sensitivity analyses. First analysis is carried out to test the changes in the yield whereas the second analysis is performed to check the effects of changing piler set up costs.

Different percentages of yield changes are assumed for performing the sensitivity analysis. The optimization model is run for these different yield values. The results of running these models are shown in Figure 26. The number of open pilers reduces as the yield at each farm is reduced by 50% and 75%. At the same time, the number of open pilers increases as the yield at each farm is increased from original yield to 300%. But this piler opening is not immediate and happens as a gradual increase. Number of open pilers is constant for original yield including a 10%-25% yield increase. As the yield increases from 25% to 50%, the number

remains the same as it does for yield increases from 50% and 100%. A gradual increase in the total cost is also seen in the Figure 26.

Figure 27 shows the effects of changes in the piler set up costs on the number of open pilers and total cost. As the setup cost reduces, the number of open pilers increases. Even though the number of open pilers increases, the total cost decreases. As the setup cost increases the number of open pilers is reduced. There is a gradual pattern in this decrease. But it settles at eight for the number of open pilers finally. Eight is the minimum required number of open pilers to satisfy all supply at the farms in week 4. The total cost increases as the setup cost increases.

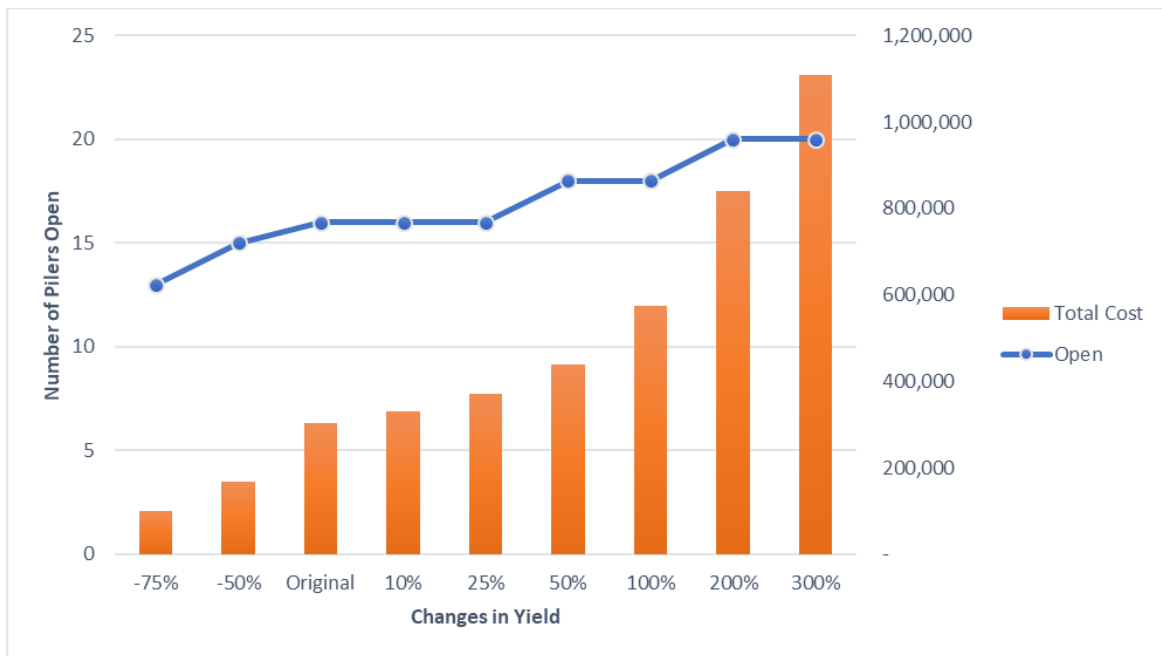


Figure 26. Sensitivity Analysis for Yield Change.

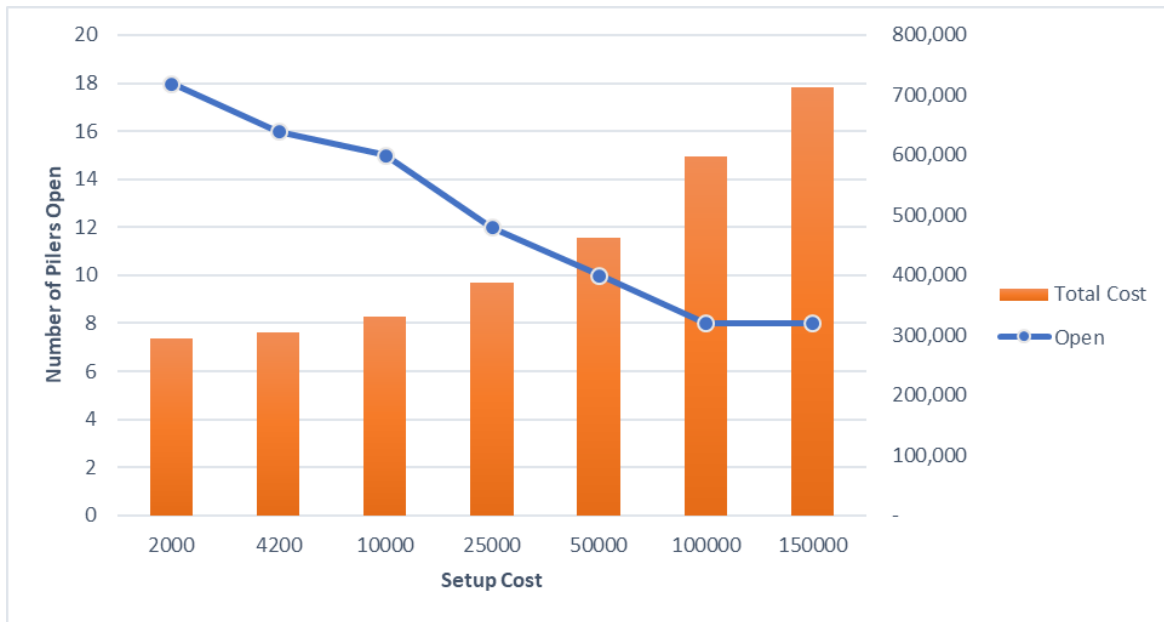


Figure 27. Sensitivity Analysis for Piler Set up cost.

Conclusion

This study shows that a two-step method using GIS and optimization can be used to allocate the sugar beet piler locations. This method can be used to save the total transportation cost. As the farm to the piler cost is incurred by the farmers, this method can be helpful for farmers to save more money and reduce overall cost. At the same time this method considers the maturity period of sugar beets thus helping ACSC to transport beets at the peak of their maturity and receive highest sugar content. As seen in the sensitivity analysis as yield changes the number of pilers changes which can attribute to the supply variation. This method is also useful to find the optimal piler locations in this scenario. A reduced time interval such as half a week or less can be used for clustering to get better assessment of piler locations.

In the future, this method can be used with the results from Dharmadhikari et al. (2017). Their research performs yield forecasting which can be used as inputs for this study. This study can also be a part of a comprehensive economic model of sugar beet production suggested in

Farahmand et al. (2013). This model can be modified to be used as a base model for crops other than sugar beet.

CHAPTER 6. DISCUSSIONS

This dissertation presents three research articles based on the study of sugar beet transportation economics. It has been observed from the extensive literature review that the sugar beet transportation economics is a novel research topic as there are sporadic research articles in this area. Thus, this dissertation will be a stepping stone for the future researchers focusing on the unique transportation challenges faced by farming industry, sugar-beet production and similar specialty crops. These articles reflect on the topics which are important to farmers, logistical operators, transportation professionals as well as planners and engineers. The yield forecasting is an important research area which studies the prediction of the yield of a particular crop using different factors. The first research article discussed different techniques available for the yield forecasting. It presented an algorithm for yield forecasting using NDVI data. This article explained that the NDVI data can be easily obtained from the Vegetation Condition Explorer (VegScape) created by National Agricultural Statistics Service (NASS). It proposed a low cost and easily implementable method for yield forecasting. It generated a regression equation involving NDVI and yield to show the relationship between the two. The validated results are proposed to be used for making the logistical decisions. Also this forecasted yield can be used in the transportation optimization study as one of the inputs.

The second research article focused on estimating the transportation cost of the sugar beet crop. There have not been a lot of studies related to the cost associated with transporting this unique crop. This article proposed a total transportation cost model for sugar beet. This model added costs of loading, unloading, front and backhaul for the harvested sugar beets. Furthermore it included a GIS model to calculate these respective costs based on the path travelled. The GIS model considered the locations of the farms and the processing facilities and used a shortest path

algorithm to connect them. The model converted these distances into costs based on the truck travel estimates. This is one of the first studies which estimated the sugar beet truck carrying capacities and its connection to the transportation costs. These costs are later used in the optimization study.

The third research article presents a two-stage model for sugar beet piler (piling center) locations optimization. It involves the first stage of the GIS analysis and the second stage of the location optimization. The first stage is similar to the model explained in the second article. It also added a component of the clustering sugar beet farms based on the maturity date. This maturity date can be projected with the help of yield forecasting method presented in article one. In the second stage, the optimization is performed to find a pair of operating pilers and farms at any given harvest times. While optimizing the piler locations, this model also minimized the total cost of logistics. The total cost of logistics included setup and storage costs along with transportation costs. This model also included yield loss costs in the overall cost calculations as it is important to provide a penalty for late harvesting and loss of sugar content. This article also presented a sensitivity analysis based on the yield change and any changes in the piler set up costs. This article is one of the very first articles presented for sugar beet logistical cost optimization thus providing a pioneering step for sugar beet transportation economic analysis.

Though it looks like these are three distinct articles, they form a cohesive narrative. As explained earlier, output from the yield forecasting is an input for the transportation model which in turns acts as one of the inputs to the optimization process. This research has also been used in the economic analysis of the sugar beet production presented by Farahmand et al. (2013). This article presented a sugar beet economic model as an addition of the production (farming) costs, the processing costs, and the transportation costs. The transportation costs section of this

research is derived from the transportation model presented in the second article. This highlights the importance of this study in the field of sugar beet research. This study was also part of the National Science Foundation (NSF) funded project titled ‘Data-driven Support for the Smart Farm’. This project researched about the ‘smart farm’ which includes a data driven decision system to help farmers to quickly provide the response to the changing production and environmental needs. This study fulfills major part of this system as all three articles can be used as a part of the data driven analytical system to provide important inputs to farmers.

CHAPTER 7. CONCLUSIONS AND FUTURE RESEARCH

Agricultural industry is crucial for the economy of the state of North Dakota and sugar-beet is one of the important crops. Transportation is one of the most important aspects of the agricultural industry. Success of the industry is very much dependent on the suitable transportation system and a good logistical support. The economic study of the transportation and logistical system provides various understandings about the agricultural economy of the state. In the reported work, interconnected research of the agricultural system and the transportation and logistical needs is performed.

Reduction of the uncertainty can provide an edge to any logistical systems. This ultimately reduces the risk and increases the returns. Yield forecasting is one of the ways to reduce the uncertainty in the agricultural logistical systems. It is shown that the yield forecasting can be performed using easily available data such as NDVI from USDA. The outputs from this research will become the input for the transportation analysis.

The production process flow for sugar-beet involves three stages: harvesting, transportation and storage, and processing. The transportation and storage steps involve various costs associated with these processes. The economic study of all these costs is performed using GIS modeling and the data analysis. A total transportation cost model is presented in this study which includes loading and unloading of beets, and front and back haul distances between the processing facility or the storage facility and the farms. A detailed model of the transportation economics is presented and is validated using the historical data.

Finally, both outputs from the previous studies are used as the inputs to the optimization study. The optimization study presents a minimization model for the total logistics cost. This minimization helps reduce the costs at the same time it protects the sugar content in the beets to

maximize the returns. This study also presents a sensitivity analysis for the yield changes and set up costs.

This research could be considered the primary building block of the transportation economic study of the sugar-beet crop. This research helped provide the study with some of the initial inputs, but with the advancements in the precision agriculture techniques more data points will be available. These data points can be treated as the inputs in the presented models. The more complex yield forecasting models can be developed with the help of these inputs.

These complex models could be added to the data driven analytical system which will be based on the optimization model. This data driven system can be developed to provide numerous outputs for the farmers in order to increase the yield and return on their investments. Staying congruent with the big data theme, there will be tons of data available from farms. This data driven system can be developed to analyze various inputs from yield forecasting stage and the transportation phase of the study.

One of the earlier data input for the data driven analytical system can be imagery from the Unmanned Aerial Vehicles (UAVs) or drones. This imagery can be processed to generate NDVI or similar indices. This imagery will be useful to substitute the NDVI data from USDA. This data will be instantaneous data and will be useful to generate prompt results which can guide farmers to make or change their logistical decisions. Precision and speed is very important in the agricultural logistics and this data driven analytical system can be a very useful tool providing both precise and timely information to farmers.

At the same time output from this system will be useful for the transportation planners and engineers. This system can generate the estimated truck volumes on the rural roads which is hard to predict. These volumes will be useful in the future decision making for the maintenance

or expansions. This can also help to test the disruption scenarios. These scenarios are encountered if there is a particular road disruption or a natural disaster affecting the crop. These scenarios will test how the system as a whole will perform or what will be the economic impacts of that disruption.

Finally, though this model is generated for the sugar-beet crop, it is versatile enough that with some changes it could be used for other crops such as wheat or corn. Combining other crops in this model will make the data driven system more complex at the same time more useful. This complex system can be used to study the agricultural economics of the entire states of North Dakota or Minnesota and not just one part or one crop.

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APPENDIX

Lingo Code

This is an example snippet of the Lingo Code used for optimization. Number of models were created. Basic code is similar in most of the models only certain changes were made to accommodate different scenarios and sensitivity analysis.

```
!
*****
I is for FARMS
J is for PILERS

Arcs should be from SUPPLY to DEMAND..
So, arc is FARM to PILER

*****;

SETS:
    FARMS: YIELD, YLOSSCOST, TRUCK;
    PILERS: CAPACITY, SETCOST, STORECOST, OPEN;
    ARCS(FARMS, PILERS) : COST, VOL;
ENDSETS

DATA:

!SUPPLY
!Farms and their yield and yield loss costs;

FARMS = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls', 'FARMS');
YIELD = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls', 'YIELD');
YLOSSCOST = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls',
'YLOSSCOST');
TRUCK = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls', 'TRUCK');

!DEMAND
!Pilers, their setup costs, and capacities;

PILERS = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls', 'PILERS');
CAPACITY = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls',
'CAPACITY');
```

```

SETCOST = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls',
'SETCOST');

STORECOST = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls',
'STORECAST' );

!Farms to pilers cost matrix;

COST = @OLE('E:\Docs\Papers\Pilers\Data\Farms\Week4_Yield6.xls', 'COST');

ENDDATA

!Objective function;

[TTL_COST] MIN = @SUM(ARCS(I,J)|COST(I,J) #NE# 100000:COST(I,J)*VOL(I,J)) +
@SUM( PILERS: SETCOST * OPEN) + @SUM(FARMS: YLOSSCOST) + @SUM (PILERS:
STORECOST * OPEN);
! 100000 IS DUMMY UNIT SHIPPING COST;

@FOR(ARCS(I,J)|COST(I,J) #EQ# 9999 : VOL(I,J) = 0);
!9999 IS INFEASIBLE (NOT WORKING LINK) UNIT SHIPPING COST;

! SUPPLY CONSTRAINTS;
@FOR(FARMS(I)|YIELD(I) #NE# 7416614.51965200: @SUM(PILERS(J): VOL(I,J)) =
YIELD(I));
! "FARMS(I)|YIELD(I) #NE# 7416614.51965200" this statement is to exclude
dummy from this rule.;

! DEMAND CONSTRAINTS;
@FOR(PILERS(J): @SUM(FARMS(I): VOL(I,J)) = CAPACITY(J)*OPEN(J));
!Yield at each farm should be great than or equal to 0;

! WHATEVER WE SHIP FROM FARM TO PILER SHOULD BE NON-NEGATIVE;
@FOR(FARMS(I): @FOR (PILERS(J): VOL(I,J) >= 0));

!DEFINE BINARY VARIABLE;
@FOR(PILERS(J): @BIN(OPEN(J)));

!TRUCKS SHOULD BE POSITIVE INTEGER;
@FOR(FARMS(I): @GIN(TRUCK(I)));
@FOR(FARMS(I): TRUCK(I)>=0));

END

```

Software Used

1. ESRI® ArcGIS ArcMap 10.2.2

Following is the screen shot of the ArcGIS software. It is used for performing GIS analysis in this research. Various tools available in the software were used.

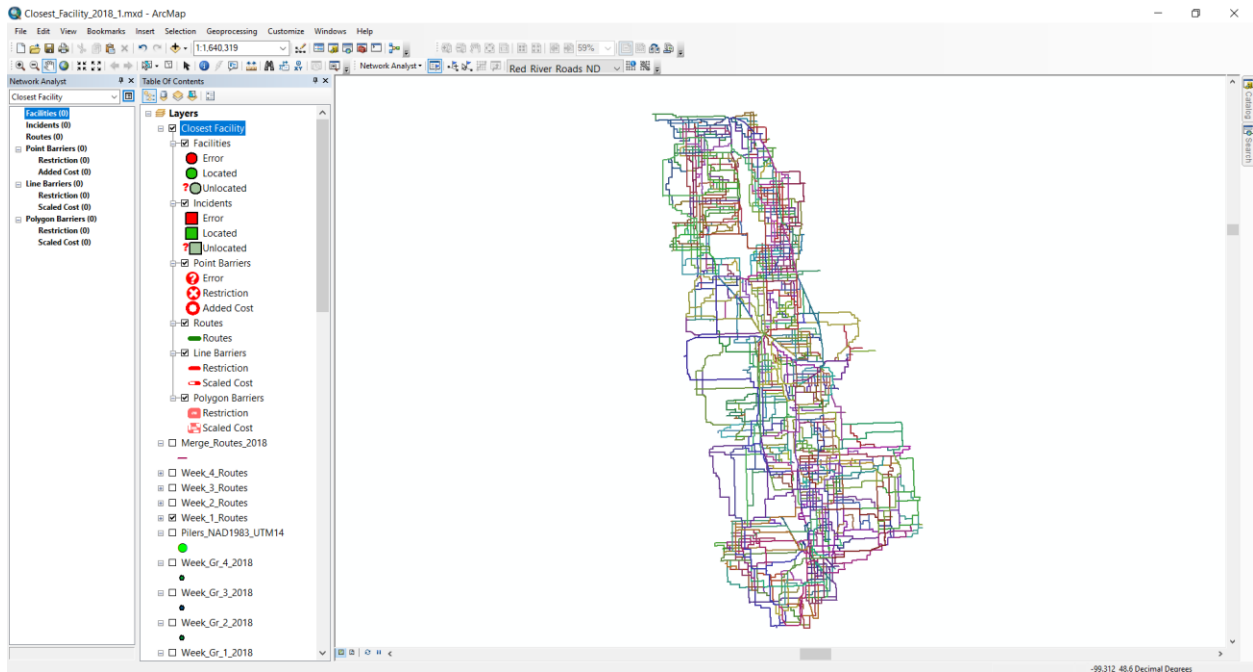


Figure A1. Screen Shot of ArcGIS Software.

2. SAS Enterprise Guide

Following is the screen shot of the SAS Enterprise Guide software. It is a simplified version of the SAS software. With minimal code writing we could perform regression analysis and generate results.

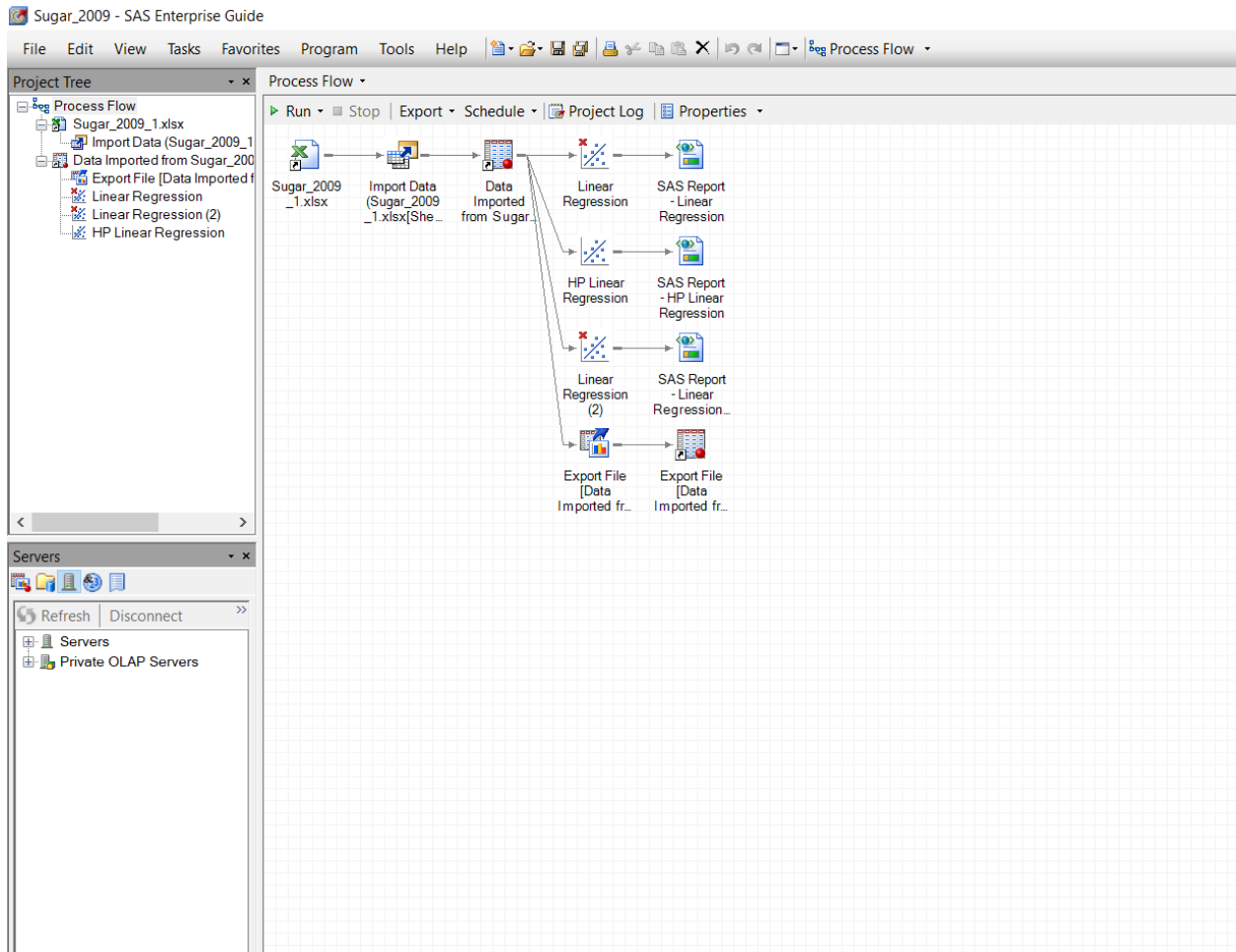


Figure A2. Screen Shot of SAS Enterprise Guide.

3. Lingo by Lindo Systems

Following is the screen shot of the Lingo 17.0 software. It is software used for the optimization analysis. It has functionality and tools to solve linear programming problems.

```
Lingo 17.0 - [Lingo Model - Plant_Location]
File Edit Solver Window Help
[Icons]
! Capacitated plant location Problem;

SETS:
! Import Plants and Customers from Excel;

  PLANTS: FCOST, CAP, OPEN;

  CUSTOMERS: DEM;

  ARCS( PLANTS, CUSTOMERS) : COST, VOL;

ENDSETS

! The objective;

[TTL_COST] MIN = @SUM( ARCS: COST * VOL) +
  @SUM( PLANTS: FCOST * OPEN);

! The demand constraints;

@FOR( CUSTOMERS( J): [DEMAND]
  @SUM( PLANTS( I): VOL( I, J) ) >= DEM( J)
);
```

Figure A3. Screen Shot of Lingo Software.