THESIS

THE ECONOMIC IMPACT OF HIGHLY PATHOGENIC AVIAN INFLUENZA ON EGG PRODUCTION IN MINNESOTA DURING THE 2014 – 2015 OUTBREAK

Submitted by

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ABSTRACT

THE ECONOMIC IMPACT OF HIGHLY PATHOGENIC AVIAN INFLUENZA ON EGG PRODUCTION IN MINNESOTA DURING THE 2014 – 2015 OUTBREAK

The 2014–2015 Highly Pathogenic Avian Influenza (HPAI) outbreak in the United States affected 48 million domestic poultry birds. Minnesota experienced 101 confirmed detections with the majority in the laying hen and turkey populations. This research employs mathematical programming to estimate individual egg producer net returns above transportation costs for each week of the outbreak period and to aggregate these estimates to an industry-level impact.

When there is a detection of HPAI the primary government response is to designate control areas around the infected premises. Within these control areas rules are established for culling of poultry and restricting travel. A three kilometer and a ten kilometer “control area” perimeter are standard guideline practices established by USDA-APHIS.

A linear programming model is developed and parameterized to calculate returns under a range of control scenarios in the face of the historical outbreak. By updating and solving the model iteratively to represent adaptation to on outbreak across time, results for each time period computed and compared to a base model that represents an uninfected circumstance. The change in net revenue as compared to the base equilibrium scenario quantify the lost benefits that comprise the economic impacts from HPAI.

Overall total industry loss for the 14-week outbreak period ranged from $7 million where three kilometer radius control areas were employed to $10 million a ten kilometer regime. Fourteen percent of producers lost less than $10,000 in revenue and approximately 3 percent of

the producers lost revenue greater than $1 million. The increase in transportation costs for the three kilometer control area was approximately $25 and approximately $11,000 for the ten kilometer control areas.

Preventing the spread of HPAI is important to society. Measures to prevent disease spread are important and need to be enforced. It is important that these additional avoidance and adaptation costs be considered when determining the best implementation of control measures in the face of a disease outbreak.

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CHAPTER 1. INTRODUCTION

Minnesota Poultry Production

Minnesota consistently ranks among the top ten states for egg production in the United States according to the Chicken and Egg Association of Minnesota (2016). Minnesota has on average 10.4 million hens producing 2.9 billion eggs per year. The majority of the layer farms are in located in the southern half of Minnesota with the average farm having 146,907 laying hens. The egg industry in the state employs more than 2,900 people and generates annual egg production valued at $168 million annually. The egg industry plays an important part in the Minnesota economy.

Beyond the egg industry, Minnesota is ranked 17th in broiler production (Chicken and Egg Association of Minnesota, 2016). Minnesota is also the number one turkey producing and processing state in the United States, with approximately 450 farms producing 44 to 46 million birds annually (Minnesota Turkey Growers Association, 2016). Poultry production in Minnesota in total employs more than 26,000 people with an economic impact of over $1 billion annually (Chicken and Egg Association of Minnesota, 2016). The poultry industry plays an important part in the Minnesota economy and contributes to the feeding of the nation. When a disruption to this industry occurs, the effect can ripple throughout the nation.

Highly Pathogenic Avian Influenza

Highly Pathogenic Avian Influenza (HPAI) is a diverse group of viruses, much like the influenza that is common in people. Common problems attributed to HPAI are necrosis in the comb and waddle, subcutaneous hemorrhage of legs, and lungs that fill with fluid and blood (Swayne, 2007). Birds infected with HPAI have a mortality rate of up to ninety to one hundred percent, often within 48 hours (Avian Influenza in Birds, 2015). With the dense population of poultry barns, spread from one bird to another can happen quickly.

HPAI is spread through droppings or nasal discharge from infected birds. People can carry the virus on clothes, shoes and vehicles when traveling from one barn to another or one farm to another. Biosecurity measures at the individual farm-level is one method to prevent spread of the disease. Biosecurity encompasses the portfolio of practices and procedures to prevent the spread of disease from one place to another. The most effective biosecurity measures for HPAI range from cleaning of vehicles and clothes to sanitizing barns and other equipment. According to the Food and Agriculture Organization of the United Nations, once introduced into a flock, the virus is spread from flock to flock by the usual method, such as the movement of infected birds, contaminated equipment, egg flats, feed trucks, and service crews, to mention a few. The disease generally spreads rapidly in a flock by direct contact, but on occasions spread is erratic (FAO Animal Production and Health Division, Bulletin 25).

Preventing the spread of the disease is an important aspect to ensure that the economic impacts can be limited. HPAI has a possibility to spread to humans (Avian Influenza in Birds, 2015) but this risk to humans is mostly from butchering, direct contact through other occupational exposures, and consumption of undercooked poultry or poultry blood. The USDA Animal and Plant Health Inspection Service (APHIS) is tasked with the protection and improvement of the health, quality, and marketability of our nation’s animals. One way this is accomplished is to prevent, control and eliminate diseases that will affect the tasks described above (Animal and

Plant Health Inspection Service, 2016). Minnesota has had a surveillance program for avian influenza in place for more than 40 years. Every commercial poultry flock in Minnesota is tested before going to market (Minnesota Board of Animal Health, 2015).

HPAI Outbreaks

HPAI outbreaks have occurred worldwide for well over one hundred years. From 1959 to 2004 there were 28 outbreaks worldwide (FAO Animal Production and Health Division, Bulletin 25). Between 1997 and 2014 there was only one outbreak of HPAI in poultry in the United States. In 2004, there were 7,000 chickens culled in Texas due to an HPAI outbreak (Center for Disease Control and Prevention, 2015). Until 2014, HPAI outbreaks in the United States were a rare occurrence.

USDA-APHIS publishes the confirmed detections of HPAI that occur in the United States. Using this published data, a timeline can be presented for the 2014-2015 HPAI outbreak. On December 14, 2014 the first case of the 2014-2015 U.S. outbreak of HPAI was detected in Douglas County, Oregon. It affected 130 birds of a mixed poultry backyard flock. The next occurrence was in Benton County, Washington where 140 mixed poultry from a backyard flock were affected. The first commercial flock to be infected was in Stanislaus County, California on January 23, 2015 where 134,400 turkeys were affected and culled. From December 2014 to June 2015, there were 219 detections of HPAI and over 48 million birds affected in the United States.

From March to June 2015, Minnesota had 101 confirmed cases of HPAI. In total, approximately 7.7 million birds were affected. The first confirmed case of HPAI in Minnesota was on March 4, 2015. A commercial turkey farm in Pope County with 44,000 birds was infected. The next case of HPAI was on March 27 and affected 66,000 turkeys. Between the first detection on March 4 and April 22 there were 45 confirmed detections of HPAI in turkey farms in Minnesota. On April 22 the first laying hen population was infected. These farms had a population of 408,500 laying hens and were located in Clay County. A large majority of the cases centered in the turkey and laying hen populations. Figure 1.1 illustrates the number of cases confirmed each week of the outbreak.

Figure 1.1 Confirmed Cases of HPAI in Minnesota (Animal and Plant Health Inspection Service, 2016)

Preventing and controlling the spread of the disease is important to limit the magnitude of an outbreak. One of the methods to achieve this is to cull all affected birds and decontaminate the premises. This helps to contain the disease, but comes with a cost.

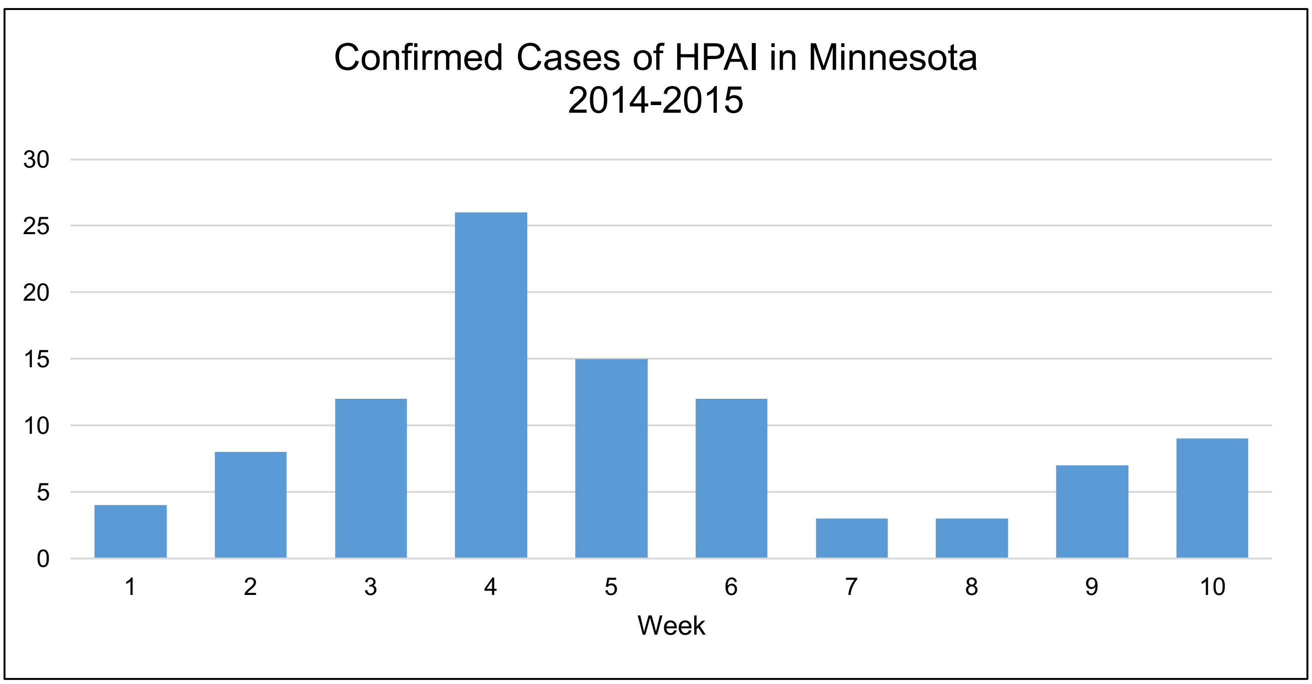

Figure 1.1 Confirmed Cases of HPAI in Minnesota (Animal and Plant Health Inspection Service, 2016)

These costs from the culling of the infected birds is partially recovered by indemnity payments from the United States government. Every bird that is alive when inspected by a government official will be included in determining the amount of the indemnity payment to the farmer for destroying the affected birds. This helps to ensure prompt notification to authorities. When a farm has a confirmed detection, the surrounding farms are notified and inspected. Producers might not be directly affected but can still be affected economically. For instance, producers who do not experience infection on their property may not be allowed to conduct business as usual if neighboring farms are infected. These indirect costs are not usually accounted for when estimating the economic impact of an HPAI outbreak.

The economic impacts to the firms that have confirmed cases, as well as the firms that have not had any infected birds, are important to the individual firms but also to society as a whole. When any animal is identified with HPAI, by law it is not allowed to enter the marketplace (Minnesota Board of Animal Health, 2015). During the time period of this outbreak, with 48 million birds being identified the cost to the economy can be significant. The economic impacts to the farms (egg producer) and egg processors, as well as the price for eggs and protein, are important when considering the economic welfare of the state.

USDA-APHIS has protocols for action when a disease is discovered to prevent the further spread of the disease. One of the protocols used for this purpose is the identification of infected zones, buffer zones, and surveillance zones. These zones are fundamental to helping prevent the spread of disease. By limiting the movement of animals and products through the control areas the risk of transfer of a particular disease can be reduced. The infected zone and the buffer zone are the components of the control area. For HPAI, the control area is currently an area contained within a ten kilometer radius surrounding an infected farm. The infected zone is the first three kilometers surrounding the infected farm, the buffer area is the zone within the three to ten kilometer distance from the infected premises. Both the infected zone and the buffer area will have movement controls and surveillance activities (Animal and Plant Health Inspection Services, Feb, 2015). The research presented in this thesis will focus on the movement controls.

In 1995, the World Trade Organization (WTO) approved the standards for HPAI. The standard is that a zone is considered infected for 21 days after the confirmation of the last case or the completion of the disinfection has taken place. If there is no disinfection, the control area would be in place for six months after the death of the last animal (Pearson, 2003). As the time to notify the authorities and the disinfection process can be approximated at one week, plus the 21-day control period, a four-week control area restriction can be approximated.

Once the control areas are placed in effect, the transportation of eggs from the farms to table becomes more complicated. The control area may restrict travel of poultry and other animals. Eggs are subject to a Secure Egg Supply procedure when moving though a control area. These procedures require testing, biosecurity measures, and an epidemiological questionnaire to ensure the safety of the food supply (United States Department of Agirculture, 2015). Farms that are not directly affected by HPAI will still have to transport their eggs to the processors and will have to make the decisions on the routes they plan to use to transport eggs to the processor. They must determine if the risk of entering a control area is greater than the cost of avoiding the control areas.

The purpose of the research presented in this thesis is to estimate the economic impacts to commercial egg producers from the changes in the operations of delivering salable eggs to processors that resulted from the 2014-2015 HPAI outbreak in Minnesota. Chapter 2 summarizes the relevant literature. Research into the economic costs of HPAI, transportation modeling, and GIS software are discussed. In Chapter 3 a general optimization model is developed and parameterized to determine value generated to farmers from operations including the determination of optimal routes for transporting eggs to from producer farms to the processing facilities. Chapter 4 reports the results from the use of the optimization model and analyzes the impacts on transportation costs as well as the impact to the industry as farms become infected and management controls are implemented. Finally, Chapter 5 provides a summary and conclusions from the study.

CHAPTER 2. LITERATURE REVIEW

In Chapter One, the Minnesota poultry industry and HPAI were discussed. In this chapter, previous research into disease costs and management practices, as well as a government's role in disease management will be discussed.

Disease Management and Outbreak Costs

According to the World Health Organization (WHO), from 2003 to 2015 globally there were 846 cases of Avian Influenza reported in humans, and of these 449 resulted in death. Outbreaks of avian influenza raise global public health concerns due to their effect on poultry populations, their potential to cause serious disease in people, and their pandemic potential (World Health Organization, 2016).

The control of animal disease is important to society as the impacts of a disease outbreak can be costly and deadly. Rat-Aspert and Krebs state that individual management may differ from the collective expectations but individual decisions have an impact to the level of risk exposure to other farms from the disease. The aggregate of the individual decisions have an effect on the epidemiologic model and individual decisions depend on the epidemiological situations (Rat-Aspert & Krebs, 2011). It is because of the circular nature of the disease related to farmer decisions that government entities have a role in disease management. Organizations such as USDA-APHIS are tasked with this role.

According to Kuchler and Hamm, disease control depends on farmers' ability to respond to relative prices they face. Using the Scrapie indemnity eradication program in the United States

(1952-1992), the authors show that payment prices set by the government played a major role in determining the programs outcome. Higher indemnity payments led to less infected animals remaining in production (Kuchler & Hamm, 2000).

Farmers are responsive to prices. In a basic supply and demand model, when the demand for a product increases the price for that product will increase. Zhou *et al*. study the effect of avian influenza on the demand for chicken in China. Using a willingness to pay survey in April 2012 and April 2013 willingness-to-pay (WTP), as well as demand for chicken was quantified. The April 2013 survey was conducted during the mist of a HPAI outbreak. Just the sheer mention of HPAI was more negative even when accompanied with risk-perception reducing or risk-perception elevating message (Zhou, Turvey, Hu, & Ying, 2015).

In 2005-06, Turkey experienced an HPAI outbreak. The HPAI outbreak in Turkey was similar to size and scope of the 2014-2015 Minnesota HPAI outbreak. In addition to the turkeys, which totaled 6,510 birds, 2.5 million backyard poultry along with 13.5 million layer hens were culled during this time period. In this instance there were human cases of HPAI, consumer panic took hold and turkey meat prices dropped below the price of production.

Yalcin *et al*. (2010) studied the economic impact to contracted turkey producers in Turkey in 2007. Using 71 randomly selected contracted farms, they were able to determine that the production level and enterprise income was reduced by 36 percent and 39 percent respectively. The 71 selected farms accounted for 23 percent of the turkey meat produced in the nation. These farms were selected from four of the five integrated firms that produce 67 percent of the turkey meat. By comparing financial indicators from before and after the HPAI outbreak, economic impacts were estimated. Labor, turkey population, number of production cycles, meat production, fattening cycles, feed conversion ratios, and mortality rate were measures that were analyzed.

When there is an outbreak of a disease in a region, international trade can be affected. During the 2014-2015 outbreak of HPAI in the United States, over 40 countries enacted some sort of ban on imports of poultry and poultry products from the United States whether the ban was for the country as a whole or individual regions. China, South Korea and South Africa enacted import bans on all poultry eggs and related products (Zhuang & Moore, 2015). These bans can have a significant impact on the prices received by poultry producers. While the price of eggs may increase due to less supply of eggs as the result of HPAI culling, the price of chicken meat may decline as a result of the bans placed on all poultry.

Diseases such as Foot and Mouth Disease (FMD) are also a concern for agriculture and public welfare. Using a dynamic computable general equilibrium model to estimate the economic costs of Foot and Mouth Disease on Brittany, France, Gohin and Rault find that the economic losses are spread over multiple time periods even with a one-time shock. The impacts on the primary sectors and the downstream food sectors do not move in parallel. The food industries suffer most in the first period and the negative impacts of agriculture are mostly observed thereafter. The decrease in cattle production led to a price increase of 1.86 cents per pound of beef. (Gohin & Rault, 2012).

Bans of products that relate to a disease outbreak can have lasting effects on prices. In the last ten years two major FMD outbreaks have occurred in Brazil. Costa *et al*. (2015) studied the impacts on FMD on the Brazilian meat market. A vector error correction model was used to quantify the effects of the 2005 Brazil FMD outbreak on three levels of industry: export, wholesale, and farm. The data that was used was the monthly Brazilian prices of beef, pork, and chicken at the export, wholesale and farm level. The largest decrease in export beef price was 13 percent and did not recover until a Russian import ban was lifted. The export pork price was negative and never recovered even after the Russian import ban lifted (Costa, Bessler, & Rosson, 2015).

Disease eradication plays an important role when limiting the economic loss from an outbreak. Forbes and van Halderen (2014) researched the economic impact on production, export losses, and eradication expenditure from Foot and Mouth Disease (FMD) in New Zealand. By modeling a hypothetical outbreak and comparing the results to actual trade data economic analysis can be accomplished. This method is unique as New Zealand exports approximately 90 percent of its dairy, beef, lamb, mutton and venison production. Creating a small, medium, and large outbreak scenario the export value losses were between $2.7 and $5.9 billion for a two-year period. Eradication method costs ranged from $24 to $249 million (Forbes & van Halderen, 2014).

Biosecurity is important to help prevent the spread of disease. Biosecurity measures may include sanitization of clothes and vehicles, keeping visitors to a minimum, limiting visitation to other poultry farms, keeping all other animal out of poultry barns and rodent and pest management (Cunningham & Fairchild, 2012). Hennessy and Wong investigate animal disease and agricultural industrialization. They state that infectious disease and animal density are related. Animal density on a farm or farm density in an area are factors in increased animal disease risk. The unit cost for biosecurity decreases with animal density and as such producers should be more apt to invest in biosecurity measure with the animal dense practices of poultry production. When the external risk of disease is reduced the incentive for a producer to scale up is improved, thus increasing the likelihood of increased biosecurity on the farm. This implies that public health efforts to reduce disease spread will complement farm level production and efficiency (Hennessy & Wang).

Transportation

Agricultural development was only possible by the advent and availability of transportation, the critical link between the production on our fields and the tables of our domestic and international consumers (Casanvant, 2015). Almost all (95-98 percent) of livestock, meat, poultry, and dairy products are shipped by truck to domestic markets (United States Department of Transportation, 2010).

The main purpose of this this thesis is to estimate the loss of production value for all producers in a region experiencing an outbreak of HPAI. This will include not only the loss of foregone production but also the additional costs associated on the transportation of the eggs from the farms to the processors as a result of the control areas that are imposed during an outbreak.

To assess the cost differential in transportation, a modelling approach will need to be developed to predict producer response and to quantify the costs of their decisions. Linear programming provides a convenient method to solve such a transportation problem. Gass (1990) discusses methods to solve the transportation problem where some quantity of goods are desired to be moved from a set of origination points to a set of destinations at the least cost possible. Mathematically the model of this basic transportation problem can be expressed as:

$$minimize\ Z = \sum_i \sum_j c_{ij} \cdot X_{ij}$$

Subject to:

$$\sum_j X_{ij} \leq a_i \quad \forall\, i$$

$$\sum_i X_{ij\,\geq} \geq b_j \quad \forall\, j$$

$$X_{ij} \geq 0 \ \ \forall\, i, j$$

Where:

X_{ij} is the quantity of product moved from source *i* to destination *j*

c_{ij} is the cost per unit of product moved from source *i* to destination *j*

ai is the quantity that is available to be moved from source *i*

bj is the quantity that is required to be moved to destination *j*

Z is the total cost of the overall plan

For the generalized problem all a_i and b_j are non-negative. These can also be thought of as *supply* and *demand*. As the Processor and Producer transportation model this paper details, this research aligns well with the supplies and demands outlined in this paper. A generalized transportation model is appropriate.

Mathematical optimization allows one to find solutions that will either maximize or minimize a particular objective function. The choice that needs to be made as to which one is appropriate in an economic sense depends on whether the goal is to minimize costs or maximize revenue. One way that can be described is this: if a goal is to maximize revenue the constraint will need to be that no more than is available can be shipped. As without this constraint, the model would ship infinity levels. On the opposite side, if the min cost model was selected the constraint would need to be that all supply must be shipped or some minimum level of demand must be met or the model would ship zero units at a cost of zero. Careful attention to the objective choice as the constraints that accompany the model will need to be adjusted accordingly.

Mathematical programming has been used to formulate transportation models for research purposes for over a half century. Cravin (1964) presents a case for a generalized linear programming model for the transportation of products. Presented in the research is a simple model that represents three products and two destinations, that results in six "products." An array with *m* rows, n columns, and *m + n* loaded squares is constructed so that the remaining A_i and B_j are obtained one at a time. As the calculations are processed one at a time, the equations can be solved. Using a min cost method will result in the transportation cost. This generalized method requires less computation power than other methods such as the Simplex method.

Currin (1986) reports on transportation problems with inadmissible routes. By adjusting demand equitably, the infeasibility of the problem can be overcome. The demand was allocated using a mathematical algorithm. This algorithm allocated the supply by adjusting demand levels fairly across all destinations. Even if the supply exceeds the total demand the equitable feasible solution can be discovered by aggregating the adjustment of demands and decomposing the cost minimization. This research will have levels of supply that are affected by the HPAI, as control areas are in place and farms are directly affected with the virus. A method such as this would not be appropriate for this research, as the routes become altered but not inadmissible.

When transporting agricultural product from producer to processor the route chosen can have lasting consequences. While some roads are built for large truck transport others are not.

These considerations are important when determining trucking routes. VanWechel *et al*. studied the WTP for local road service improvements. Through a survey method they found that 32 percent of respondents would be willing to pay for improved services, 50 percent said they would be willing to drive further for faster freight transportation. In other words, half of the producers said they would be willing to pay more by spending more fuel for their trucks to use better roads, but only one third would pay the government more for improved roads (VanWechel & Vachal).

In this research the miles that are necessary to be travelled between the producers and the processors must be estimated. This will include egg producers that are either directly infected with HPAI or are enclosed in a control are and thus their travel is restricted. Christenson (1980) calculated the impact to New England Agriculture due to rising fuel costs. His method was the equation:

$$C_d = (P_d\ [D/MPG])/C$$

where

C_d is the change in cost as the result of rising fuel costs

P_d is the change in fuel price

D is the distance traveled

C is the capacity or units carried on truck

MPG = miles per gallon

The research in this thesis will build upon this method by making use of the computation power of computers available today. Using the constant cost of the shipping to calculate the cost of per mile transport will simplify the MPG variable as each semi-truck used would be have a different

MPG. This method would be appropriate for a producer or trucking company that has only a few scenarios to iterate.

Geographical Information Systems

Geographical Information Systems (GIS) is a platform of software applications that help to solve problems of space. Whether state, county or global problems, GIS can model and assist with finding solutions. As control areas, producers and processors are all physical locations. GIS software was used to obtain the road mileage to processors from producers. Tools that are standard to GIS software today can be used to represent buffer zones as control areas and will evaluate these restrictions in recalculating the effective road mileage between farms and processors in the face of an outbreak.

Boothby and Dummer (2003) discuss the role of GIS to facilitate mobility. A general overview and discussion of GIS in problems of mobility is presented. The authors state that GIS is designed to answer questions that involve location. The question that will need to be answered is the optimal route from the egg producers to the egg processors. Using a GIS software platform will result in the mileage from each egg producer to each egg processor. GIS software is able to iterate the scenario to model each time period, as well as being able to enact the restrictions of the buffer areas will result in a proper method of obtaining the Mileage Matrix needed for the linear programming model.

GIS software has several uses in agriculture. Laing and Nolan use GIS software to analyze spatial and temporal market structure in for-hire grain trucking at the Alberta-Saskatchewan border in Canada. By building freight rate contours for the trucking market through space a set of data is developed to econometrically analyze market structure. They find that trucking market power is not persistent but non-competitive pricing is present during certain times of the year (Laing & Nolan, 2013).

ArcGIS Network Analyst provides network-based spatial analysis tools for solving complex routing problems. It uses a configurable transportation network data model, allowing organizations to accurately represent their unique network requirements. You can plan routes for an entire fleet, calculate drive-times, locate facilities and solve other network related problems (ArcGIS Network Analyst, n.d.). Xie *et al*. uses GIS software to find the optimal locations of bio-refineries of switch grass in South Carolina. By first obtaining biomass distribution data from remote sensing images a mixed integer linear programming tool is developed to find the optimal location of bio-refineries. (Xie, Zhao, & Hemingway, 2009). In this case the GIS platform is complementary to the mathematical optimization model.

CHAPTER 3. STUDY METHODOLOGY

The egg industry in Minnesota is consistently ranked among the top ten states for egg production in the United States (Chicken and Egg Association of Minnesota, 2016). When a disease such as HPAI enters the area and infects the poultry population the economic impacts can be significant. This chapter documents the development of the analytic model that will be used to provide an estimate of the cost imposed on the uninfected farms in the industry.

Mathematical Model of Farm Returns

A linear programming model that determines the maximum total farm net return in the face of transportation cost will be utilized. This model will allow for a number of egg producers to ship to a set of egg processors. The decision variables are the quantity of eggs to be shipped from each farm to each processor. The revenue from the truckloads shipped as well as the cost of the transportation will be included. The constraints included will that no more eggs can be shipped than are available at each farm and that demand at each processor has a maximum quantity of eggs that it can accept and process.

For the base model, the industry will be assumed to be running at an equilibrium that fully utilizes the present capacity. If the demand for more eggs from the processors was present, the price of eggs would rise. As the price of eggs rise the producers would obtain more laying hens to produce the eggs needed. Doing so would take advantage of the higher egg prices until such time as the demand is met. When the demand is met and the producers have excess supply the price of eggs would fall. Due to the supply and demand condition, a market equilibrium would be set.

One of the assumptions of this model is that the egg producer is a profit maximizing firm. To maximize the profits of the firm the producer will deliver the eggs to the processor with the least transportation cost. In this model, the least cost processor will be the closest processor. As the model is used to evaluate the cost of an outbreak and the mileage to available processors changes, the processor chosen may vary.

As demand is not known, a max profit model was necessary develop a model to “push” the eggs to the processors unlike the Gass model described in the previous chapter. The objective of the model is to maximize total industry net returns. In this setting, net return is defined as total revenue minus transportation costs. This is not the total net income for the firm as other expenses are not accounted. This can be thought of as the gross margin above transportation costs. As will be discussed subsequently, for the purposes of this study other expenses are assumed to remain constant so are thus omitted at this stage.

The algebraic representation of the model is:

$$maximize\ Z = \sum_i \sum_j \left(A - B \cdot Y_{ij}\right) \cdot X_{ij}$$

Subject to:

$$\sum_j X_{ij} \le Supply_i \quad \forall\, i$$

$$\sum_i X_{ij} \le Capacity_j \quad \forall\, j$$

$$X_{ij} \ge 0 \;\; \forall\, i, j$$

where

i = index representing individual producers

j = index representing individual processors

A = revenue received from each truckload of eggs

B = cost per mile of transport for each truckload

X_{ij} = truckloads of eggs shipped from producer i to processor j

Y_{ij} = miles for the transportation route from producer i to processor j

$Supply_i$ = the truckloads of eggs available to be shipped by ith producer

$Capacity_j$ = the truckloads of eggs that can be accepted by jth processor

Parameter Estimates

The locations of individual farms located is proprietary knowledge, not available from a public database. To identify the *Yij* values inferred above, it is necessary to find some means to proxy for both farmer and producer locations. For farmer locations, USDA publishes census summaries of animal numbers for each state that is obtained through a survey process, but does not include a specific location of individual farms.

This problem can be overcome by the use of the Farm Location and Animal Population Simulator (FLAPS). With funding from USDA-APHIS and the US Food and Drug Administration (FDA) Burdett, Kraus, and Garza of the Colorado State University Biology Department have created at tool that uses available USDA Census of Agriculture data to simulate farm locations and populations of individual livestock farms (Kraus, 2015). This present research will make use of the FLAPS simulation program to synthesize estimates for the location of the turkey and laying hen farms in Minnesota. This simulation program makes use of the USDA population data to simulate the location of the farms and the population sizes. Running the simulator for the laying hens and the turkey populations of Minnesota resulted in latitude and longitude coordinates plus population sizes. FLAPS yielded an estimate of the Minnesota laying hen population being comprised of 79 operations that will be used through the remainder of this paper. Locations and flock sizes for these farms are reported in the Appendix Table A.2.

Egg processor locations are also not readily available through secondary data sources. Making use of internet searches, all egg processing firms in Minnesota were identified. Subsequently another set of searches was applied for each firm to identify addresses of physical presence. Google Maps was then used to identify the nature of the facility present at each address. Through this process, seven egg processing plant locations were identified.

The map depicted in Figure 3.1 depicts the geographic location of the laying hen farms and the egg processors. The green circles represent the location of the seventy-nine egg producers generated by FLAPS and the seven yellow squares are the location of the egg processors identified as described above. The average distance from each egg producer to their closest egg processor is 34 miles. The minimum and maximum distances from the producer to the nearest processor are 6 and 81 miles, respectively.

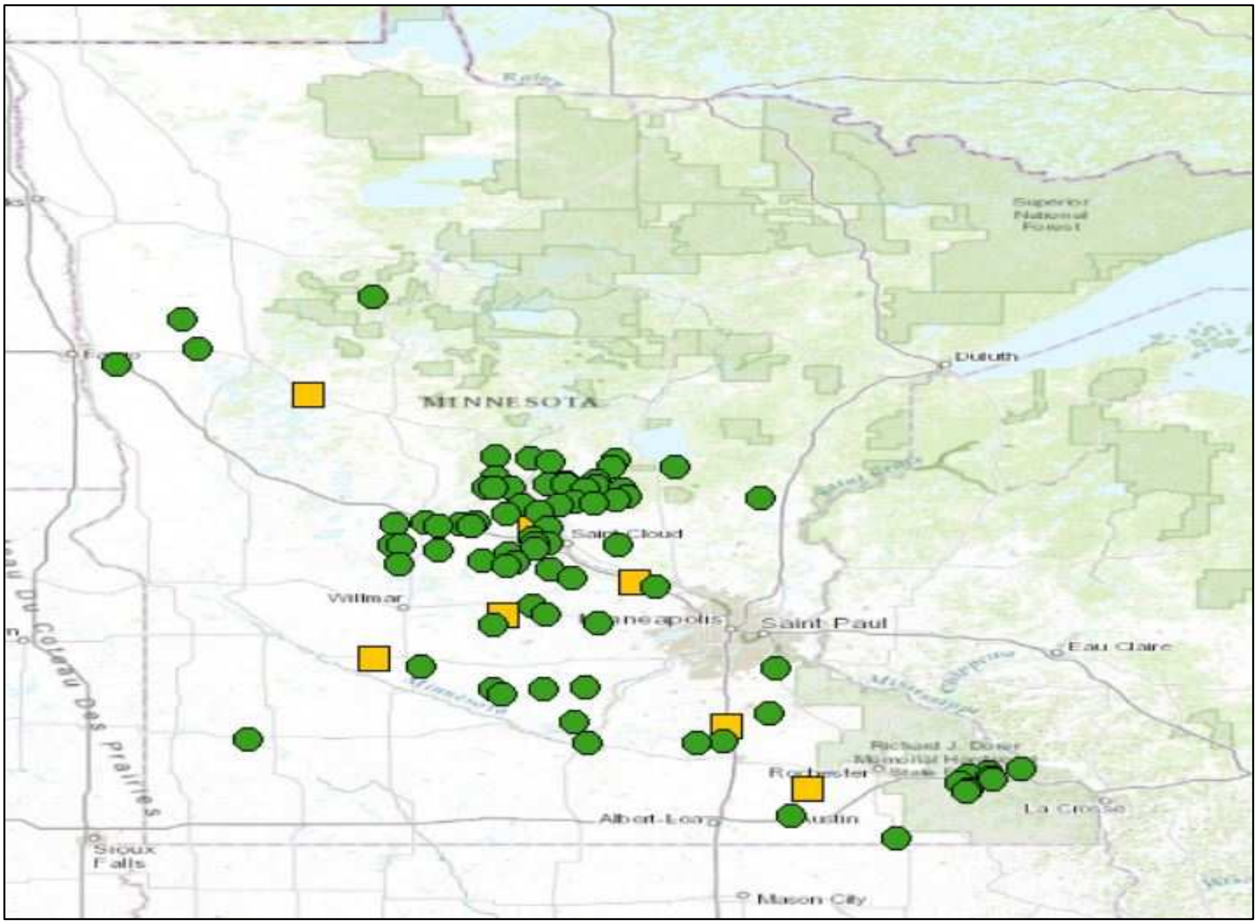

Figure 3.1. Map of Egg Producer and Processor Locations for Analytic Model

Egg Revenue and Transportation Costs.

The Minnesota egg price is needed when calculating the economic impact. The coefficient A in the objective function of the optimization model is the revenue received from each truckload of eggs. For the context of this research it is most appropriate to use a constant egg price when calculating the average net return of a firm. If the egg price during the time period changes, the resulting changes in re-routing around the control areas will include the changing price of eggs and would result in a misrepresentation of the firms' average profit. The price of eggs was determined by averaging the small, medium, and large eggs of prices paid to producers in Minnesota, Iowa, and Wisconsin during the 14-week period of the outbreak. The average was

110.5426 cents per dozen for this period (Economic Research Service). Converting the average price for a dozen eggs to the price per truckload is necessary to support the linear model chosen. Standard units of commerce in the industry are of 30 dozen eggs per case and 325 cases of eggs per truck (Christensen, 1980) yielding 9,750 dozen eggs per truckload, or 117,000 eggs. Each truckload of eggs is estimated to earn revenue of $10,777.91 for each producer.

The model also requires a measure of the number of truckloads of eggs that were available to ship from each producer. This is represented by the $Supply_i$ parameter vector in the first set of constraints. Each farm has a population of laying hens unique to that farm. On average, a laying hen will produce five eggs per week so weekly production per farm is simply the product of the hen population and five which is then transformed into a number of truckloads to be shipped.

The cost per mile for the transportation of eggs is another important factor to consider. In this research it was estimated that each truckload of eggs would incur a cost of $2.67 per mile. This value was obtained from the DAT solutions website for the National Reefer Rates during the time period. This rate, is a per mile contracted rate for the Midwest. The values are calculated using a database that is comprised of 24 billion in freight bills (DAT Solutions, n.d.). As a result, the coefficient *B* is $2.67

To obtain the values of coefficient *Y* for the model, a mileage matrix was created. The mileage matrix is the distance from each producer, *I,* to each processor, *j*. Using the ArcGIS software Network Analyst tool, the road mileage for each producer to each processor can be calculated. This was accomplished by first importing the latitude and longitude coordinates of each of the 79 producers and 7 processors identified above. The Network Analyst tool was then utilized to calculate the mileage from each producer to each processor. The resulting product was a seven by seventy-nine matrix of parameter values.

The only remaining set of parameters necessary for the model were the measures of the operating capacities of the seven processing firms ($Capacity_j$). The only information available regarding the plants was the geographic location. Assuming that the plants were best positioned to provide the greatest value to the producers in the region, one could surmise that transportation costs should be minimized for each producer. As such, the baseline solution was solved without this constraint activated. The resulting distribution of egg delivery to each of the seven egg plants then was assumed to represent the capacity available at that plant. While this assumption introduces some error in absolute terms, all subsequent analysis relies on relative comparisons to this baseline, greatly reducing the error in the final analysis.

Modeling Response to an Outbreak

Once the baseline scenario is modeled in the absence of HPAI, the model parameters can be adjusted to account for the changes in the supply of eggs and the transportation of eggs resulting from the HPAI outbreak. The primary impact in parameter space for an HPAI outbreak would be that the Y_{ij} values (the mileage matrix) would need to be updated to reflect the changes in available transportation routes as control areas are implemented.

When a poultry producer becomes infected with HPAI a control area is established relative to the premises. The area within three kilometers surrounding the infected farm is identified as an infected zone. In this zone there are movement and surveillance activities. In the three to ten kilometer perimeter area there are also movement controls and surveillance activities. This is called the buffer zone. In this zone there may be some movement with a permitting process. For this analysis there will be scenarios created to represent the impact of a movement-restricted zone in both the three kilometer and the ten kilometer area. Analysis in the cost of rerouting around the control area will be available to evaluate the impact of the movement restrictions.

As the control areas are implemented, the mileage from producer to processor will be recalculated to reroute around the control areas. This is accomplished by adding a restricted travel buffer area to the affected locations in the GIS software and rerunning the Network Analyst tool to create a new mileage matrix that will then be fed into the LP farm transport model. These buffer areas are a three or ten kilometer perimeter surrounding the affected firm. Each time period the mileage matrix is iterated and the Y_{ij} coefficient is updated.

In the face of an outbreak, the footprint of the disease impact changes across time. The maps presented in Figures 3.1 through 3.14 illustrate the dynamics of the 2015 HPAI outbreak in Minnesota. This illustration will allow for a visual understanding of the outbreak and disease movements starting with week 0 (Figure 3.1) when there is no outbreak present, moving each week to week 13. The yellow squares are the location of the processors, the green dots are the location of the producers. The pink and blue circles are centered on an infected farm location and represent the 3 kilometer and 10 kilometer potential control zones in each week.

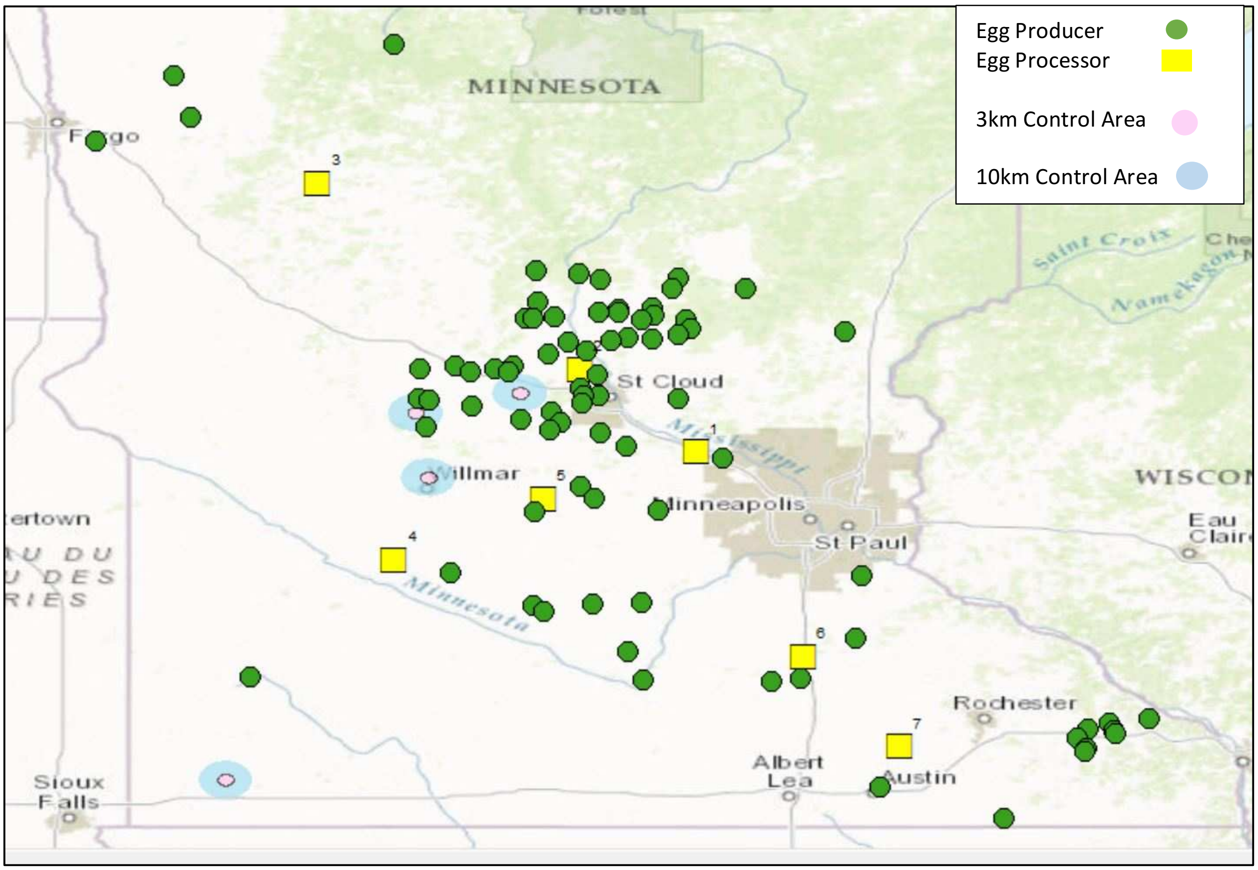

Figure 3.2. Map of Week 1 of HPAI Outbreak

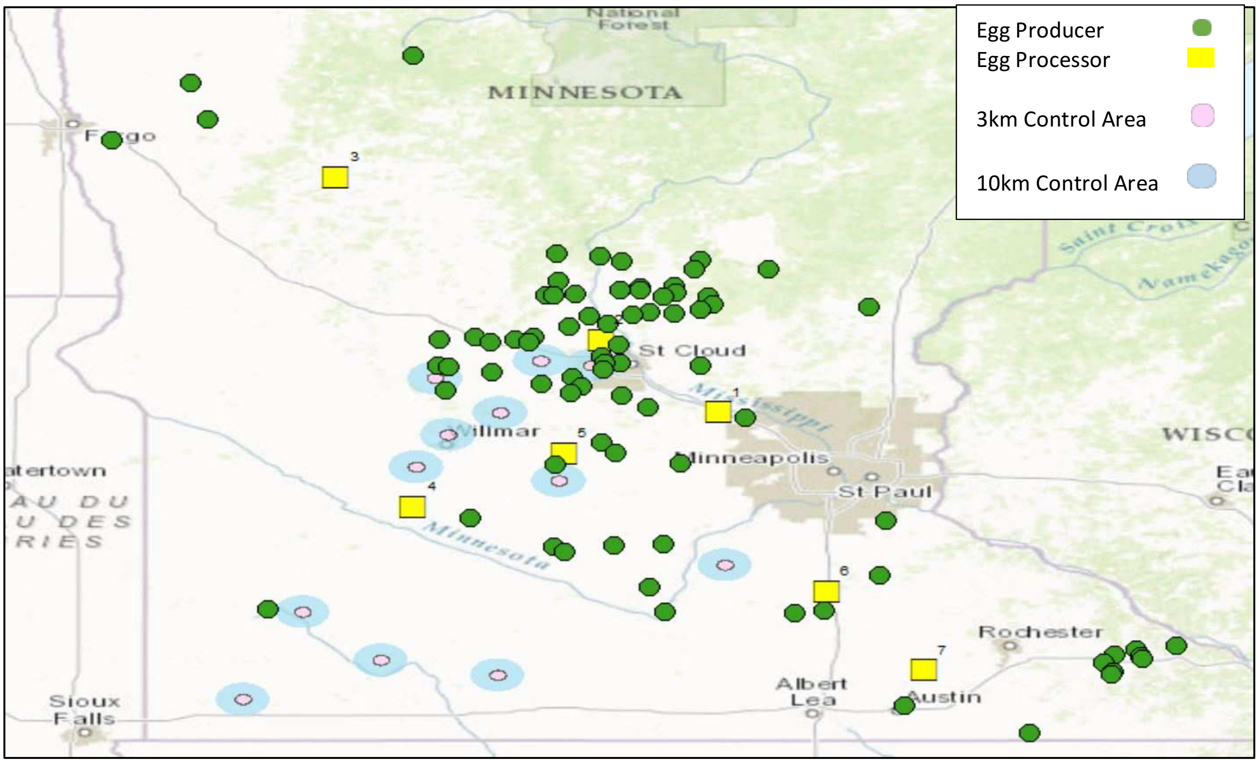

Figure 3.3. Map of Week 2 of HPAI Outbreak

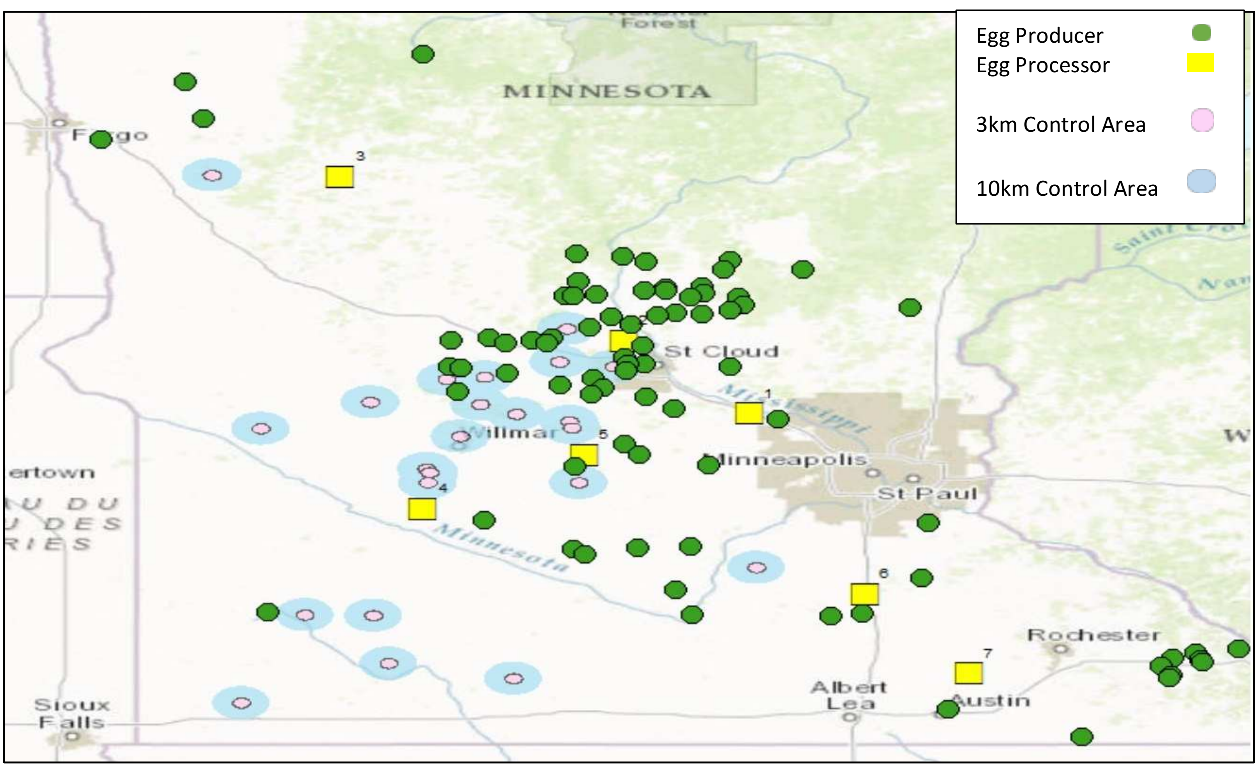

Figure 3.4. Map of Week 3 of HPAI Outbreak

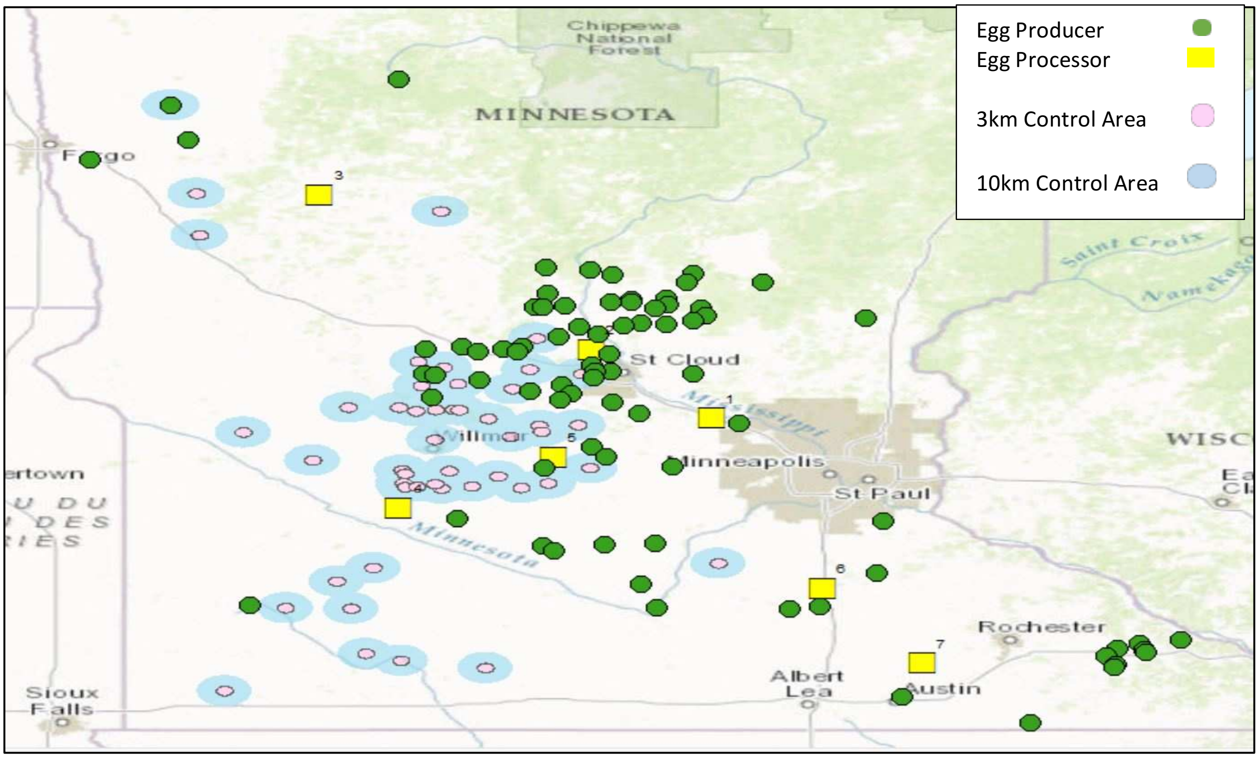

Figure 3.5. Map of Week 4 of HPAI Outbreak

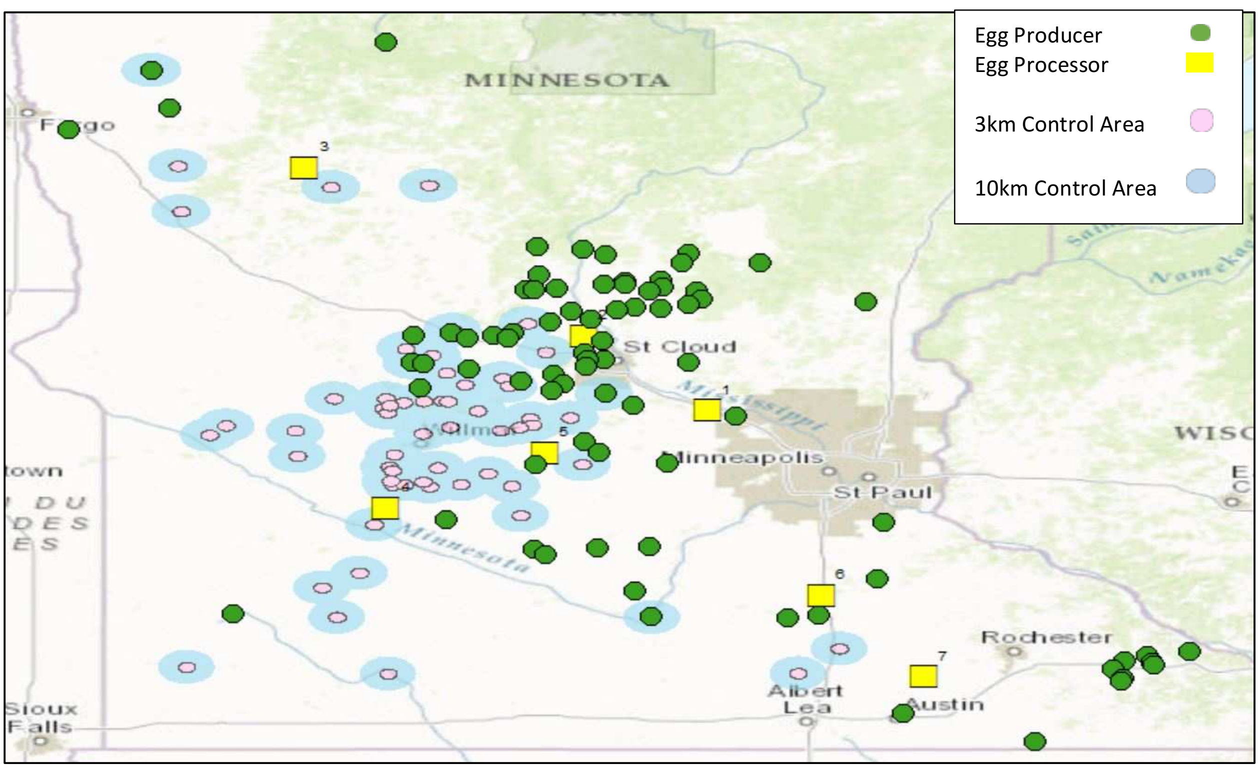

Figure 3.6. Map of Week 5 of HPAI Outbreak

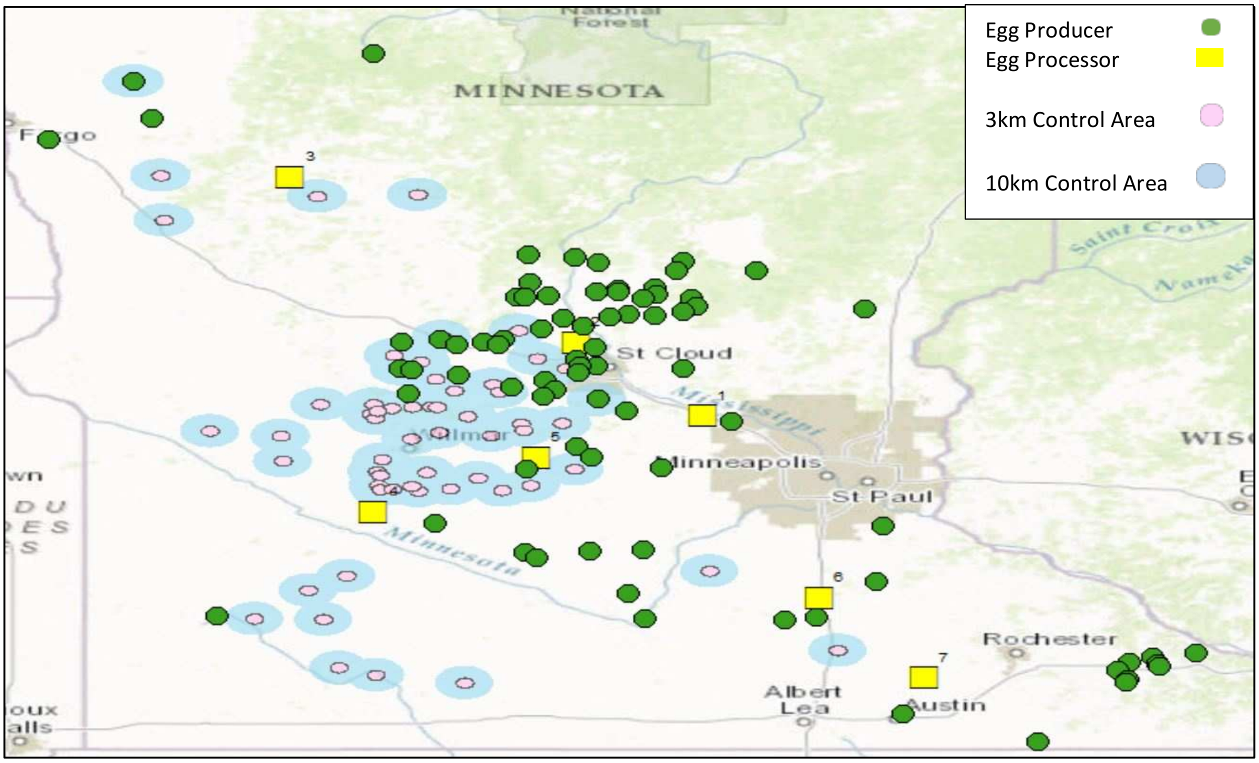

Figure 3.7. Map of Week 6 of HPAI Outbreak

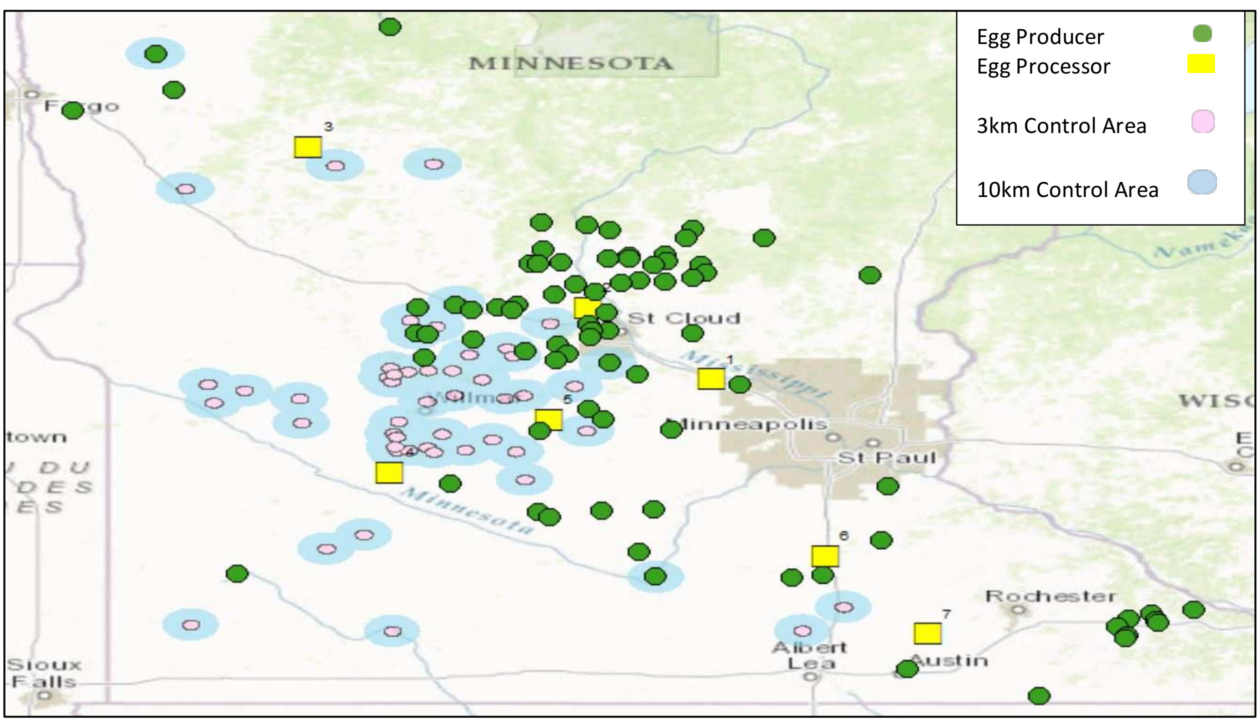

Figure 3.8. Map of Week 7 of HPAI Outbreak

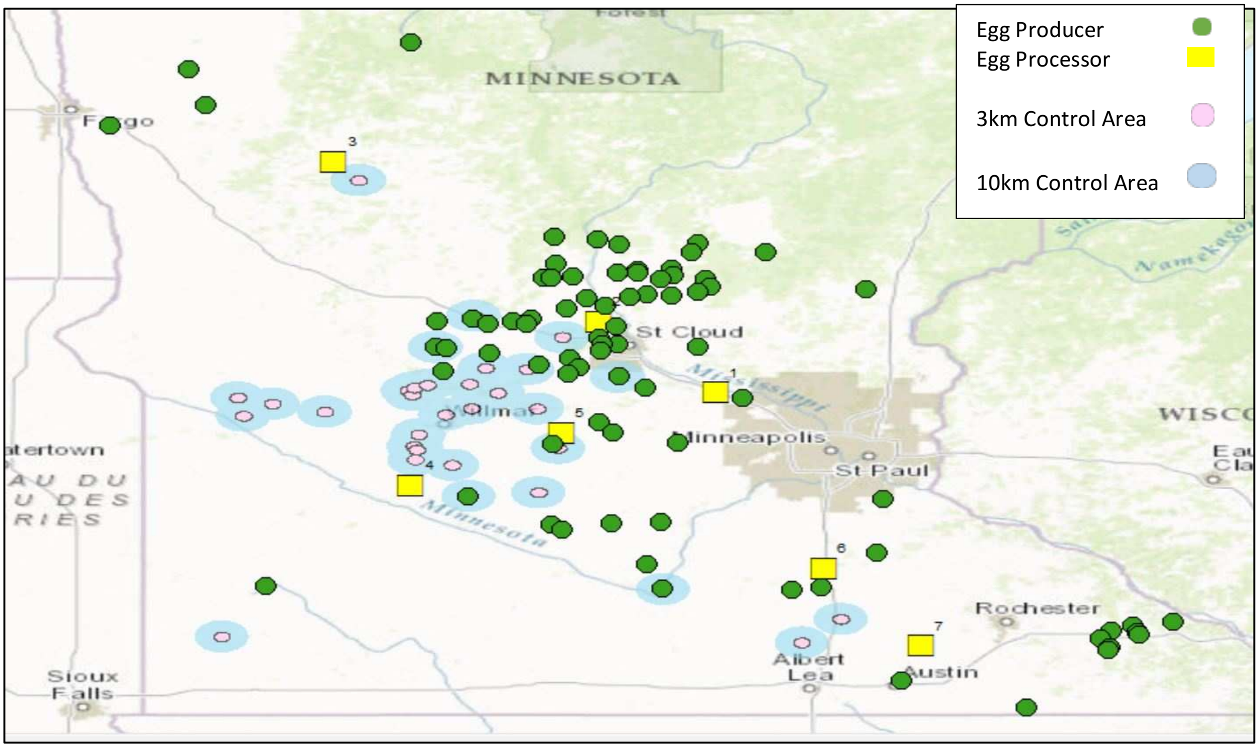

Figure 3.9. Map of Week 8 of HPAI Outbreak

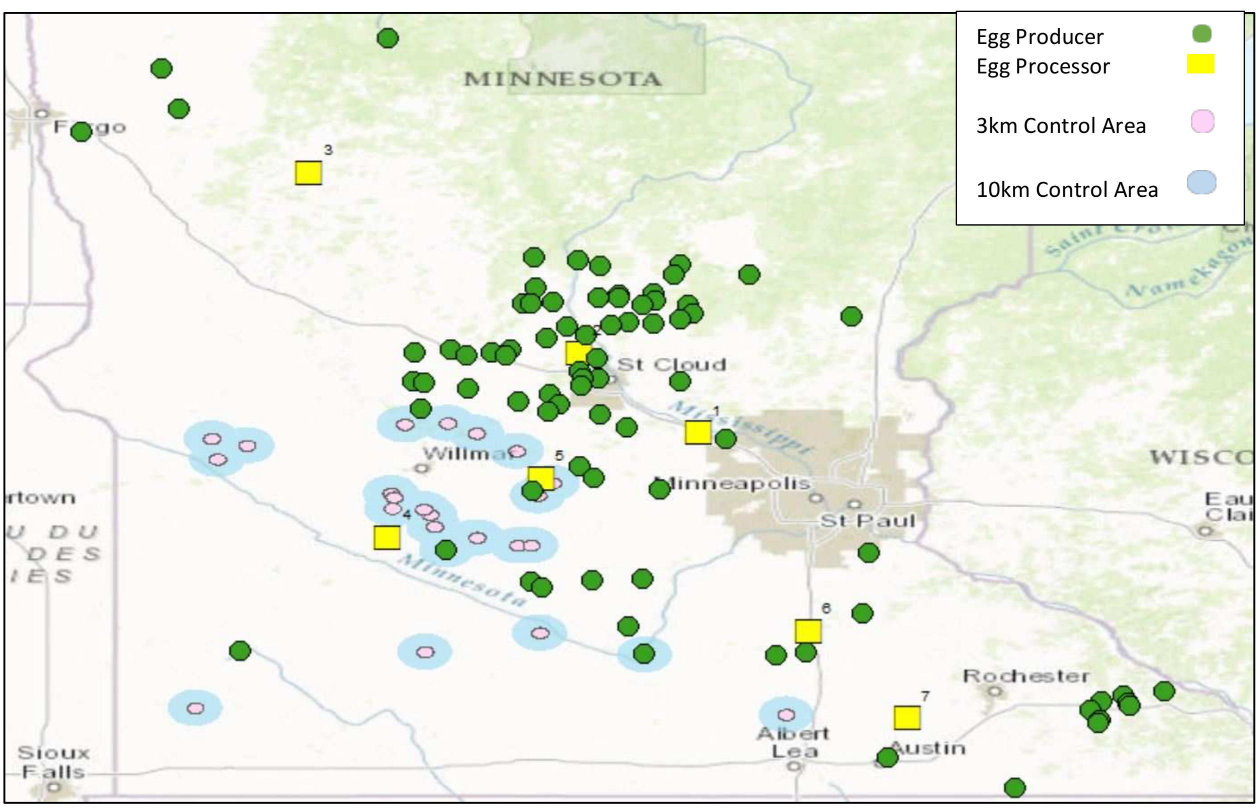

Figure 3.10. Map of Week 9 of HPAI Outbreak

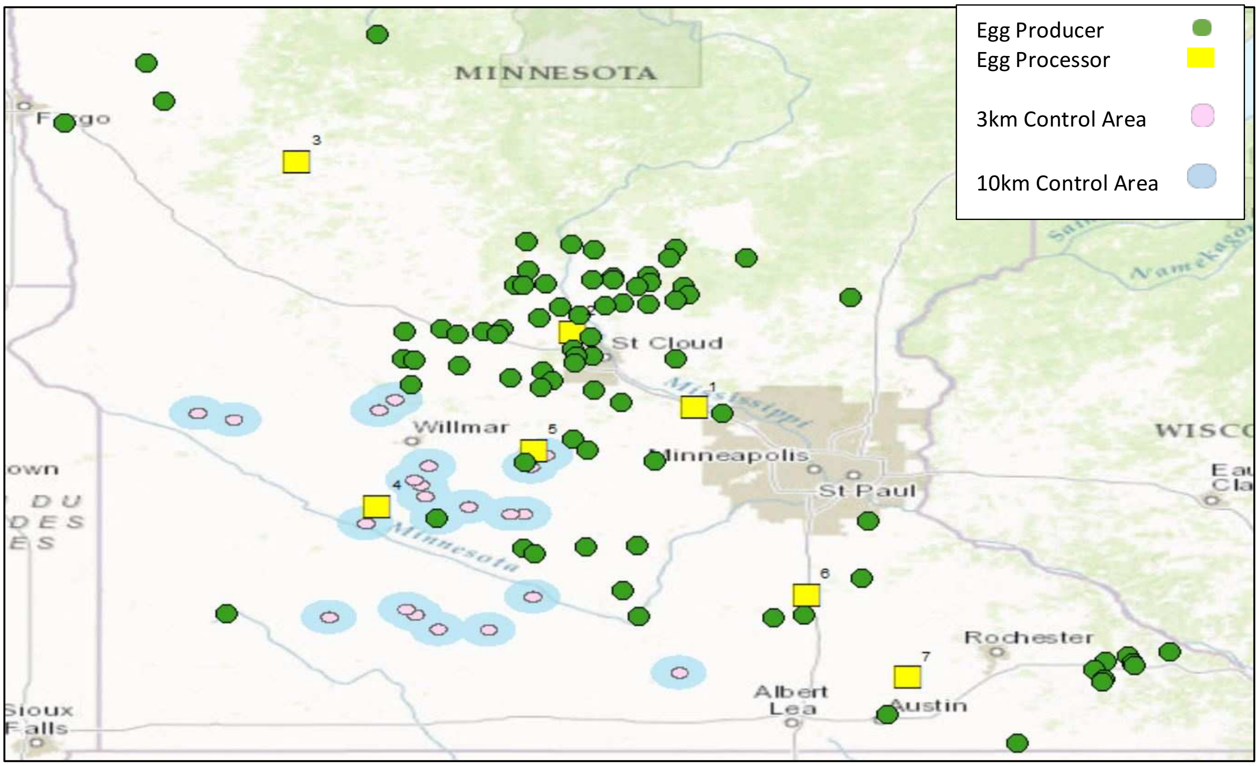

Figure 3.11. Map of Week 10 of HPAI Outbreak

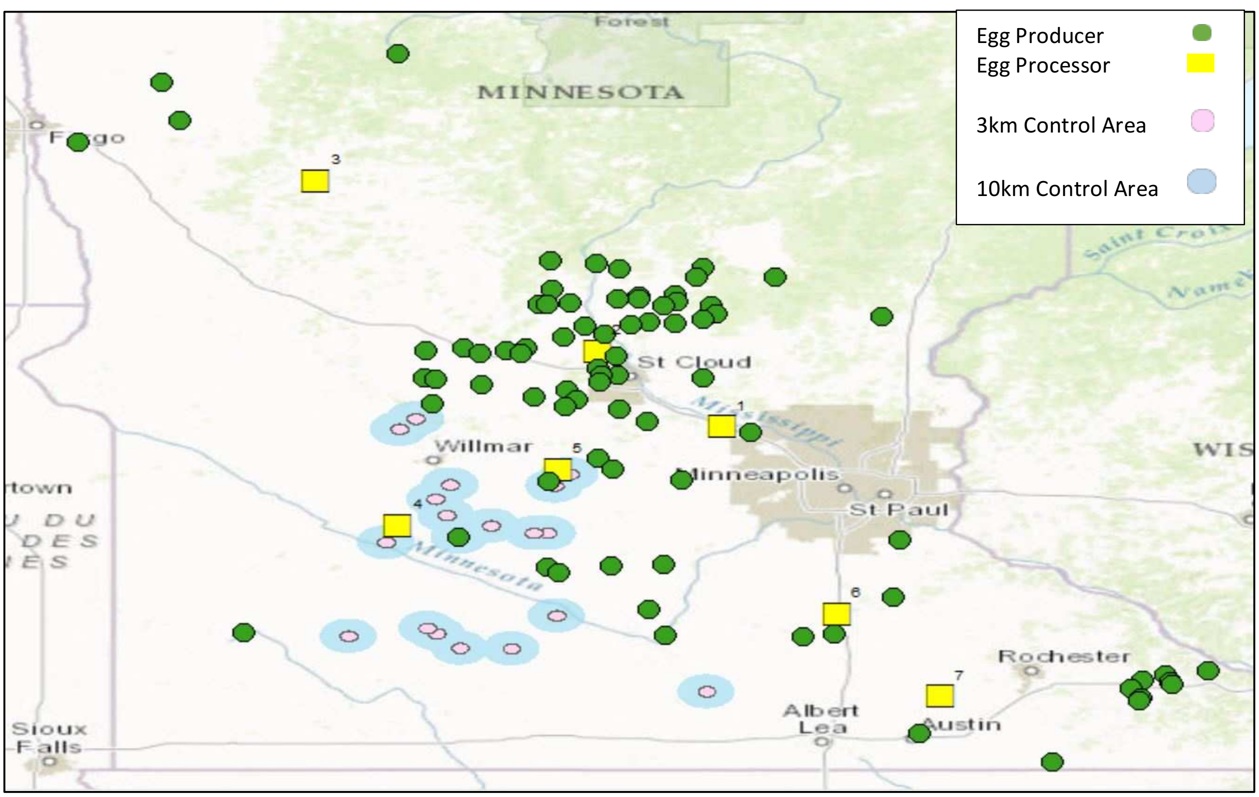

Figure 3.12. Map of Week 11 of HPAI Outbreak

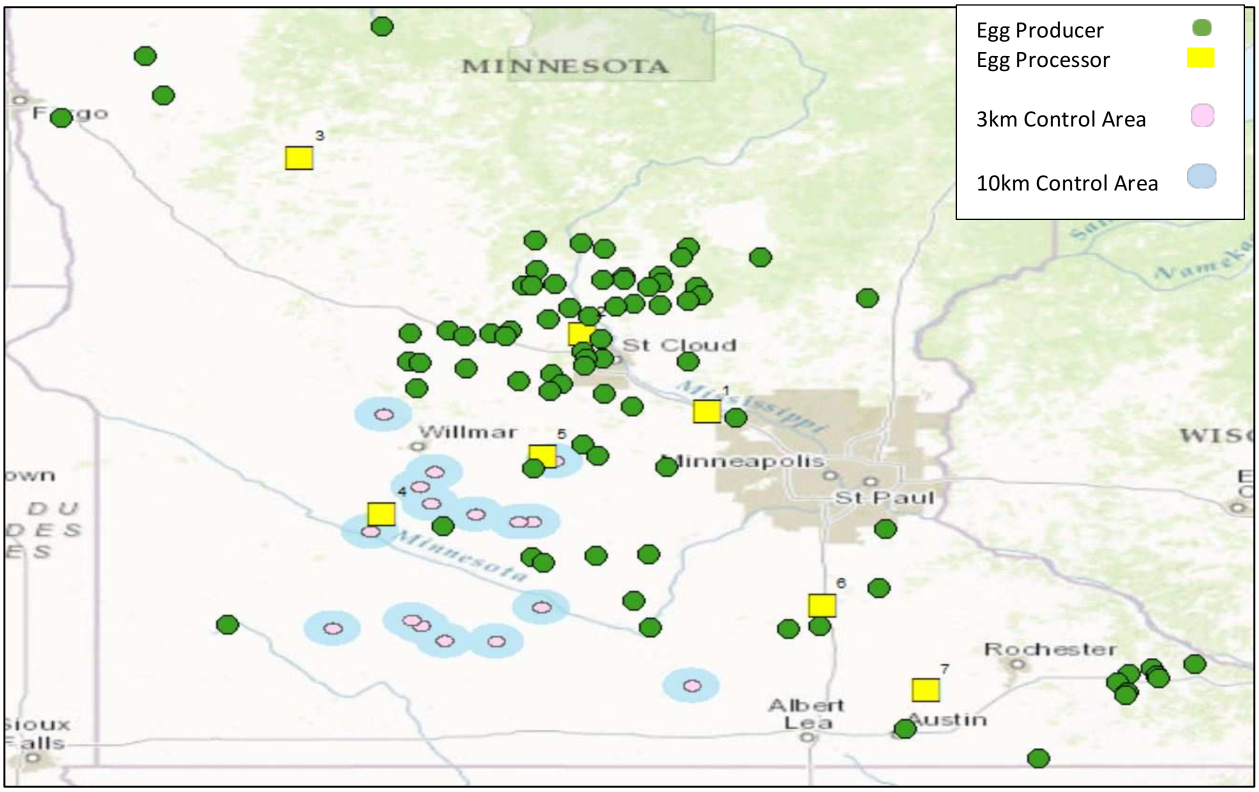

Figure 3.13. Map of Week 12 of HPAI Outbreak

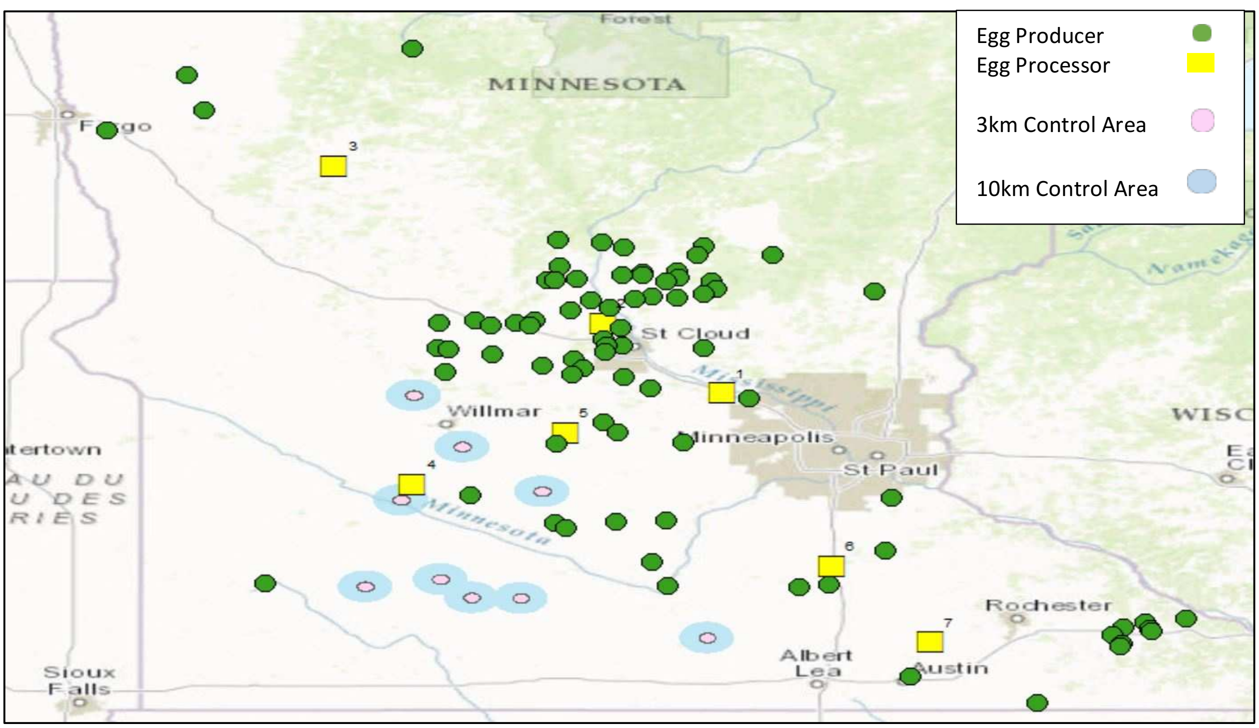

Figure 3.14. Map of Week 13 of HPAI Outbreak

As the location of the HPAI affected farms is not public knowledge, making use of the FLAPS data is necessary to accomplish analysis of the model. USDA APHIS publishes the county, date, production type, and population size of the affected farms. The complete list for Minnesota is located in the Appendix Table A.4. Comparing the FLAPS laying hen and turkey data to the APHIS HPAI confirmed detection data to locate the infected firms will allow the locations of the control areas to be modeled.

First, the FLAPS data is in a latitude and longitude format. The US Federal Communications Commission has an application program interface (API) that allows for a user to input a latitude and longitude coordinates and the county name will be returned. All 79 laying hen farms and 412 commercial turkey farms from the FLAPS simulation was entered and converted to a county value (Census Block Conversions API, 2015). The county level data was compared to the APHIS confirmed case data. Finding the matching county level to the closest population size and population type resulted in a converted FLAPS farm now becoming the designated infected farms. Once designated an affected farm, the farm was deemed affected for a four-week period. This is one week for notification of authorities and sanitization, plus the three-week requirement of the OIE. The assumption that all affected farms will follow the sanitization processes required will be enacted. The first two confirmed cases of HPAI and the April 22, 2015 case were not included. The locations of these farms are in Pope, Lac Que Parle, and Pipestone counties and were not in the area of the model populations, thus had no effect on laying hen farms. Figure 3.15 illustrates the number of control areas that were in place for each week of the outbreak. During week one there are four affected farms. These farms are then affected for the next four weeks. The number of control areas reached its peak at 64 in week 6.

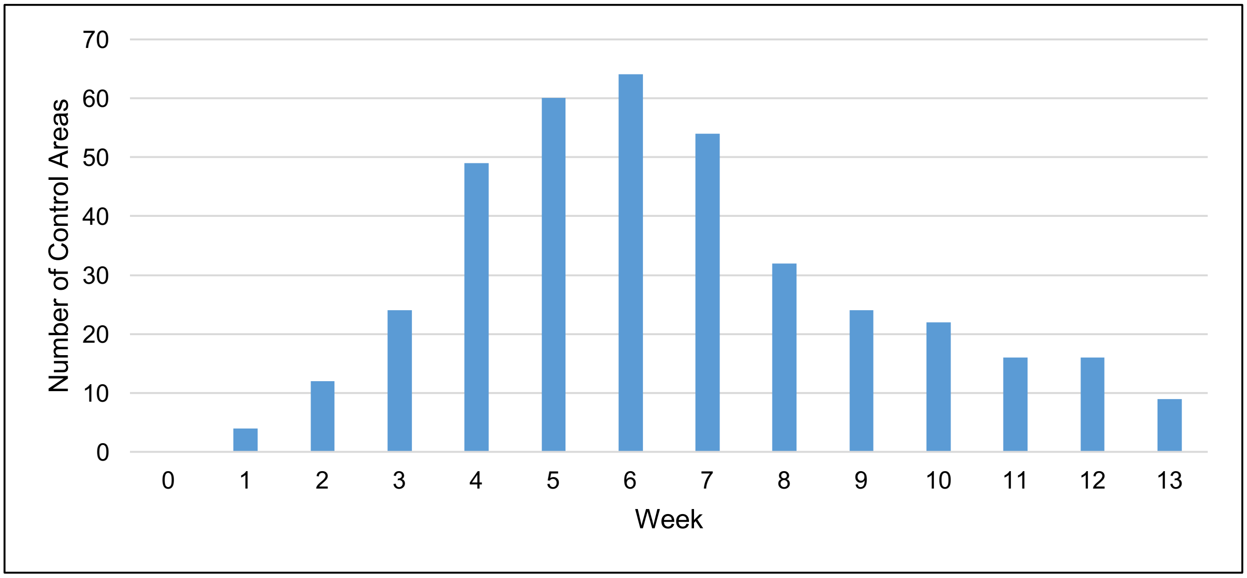

Figure 2.15 Number of Control Areas per Week of 2015 Minnesota HPAI Outbreak

For the modeling in this research project, the control areas are separately represented using a three kilometer and ten kilometer radius around the infected farm. Once a control area is in place all travel is restricted inside the control area and all farms that are not directly affected by HPAI, yet still in a control area are considered “restricted travel”. This meets the general guidelines to prevent the spread of HPAI to nearby farms.

HPAI affected turkey farms as well as laying hens. When a turkey farm is affected the control area for the turkey operation results in travel restrictions for the transport of egg products as well as operations for egg producers and processors that are located within the control areas. Thus it was necessary to represent incidents at turkey farms to be able to accurately model the outbreak. Using the location of affected turkey farms, respective control areas are identified and implemented in the same manner as for the laying hen farms described previously. The FLAPS turkey simulation results used to identify these additional control areas is reported in Appendix Table A.3.

Once an egg producer is inside the perimeter of a control area, or is deemed an affected farm, the supply of eggs that is available from that farm is zero, and will remain zero for the four-week period. This will be an adjustment of the parameter $Supply_i$. After four weeks, production levels will return to the original production levels.

While a least cost model could be appropriate here, especially if contracting were heavily used, it was not chosen because the demand of each processor is not known. At the baseline condition when before the outbreak (always depicted in the model as Week Zero) each individual farm's production is delivered to their least costly processor. This is an assumption that the market is at equilibrium and the production capacity at each processor is met at the optimum.

A scenario where the level of demand at each processor is no more than the optimum value will be evaluated as well as when the demand at the processor can vary based on the level supplied. Another scenario will be analyzed when at the baseline the producer is under contract for a given processor and will be required to ship eggs to the same processor each week regardless of transportation costs. Varying the scenarios will give a broader view of the industry and allow for comparisons between an open market, a demand market, and a contracted market.

CHAPTER 4. RESULTS

The purpose of this research is to determine the transportation cost impacts to Minnesota egg producers as a result of the 2014-2015 HPAI outbreak. To accomplish this, the base model outlined in Chapter 3 was formulated and solved using the GAMS mathematical programming software platform. Looping features in GAMS were used to run the model iteratively to solve the transportation model for each week of the outbreak period where the model parameters were systematically updated to reflect the changing geographic distribution of infected farms each week. Several versions of the model were developed to reflect differences in both processor demand and variations on outbreak controls.

In this chapter, first the base model that was used to characterize the pre-outbreak situation will be discussed. Next, the HPAI outbreak models will be explored. The HPAI outbreak models will be divided in to two sections, the three kilometer models and the ten kilometer models. Within each of these sections there will be an evaluation of open market access to egg processors, a case where producers are free to ship where they like but processors have an effective limit on their capacity, a demand model, and finally a situation where egg producers are bound to deliver eggs to a given processor due to an enforced contract. Finally, costs that are associated with transportation will be discussed.

Base Model

In the base model, seventy-nine egg producers are shipping their supply of eggs to the seven processors. Absent HPAI, the producers ship to the processor that maximizes total industry profit. The total industry profit, the number of truckloads shipped to each individual processor from each individual producer are reported. This allows the determination of total industry profit, individual producer profit, and the truckloads received for each individual producer.

Week 0 is the circumstance when there is no reported HPAI in Minnesota as represented by the base model scenario. The results for this base model result in allocation of producers and their respective production as summarized in Table 4.1. After the first iteration, the distribution of eggs to the processors is now considered the equilibrium level. At this equilibrium, 42 producers ship eggs to producer 2. These 42 producers account for 19 percent of all eggs available. 19 percent is 10.9 million eggs per week. Processor 7 accounts for 1 percent of the weekly eggs available or 384 thousand eggs.

At the equilibrium level, there are 58 million eggs that are produced each week. The total industry revenue for the base model is $5,298,296. Table 4.2 shows the equilibrium revenue for each of the 79 individual producers. Producer 79 is the largest producer with weekly revenue of almost a million dollars. There are 16 producers with over $100,000 in weekly revenue. Six producers that have weekly revenues between $50,000 and $100,000, and the remaining 57 have revenue of less than $50,000.

Table 4.1. Equilibrium Processor Allocation of Egg Production

	Processor						
	1	2	3	4	5	6	7
Producer count	5	42	4	3	8	7	10
% of Eggs	15%	19%	14%	24%	6%	22%	1%
Truckloads	73.59	93.42	67.3	119.39	32.12	106.87	3.28

Table 4.2 Revenue per Producer at Solution for Equilibrium Base Scenario

Producer	Revenue	Producer	Revenue	Producer	Revenue
1	$219,635.18	28	$5,327.59	55	$4,707.00
2	$201,886.21	29	$5,602.38	56	$6,033.63
3	$145,725.48	30	$8,194.29	57	$61,877.25
4	$147,749.12	31	$79,359.03	58	$82,228.66
5	$705.27	32	$5,639.75	59	$22,931.85
6	$520.96	33	$7,202.86	60	$7,168.83
7	$31,439.23	34	$5,662.68	61	$9,694.28
8	$7,260.98	35	$14,109.50	62	$15,725.86
9	$34,816.16	36	$221,173.91	63	$4,691.56
10	$147,192.08	37	$273,696.69	64	$4,717.38
11	$94,895.10	38	$116,554.29	65	$4,682.25
12	$5,540.16	39	$1,048.83	66	$4,931.52
13	$5,555.65	40	$747.30	67	$6,618.54
14	$5,565.80	41	$1,041.84	68	$7,472.69
15	$75,708.75	42	$273,138.28	69	$3,464.24
16	$5,580.93	43	$639,350.26	70	$3,495.23
17	$4,899.77	44	$827.17	71	$3,122.55
18	$5,561.40	45	$309,216.28	72	$497.63
19	$5,706.68	46	$139,531.43	73	$2,330.42
20	$147,118.57	47	$11,992.17	74	$3,465.19
21	$5,599.24	48	$117,444.92	75	$3,489.87
22	$5,937.01	49	$73,142.62	76	$544.99
23	$4,658.15	50	$6,752.36	77	$391,046.04
24	$6,346.79	51	$30,806.37	78	$642.70
25	$5,596.46	52	$4,702.71	79	$938,453.16
26	$5,583.11	53	$4,776.35		
27	$8,471.23	54	$11,965.06		

Three Kilometer Models

The first set of results all apply to a circumstance control area when a three kilometer radius is imposed around infected farms as the outbreak progresses. For the modeling this means that no egg transportation will be allowed in these areas.

OPEN Model

The first model that will be analyzed will be a three kilometer control area with open demand and no contracts. This is the OPEN Model. As the control areas are placed throughout the 13-week period. The processor is free to ship to any producer and there is no demand level restriction, such as a minimum or maximum demand. The constraint that will be in place will be that no more than available eggs can be shipped. This will be an objective maximizing model. Solving the model iteratively for each of the 13 weeks with the mileage matrix (Y_{ij}) updated to reflect the changing control areas yields weekly net return values that can be compared to estimate the costs associated with HPAI. When an egg producer is inside the control area, the supply level ($Supply_i$) for the affected producer will be set to zero. This is as a result of either the firm being directly affected with HPAI or the firm is within the control area perimeter and thus travel restricted.

At the pre-outbreak equilibrium, industry total net return is approximately 5.3 million dollars. Figure 4.1 shows the change in industry profit and the number of control areas that are in place for each week. The first major decrease in of industry returns is evident in Week 4. Week 4 brings an industry loss of $201,826. While the first three weeks have control areas in place, this is the first week that a producer is inside a control area and as a result has an egg supply of zero. In total there are 24 control areas in place in Week 4. Weeks 6 and 7 show a loss of $681,900 and $681,905, respectively. The week that had the greatest loss of industry profit was Week 8, which lost 1.565 million dollars. With the three kilometer control area put in place the 14-week period saw a decrease of industry profit of approximately $7.07 million with the OPEN model. This decrease in profit is due to the loss of eggs as well as the increased transportation costs.

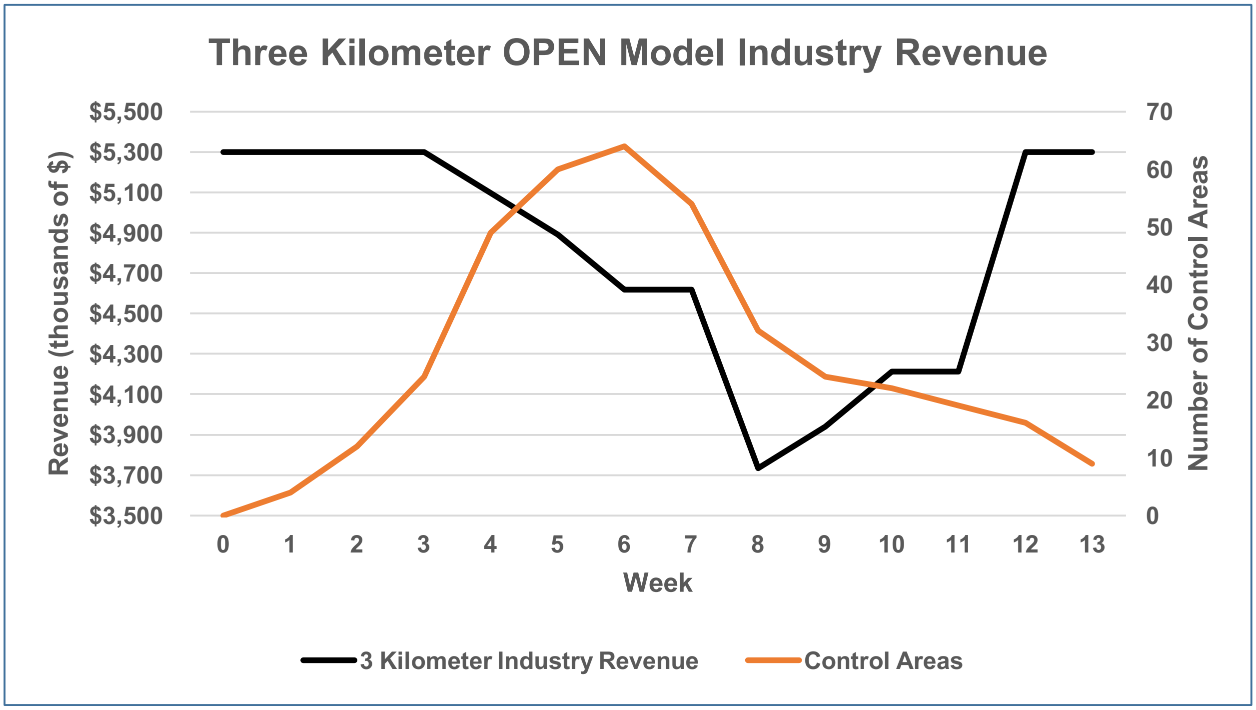

Figure: 4.1 Three Kilometer OPEN Model Industry Revenue

In each of the models, except the contract model, the producers are allowed to ship eggs to the least cost destination. Table 4.3 shows the number of truckloads shipped each week to each of the seven processors under the OPEN model. The HPAI-Free row is calculated by multiplying Week Zero by 14. That result would give us the value (equilibrium revenue) if the control areas where not put into place. Two of the processors (1 and 7) saw an increase in truckloads received, the other five saw a decrease. Processor 4 is the largest processor and saw the largest decrease of truckloads received.

Figure 4.3. Three Kilometer OPEN Model Truckloads Received

Week	Processer 1	Processor 2	Processor 3	Processor 4	Processor 5	Processor 6	Processor 7
0	73.59	93.42	67.30	119.39	32.12	106.87	3.28
1	73.59	93.42	67.30	119.39	32.12	106.87	3.28
2	73.59	93.42	67.30	119.39	32.12	106.87	3.28
3	73.59	93.88	67.30	119.39	31.66	106.87	3.28
4	73.59	93.88	48.30	119.39	31.66	106.87	3.28
5	73.59	74.98	48.30	119.39	31.22	106.87	3.28
6	73.59	74.98	48.30	119.39	31.22	81.18	3.28
7	73.59	74.08	48.30	119.39	32.12	81.18	3.28
8	74.59	76.08	70.30	49.08	10.33	87.18	10.28
9	73.59	93.42	67.30	45.08	5.33	81.18	3.28
10	73.59	93.42	67.30	45.08	5.33	106.87	3.28
11	73.59	93.42	67.30	45.08	5.33	106.87	3.28
12	73.59	93.42	67.30	119.39	32.12	106.87	3.28
13	73.59	93.42	67.30	119.39	32.12	106.87	3.28
Sum	1031.27	1235.27	869.23	1378.22	344.80	1399.42	52.97
HPAI-Free	1030.27	1307.90	942.23	1671.48	449.66	1496.15	45.97
Difference	1.00	-72.64	-73.00	-293.27	-104.86	-96.73	7.00

For the three kilometer OPEN model, on average the producers lost $89,497.20 during the 14-week period. The producer that lost the most money lost $3,753,812.60. In total 26 producers were affected in the OPEN model scenario. Table 4.4 shows the changes in revenue for the producers that were affected during the outbreak. The loss to the producers is the loss of the eggs as well as the cost of transportation.

Table 4.4. Three Kilometer OPEN Model Producer Revenue Change

Producer Index	More Than 1,000,000	$500,000- $999,999	$10000 - $499,999	$0 - $9,999	Positive $
1		$ (807,544.81)			
2				$ (2.37)	
3				$ (41.45)	
4		$ (588,768.33)			
5					$ 0.61
6					$ 3.41
7	$ (1,094,786.76)				
8				$ (5.17)	
9				$(108.09)	
10				$ (92.22)	
11			$ (469,653.39)		
12					$ 0.01
13				$ (65.34)	
14					$ 15.56
15				$ (0.22)	
16					$ 2.45
17			$ (328,914.46)		
18					$ 0.12
19				$ (0.18)	
20					$ 0.03
21				$ (5.03)	
22					$ 0.01
23				$ (14.55)	
24				$ (12.08)	
25			$ (26,474.16)		
26	$ (3,753,812.63)				
Average	$ (2,424,299.69)	$ (698,156.57)	$ (275,014.00)	$ (31.52)	$ 2.78

CONTRACT Model

The three kilometer CONTRACT model is scenario that does not allow the egg producer to choose the processor to whom they will be shipping their eggs. As there is vertical integration in the egg industry or producers may want to take advantage of contracts or forward pricing, this is one way that this scenario can be modeled. Once the producer ships to the processor in the equilibrium baseline scenario this will be the processor that the producer must ship to for the rest of the planning horizon. This is the model that will give the transportation costs as the only variable is the mileage matrix. As this is a common practice in the industry, rather than taking a spot price for the eggs the processor may contract a producer for a set time period and set price, it may well represent some dimensions of reality better than other approaches.

The first week to see a significant decrease in revenue is Week 4, which saw a decrease in revenue of $201,826. Just as the previous model, Week 8 saw the biggest decrease, totaling $1.565 million. Figure 4.2 show the industry revenues for each week. When in Week 6 and there are 64 control areas present in the state, industry revenue is at is at $4.616 million. In Week 8 and industry revenue is at the lowest point of $3.732 million there are 32 control areas in place. That is half of the control areas of when they are at the peak. This suggests that location of control area is more of a factor than amount of control areas.

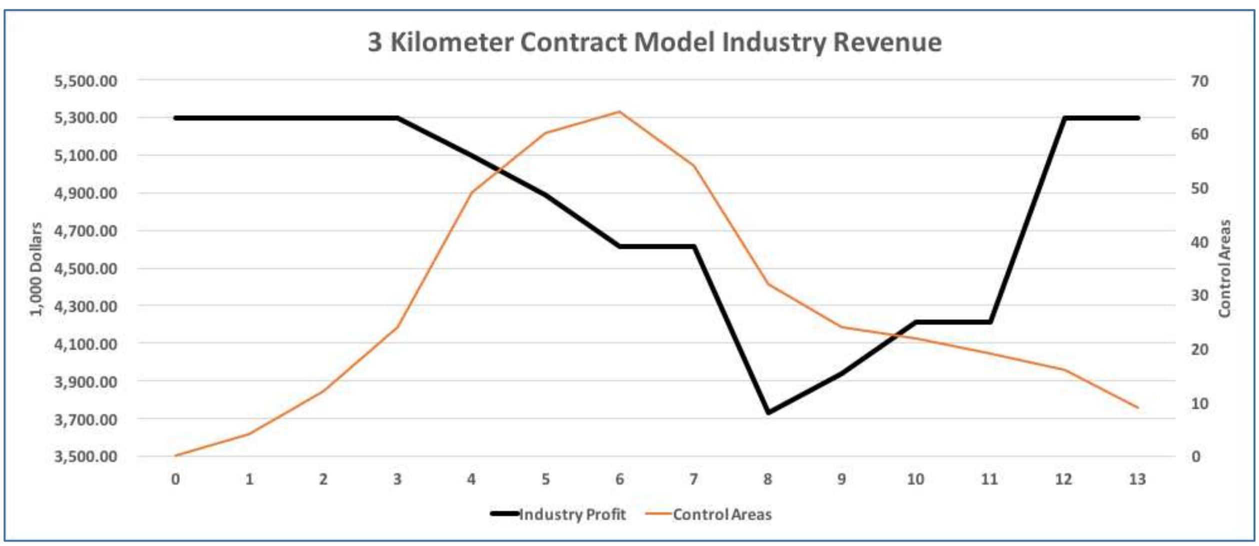

Figure 4.2 Three Kilometer CONTRACT Model Industry Revenue

One of the pieces of information the CONTRACT model will give us is the number of truckloads lost over the whole study period. As the producers are restricted to one processor, the HPAI-Free, the difference in HPAI-Free and actual values will result in the loss due to HPAI and control areas for each processor, as the producers cannot switch processors during the time period. Table 4.5 shows the results for the processors for the 14-week period. Just as in the OPEN model, Processor 4 suffered the most loss. This is as the result of one large producer being infected with HPAI and a control area enacted.

In the three kilometer DEMAND model 52 producers were affected. Table 4.6 shows the producer level effects of the control areas for the CONTRACT model iteration.

Table 4.5. Three Kilometer Contract Model Truckloads Received

Week	Processor 1	Processor 2	Processor 3	Processor 4	Processor 5	Processor 6	Processor 7
0	73.59	93.42	67.30	119.39	32.12	106.87	3.28
1	73.59	93.42	67.30	119.39	32.12	106.87	3.28
2	73.59	93.42	67.30	119.39	32.12	106.87	3.28
3	73.59	93.42	67.30	119.39	32.12	106.87	3.28
4	73.59	93.42	48.30	119.39	32.12	106.87	3.28
5	73.59	74.08	48.30	119.39	32.12	106.87	3.28
6	73.59	74.08	48.30	119.39	32.12	81.18	3.28
7	73.59	74.08	48.30	119.39	32.12	81.18	3.28
8	73.59	74.08	67.30	119.39	18.44	81.18	3.28
9	73.59	93.42	67.30	31.97	18.44	81.18	3.28
10	73.59	93.42	67.30	31.97	18.44	106.87	3.28
11	73.59	93.42	67.30	31.97	18.44	106.87	3.28
12	73.59	93.42	67.30	31.97	32.12	106.87	3.28
13	73.59	93.42	67.30	119.39	32.12	106.87	3.28
Sum	1030.27	1230.55	866.23	1321.81	394.93	1393.42	45.97
HPAI-Free	1030.27	1307.90	942.23	1671.48	449.66	1496.15	45.97
Difference	0.00	77.36	76.00	349.68	54.73	102.73	0.00

Table 4.6. Three Kilometer CONTRACT Model Producer Revenue Change

Producer Index	More Than 1,000,000	$500,000- $999,999	$10000 - $499,999	$0 - $9,999	Positive $
1				(0.01)	
2		(807,544.54)			
3					0.11
4				(0.08)	
5					0.05
6				(2.38)	
7				(41.42)	
8		(588,768.22)			
9					0.15
10				(0.09)	
11					0.01
12				(0.01)	
13				(0.01)	
15					0.13
16					0.61
17					3.42
18					0.02
19				(0.01)	
20					0.01
22				(0.01)	
23					0.01
24				(0.42)	
25	(1,094,786.74)				
26				(0.02)	
27				(0.58)	
28				(0.86)	
29				(5.17)	
30				(108.41)	
31				(890.64)	
32			(469,653.29)		
33					0.03
34				(65.33)	
35					15.54
36				(0.21)	
37					2.45
38					0.02
39				(0.01)	
40			(328,914.46)		
41					0.12
42				(0.01)	
43				(0.19)	
44					0.01
45				(9.34)	
46					0.02
47				(14.54)	
48				(13.28)	
49			(26,474.16)		
50					0.01
51					0.52
52	(3,753,812.48)				
Average	(2,424,299.61)	(698,156.38)	(275,013.97)	(48.04)	1.22

Demand Model

The third, 3 kilometer model that was formulated was a DEMAND model. The DEMAND model implies that the processor cannot accept more eggs than the amount received when at the equilibrium level in Week Zero. This model suggests that the processor is running to capacity and has no room for excess processing in the short run. In the long run, the processor may be able to adjust their resources to accept more product, but the resources are fixed in the short run.

During the 14-week period of the HPAI outbreak the total loss of revenue from the DEMAND model was $7.07 million dollars. Figure 4.3 shows the industry revenue for the time period as well as the control areas. As expected the in industry revenue reached its lowest level of $3.732 million in Week 8.

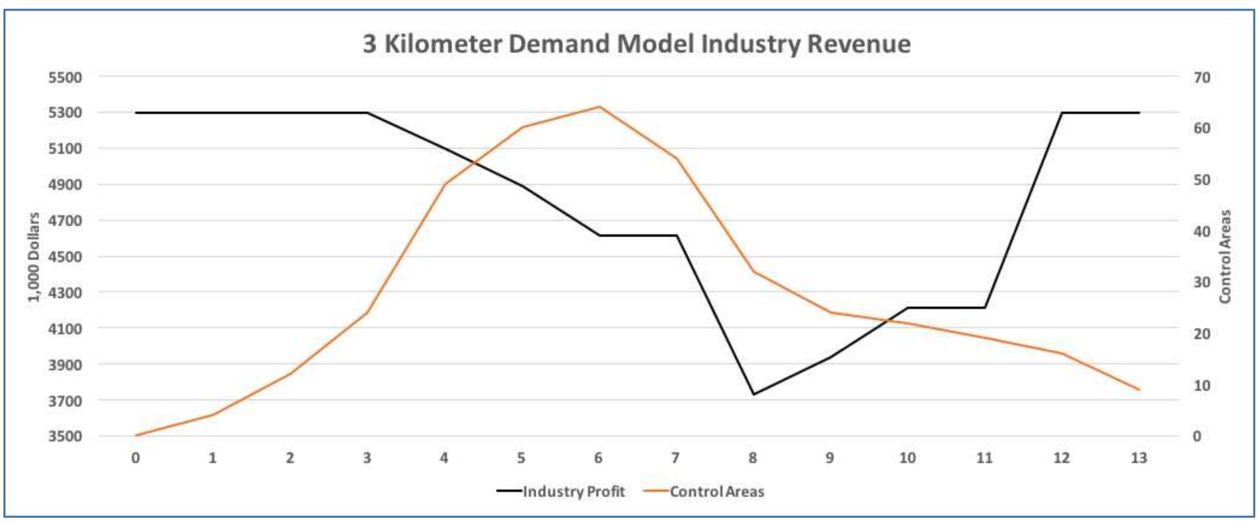

Figure 4.3. Three Kilometer DEMAND Model Industry Revenue

The three kilometer DEMAND model implies that each processor is running at capacity. In the short run, the resources are fixed and the processor is not able to make adjustments to its resources to accept the excess supply. The quantity of eggs processed at the optimum (Week 0) cannot be exceeded for the 14-week time period. In this scenario Processor 4 had the most loss of production for the outbreak time period. Processor 1 and 7 had no effect and Processors 2-6 all had significant losses in truckloads received.

Table 4.7. Three Kilometer DEMAND Model Truckloads Received

Week	Processor 1	Processor 2	Processor 3	Processor 4	Processor 5	Processor 6	Processor 7
0	73.59	93.42	67.30	119.39	32.12	106.87	3.28
1	73.59	93.42	67.30	119.39	32.12	106.87	3.28
2	73.59	93.42	67.30	119.39	32.12	106.87	3.28
3	73.59	93.42	67.30	119.39	32.12	106.87	3.28
4	73.59	93.42	48.30	119.39	32.12	106.87	3.28
5	73.59	74.98	48.30	119.39	31.22	106.87	3.28
6	73.59	74.98	48.30	119.39	31.22	81.18	3.28
7	73.59	74.08	48.30	119.39	32.12	81.18	3.28
8	73.59	74.08	67.30	45.08	5.33	81.18	3.28
9	73.59	93.42	67.30	45.08	5.33	81.18	3.28
10	73.59	93.42	67.30	32.41	18.00	106.87	3.28
11	73.59	93.42	67.30	45.08	5.33	106.87	3.28
12	73.59	93.42	67.30	119.39	32.12	106.87	3.28
13	73.59	93.42	67.30	119.39	32.12	106.87	3.28
Sum	1030.27	1232.35	866.23	1361.55	353.39	1393.42	45.97
HPAI-Free	1030.27	1307.90	942.23	1671.48	449.66	1496.15	45.97
Difference	0.00	75.56	76.00	309.93	96.27	102.73	0.00

After evaluating the individual model results it is important to compare the models. Table 4.8 shows the 14-week total truckloads received for each model for each processor. Processor 1 and 7 received more truckloads in the OPEN model. The DEMAND and CONTRACT models both received 6,283 truckloads and the OPEN model received 6,311 truckloads. The OPEN model was able to adapt to the changes and ship more eggs. If there was a change for the processor, the OPEN model had more truckloads received, except for Processor 5 which had 50 less truckloads.

Table 4.8 Processor Side Model Comparison

Model	Processor 1	Processor 2	Processor 3	Processor 4	Processor 5	Processor 6	Processor 7	Total
OPEN	1031.27	1235.27	869.23	1378.22	344.80	1399.42	52.97	6311.17
DEMAND	1030.27	1230.55	866.23	1321.81	394.93	1393.42	45.97	6283.17
CONTRACT	1030.27	1230.55	866.23	1321.81	394.93	1393.42	45.97	6283.17

The three kilometer DEMAND model DEMAND model results are in Table 4.9. In this case 41 producers were affected in the DEMAND model. The majority of the producers had less than $10,000 in revenue loss. Two producers had greater than $1 million in losses and 2 producers had revenue loss between $500,000 and $999,999.

Table 4.9. Three Kilometer DEMAND Model Producer Revenue Change

Producer Index	More Than 1,000,000	$500,000-$999,999	$10,000-$499,999	$0-$9,999	Positive $
1		(807,544.54)			
2					0.11
3				(0.08)	
4					0.05
5				(2.38)	
6				(41.42)	
7		(588,768.22)			
8					0.15
9				(0.09)	
10					0.01
11					0.13
12					0.61
13					3.42
14					0.02
15	(1,094,786.74)				
16				(0.58)	
17				(0.86)	
18				(5.17)	
19				(108.41)	
20				(329.97)	
21					0.00
22			(469,653.29)		
23					0.03
24				(65.33)	
25					15.54
26				(0.21)	
27					2.45
28					0.02
29			(328,930.28)		
30					0.12
31					
32					
33					0.01
34					
35					0.02
36					
37					
38			(26,474.16)		
39					0.01
40					0.52
41	(3,753,812.48)				
Average	(2,424,299.61)	(698,156.38)	(275,019.24)	(50.41)	1.29

Ten Kilometer models

OPEN Model

The ten kilometer OPEN model is the same scenario as the three kilometer OPEN model except that control areas are now defined by a control area with a ten kilometer radius. Each week is its own iteration where producers are free to ship to any processor. As the control areas are placed into effect the mileage matrix is recalculated, and when a firm is inside the control area the firms supply is zero. Figure 4.4 shows the industry profit for the ten kilometer control area in Week 8 the industry profit is at $3.685 million. This is $47 thousand dollars less than the same week in the three kilometer OPEN model. Over the 14-week period the loss of revenue to the industry for the ten kilometer OPEN model amounts to $9.442 million. Compared to the average loss of revenue for the three kilometer models of $7.073 million, the ten kilometer control OPEN model lost $2.369 million more revenue.

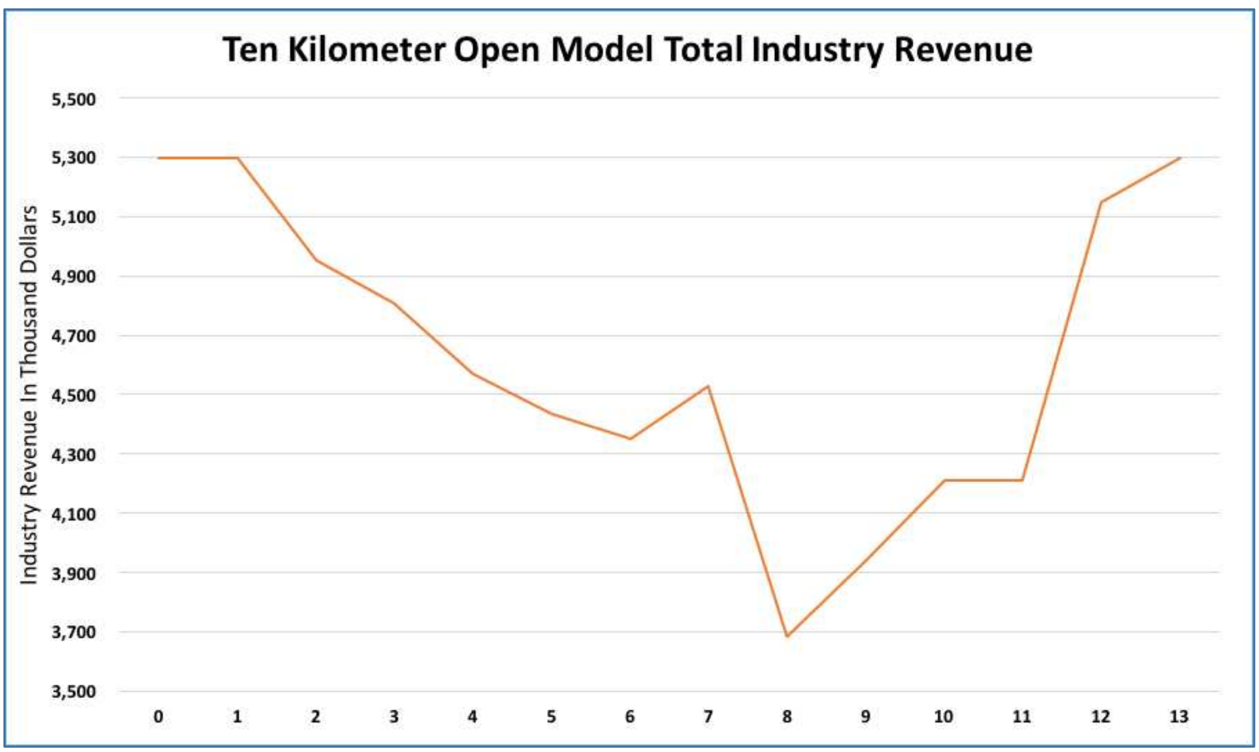

Figure 4.4. Ten Kilometer OPEN Model Total Industry Revenue

The ten kilometer DEMAND model and CONTRACT model produces much the same results as the OPEN model. In the DEMAND model the total industry loss for the 14-week period was $9.657 million and the loss of revenue for the CONTRACT model was $9.4 million. All three models had the greatest revenue loss in Week 8. Figure 4.5 shows the differences between each of the models. The blue and gray lines are the OPEN model minus the CONTRACT model (blue) and the OPEN model minus the DEMAND model (gray). The orange line is the CONTRACT model minus the DEMAND model. Over the course of the 14-week period the DEMAND model saw the largest decrease in revenue. The total decrease in revenue during the 14 week for each of the three models was $9,400,679 for the CONTRACT model, $9,442,581 for the OPEN model, and 9,657,557 for the DEMAND model.

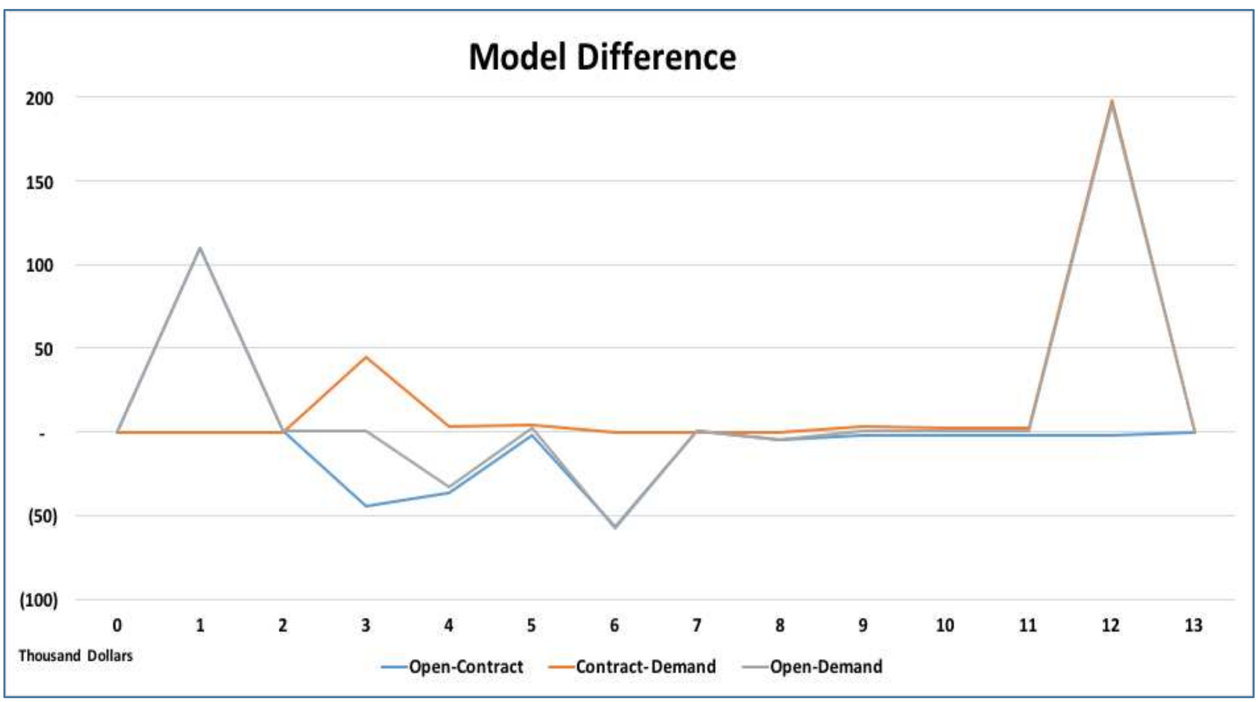

Figure 4.5. Pairwise Comparison of Industry Revenue Between the Three Models

Just as in the three kilometer models the ten kilometer control areas are restricted travel. Table 4.10 shows the ten kilometer OPEN model processor results. One result was that in Weeks 4, 5, 9, 10, 11 and 12, Processor 5 shuts down. In Weeks 4 and 5 this is the result of the producers that supply the processor are in a control area and the remaining processors are a less costly transportation location. In the Weeks 9-12 the processor is in a control area and as is now in a restricted travel area, producers are not allowed to ship to the processor. While Processor 5 shut down for five weeks the processor that had the most reduction in truckloads was Processor 6, in the three kilometer models it was Processor 4 that had the most in truckload loss.

The ten kilometer control areas are one measure to help prevent the spread of HPAI. Table 4.11 shows the results for the change in revenue for the producers that had a change due to the ten kilometer control area. The average change in the producers that lost more than one

Table 4.10. Ten Kilometer OPEN Model Truckloads Received

	Processor						
Week	1	2	3	4	5	6	7
0	73.59	93.42	67.30	119.39	32.12	106.87	3.28
1	73.59	83.54	67.30	119.39	31.68	106.87	3.28
2	73.59	75.21	67.30	132.49	65.00	46.77	3.28
3	73.59	63.10	67.30	132.49	64.10	46.77	3.28
4	74.27	66.20	48.30	132.57	0.00	106.87	3.28
5	74.27	49.93	48.30	132.57	0.00	106.87	3.28
6	62.89	72.09	48.30	90.46	93.03	38.03	2.49
7	73.59	70.41	48.30	119.39	27.54	81.18	3.28
8	73.59	71.48	67.30	45.08	4.00	81.18	3.28
9	77.51	94.76	67.30	45.08	0.00	81.26	3.28
10	77.51	94.76	67.30	45.08	0.00	106.95	3.28
11	77.51	94.76	67.30	45.08	0.00	106.95	3.28
12	77.51	94.76	67.30	132.49	0.00	106.95	3.28
13	73.59	93.42	67.30	119.39	32.12	106.87	3.28
Sum	1036.60	1117.84	866.23	1410.95	349.57	1230.36	45.18
HPAI-Free	1030.27	1307.90	942.23	1671.48	449.66	1496.15	45.97
Difference	6.33	-190.06	-76.00	-260.53	-100.09	-265.79	-0.79

Table 4.11. Ten Kilometer OPEN Model Producer Revenue Change

Producer Index	More Than 1,000,000	$500,000- $999,999	$10000 - $499,999	$0 - $9,999	Positive $
1				(0.13)	
2		(807,544.82)			
3					0.25
4					0.24
5					0.03
6			(297.78)		
7			(140,051.40)		
8	(1,324,728.60)				
9					0.19
10					0.02
11					0.01
12				(1.39)	
13					0.02
15					6.18
16					9.27
17					0.01
18					0.01
19					0.02
20					0.05
22				(2,347.17)	
23	(1,094,787.16)				
24				(0.32)	
25				(4,052.78)	
26				(24.37)	
27				(3,683.47)	
28				(649.53)	
29			(36,122.56)		
30		(587,871.89)			
31			(220,011.37)		
32			(27,058.90)		
33			(62,314.03)		
34			(18,893.47)		
35				(9,599.65)	
36			(11,965.05)		
37			(18,827.99)		
38					21.72
39			(247,509.04)		
40		(575,643.04)			
41			(160,534.75)		
42			(28,675.34)		
43			(58,178.68)		
44			(62,941.93)		
45			(23,470.55)		
46				(4,740.90)	
47			(32,803.66)		
48				(4,975.63)	
49			(26,464.12)		
50	(3,753,993.94)				
Average	(2,057,836.57)	(657,019.92)	(69,183.57)	(2,734.12)	2.72

million in revenue was less than the three kilometer OPEN model but there was one more producer affected by the larger control area and one more in the $500,000 to $999,999 category. All of the categories except the $0 - $9,999 category saw an increase in producers losing revenue. This result is expected as the control areas area larger more surrounding farms will be affected.

CONTRACT Model

The ten kilometer CONTRACT model limits the producer to ship to the processor that is utilized in Week 0. Table 4.12 shows the CONTRACT model processor results. This model uses the equilibrium processor and calculated the cost to the processor from the processor using the mileage matrix. If the producer is in a control area the supply from the producer is zero. As in the OPEN and DEMAND models the Processor 5 has 6 weeks of shutdown. Processor 4 has the greatest reduction in truckloads and Processor 1 and 7 have no change.

Table 4.12. Ten Kilometer CONTRACT Model Truckloads Received

	Processor						
Week	1	2	3	4	5	6	7
0	73.59	93.42	67.30	119.39	32.12	106.87	3.28
1	73.59	83.54	67.30	119.39	31.68	106.87	3.28
2	73.59	75.21	67.30	119.39	18.00	106.87	3.28
3	73.59	62.20	67.30	119.39	18.44	106.87	3.28
4	73.59	65.74	48.30	119.39	0.00	106.87	3.28
5	73.59	49.93	48.30	119.39	0.00	106.87	3.28
6	73.59	58.70	48.30	119.39	28.44	81.18	3.28
7	73.59	69.95	48.30	119.39	28.00	81.18	3.28
8	73.59	70.58	67.30	31.97	18.00	81.18	3.28
9	73.59	93.42	67.30	31.97	0.00	81.18	3.28
10	73.59	93.42	67.30	31.97	0.00	106.87	3.28
11	73.59	93.42	67.30	31.97	0.00	106.87	3.28
12	73.59	93.42	67.30	119.39	0.00	106.87	3.28
13	73.59	93.42	67.30	119.39	32.12	106.87	3.28
Sum	1030.27	1096.37	866.23	1321.81	206.78	1393.42	45.97
HPAI-Free	1030.27	1307.90	942.23	1671.48	449.66	1496.15	45.97
Difference	0.00	-211.53	-76.00	-349.68	-242.88	-102.73	0.00

The ten kilometer CONTRACT model average loss in revenue is $206,206.50. The average producer loss for a three kilometer CONTRACT model is $89,507.39. When the CONTRACT model is used the increased cost of the ten kilometer control area compared to the three kilometer control area is $116,699.10. Table 4.13 show the results for the ten kilometer CONTRACT model. While the average loss was greater less producers were affected.

Table 4.13. Ten Kilometer CONTRACT Model Producer Revenue Change

Producer Index	More Than 1,000,000	$500,000- $999,999	$10000 - $499,999	$0 - $9,999	Positive $
1					0.11
2		(807,544.82)			
3					0.08
4					0.08
5			(43,567.56)		
6			(278,539.62)		
7					
8					0.16
9					0.07
10				(1.38)	
11					6.18
12					9.27
13					0.01
15					0.01
16					0.13
17			(226,011.19)		
18					
19				(4,474.76)	
20				(4,966.01)	
22				(3,683.73)	
23		(837,758.14)			
24			(47,968.67)		
25			(471,723.95)		
26			(292,570.47)		
27			(27,061.25)		
28			(62,303.21)		
29			(18,892.88)		
30				(9,671.45)	
31			(18,827.99)		

32				21.71
33		(247,508.99)		
34	(657,871.75)			
35		(183,466.60)		
36		(28,675.33)		
37		(58,179.59)		
38		(62,941.94)		
39		(42,252.42)		
40			(4,740.93)	
41		(51,666.35)		
42		(29,932.76)		
43		(26,464.12)		
44				
Average	(767,724.90)	(116,766.05)	(4,589.71)	3.44

DEMAND Model

In the ten kilometer DEMAND model, the demand that is established in the equilibrium scenario must not be surpassed. So if the least cost processor has met its capacity the producer must ship to another processor. Each week will be run as an independent model and the results for each iteration are calculated, the difference between the OPEN and the DEMAND model is the constraint that demand cannot be exceeded. Table 4.14 shows the processor results for the ten kilometer DEMAND model. Just as in the three kilometer models Processor 4 has the greatest loss in truckloads received. Processor 5 still has the six weeks of shut down. Processor 5 in the OPEN model had a loss of 100.09 truckloads. In the DEMAND model the truckloads are limited to 32.12 per week. In the OPEN model Processor 5 is able to carry the excess capacity to overcome a portion of the truckload loss. In the DEMAND model, where this is restricted, Processor 5 has 130.35 less truckloads than the OPEN model for a total loss of 230.44 truckloads. Processors 1 and 7 have no effect.

Table 4.14. Ten Kilometer DEMAND Model Truckloads Received

	Processor						
Week	1	2	3	4	5	6	7
0	73.59	93.42	67.30	119.39	32.12	106.87	3.28
1	73.59	83.54	67.30	119.39	31.68	106.87	3.28
2	73.59	75.21	67.30	119.39	32.12	92.75	3.28
3	73.59	63.10	67.30	119.39	32.12	91.85	3.28
4	73.59	80.05	48.30	119.39	0.00	106.87	3.28
5	73.59	63.78	48.30	119.39	0.00	106.87	3.28
6	73.59	59.16	48.30	119.39	27.54	81.18	3.28
7	73.59	70.41	48.30	119.39	27.54	81.18	3.28
8	73.59	71.48	67.30	45.08	4.00	81.18	3.28
9	73.59	93.42	67.30	45.80	0.00	85.80	3.28
10	73.59	93.42	67.30	50.41	0.00	106.87	3.28
11	73.59	93.42	67.30	50.41	0.00	106.87	3.28
12	73.59	93.42	67.30	119.39	0.00	106.87	3.28
13	73.59	93.42	67.30	119.39	32.12	106.87	3.28
Sum	1030.27	1127.27	866.23	1385.60	219.22	1368.89	45.97
HPAI-Free	1030.27	1307.90	942.23	1671.48	449.66	1496.15	45.97
Difference	0.00	-180.64	-76.00	-285.88	-230.44	-127.26	0.00

The ten kilometer DEMAND model result show that the average loss to the producer was $134,132.74. This is right in the middle of the average result for the ten kilometer control areas. In the CONTRACT model when the Processor 5 shuts down, all the eggs that normally ship to that processor are lost. In the DEMAND model producers are able to adapt to the lost processor. Table 4.15 shows the results for the DEMAND Model.

Table 4.15. Ten Kilometer DEMAND Model Producer Revenue Change

Producer Index	More Than 1,000,000	$500,000- $999,999	$10,000 - $499,999	$0 - $9,999	Positive $
1		(807,544.94)		(0.44)	
2					0.44
3					0.37
4			(31,439.18)		
5				(297.77)	
6			(140,051.39)		
7	(1,324,754.38)				
8				(8.26)	
9					0.01
10					0.02
11					0.01
12				(1.39)	
13					0.01
15				(0.01)	
16					6.19
17					9.26
18					0.01
19					0.01
20					0.02
22					0.02
23				(0.08)	
24				(0.01)	
25				(2,346.81)	
26	(1,094,786.97)				
27			(56,365.05)		
28				(147.62)	
29				(4,602.44)	
30				(862.10)	
31				(3,683.97)	
32			(111,875.52)		
33			(36,122.55)		
34		(587,825.86)			
35			(220,342.84)		
36			(27,055.23)		
37			(62,310.16)		
38			(18,893.52)		
39			(9,599.65)		
40		(11,965.05)			
41		(18,827.99)			
42			(247,509.07)		21.72
43		(658,565.64)			
44			(183,466.61)		
45			(28,675.34)		
46			(58,179.58)		
47			(62,941.93)		
48			(23,469.88)		
49			(4,740.93)		
50			(32,894.64)		
51			(26,470.21)	(4,975.63)	
52	(3,753,994.73)				
Average	(2,057,845.36)	(416,945.89)	(72,758.07)	(1,302.04)	2.93

One important aspect to consider when determining the average cost to the producers is that one large producer who produces 87.4188 truckloads per week is affected by a control area and significantly shift the average higher. In the previous tables the average loss of revenue for each category was shown, comparing these values in Table 4.16. In the three kilometer models the difference for the average loss of revenue for the producers is eight cents for the category of producers that lost more than $1,000,000. Using the three kilometer OPEN model producers in the $500,000 to $999,999 category lost 19 more cents than using the DEMAND or CONTRACT model. When the producer is in the 10,000 to 9,999 category the DEMAND model saw three more cents in the CONTRACT model over the OPEN model and $5.24 in the DEMAND model over the OPEN model. In the $0. $9,999 category when using the CONTRACT model instead of the OPEN model the producers lost an average of $16.53 more and an average of $18.89 more when using the DEMAND model over the OPEN model.

The more restricting the model the more the producers lost on average. The significant changes occurred when the larger control areas are enforced. First, the type of structure the industry engages in makes a significant difference for the smaller producers. When CONTRACT model is enforced the producers in the $10,000 - $499,000 category lost on average $44,007.98 more than the DEMAND model and $47,582.48 more than the OPEN model. In the category of producers that lost on average $0 to $9,999 the CONTRACT model had losses of $1,855 more than the CONTRACT model and $3,287.67 more than the DEMAND model. One of the reasons for the increase revenue loss of the CONTRACT model is that the eggs that would have gone to Producer 5 during the shutdown were lost and not able to be processed.

Table 4.16. Average Loss in Firm Revenue for Each Model

Model	More Than 1,000,000	$500,000- $999,999	$10,000 - $499,999	$0 - $9,999	Positive $
3 Kilometer OPEN	(2,424,299.69)	(698,156.57)	(275,014.00)	(31.52)	2.78
3 Kilometer CONTRACT	(2,424,299.61)	(698,156.38)	(275,013.97)	(48.04)	1.22
3 Kilometer DEMAND	(2,424,299.61)	(698,156.38)	(275,019.24)	(50.41)	1.29
10 Kilometer OPEN	(2,057,836.57)	(657,019.92)	(69,183.57)	(2,734.12)	2.72
10 Kilometer CONTRACT	(2,057,836.48)	(767,724.90)	(116,766.05)	(4,589.71)	3.44
10 Kilometer DEMAND	(2,057,845.36)	(416,945.89)	(72,758.07)	(1,302.04)	2.93

Comparing the cost of the control area will give a measure of the cost of reducing the risk of disease spread. In the ten kilometer OPEN model the average cost to the producer is $118,363 comparing the average to the three kilometer OPEN model of $89,497.20. On average the increase of costs to producers is $28,884.44 for enforcing a ten kilometer control area instead of a three kilometer control area. Table 4.17 shows the number of producers in each category for the ten kilometer and three kilometer OPEN models. As the size of the control area increase more producers are affected. The $10,000 to $499,999 category has the greatest increase in producers that are affected. Going from 3 producers to 17 producers.

Table 4.17. Producers with a Change in the Three and Ten Kilometer Control Areas

Model	More Than 1,000,000	$500,000- $999,999	$10000 - $499,999	$0 - $9,999	Positive $
3 km	2	2	3	11	8
10 km	3	3	17	11	14

Transportation Costs

Identifying the transportation costs from the ten kilometer CONTRACT model is more complicated than in the three kilometer CONTRACT model. As Processor 5 has a shutdown period, which adds the element of the lost eggs that were available to be shipped but due to the contract restriction were lost. To make the three kilometer and the ten kilometer comparable models. During all time periods, all eggs that are shipped to Processor 5 will be excluded for both models. This will allow the average transportation costs to be calculated. To obtain the result, first you must sum all revenue received over the time period. Second multiply the Week Zero value by the number of weeks that the processor was in operation. The difference between the revenue the producer actually received and the HPAI-Free revenue will result in the increased transportation costs. In the three kilometer CONTRACT model the average loss in revenue due to transportation was 36 cents. In total for the three kilometer CONTRACT model the loss was $25.98 For the ten kilometer CONTRACT model the average cost to the producers was $156.12 and the total cost to producers was $11,084.40. This was calculated using a sample of 71 of the 79 producers. The 8 producers that at the optimum were shipping to producer five were excluded. This results would be the minimum that the producers would be paying to re-route around the known control areas. Due to privacy concerns the exact location of control areas are not reported, only approximate locations. In this research the exact locations are known and thus will be the minimum costs that are absorbed by the egg producers.

CHAPTER 5. SUMMARY AND CONCLUSIONS

The purpose of this thesis was to identify the economic impacts to the laying hen industry of Minnesota during the 2014-2015 Highly Pathogenic Avian Influenza (HPAI) outbreak. While the government provides indemnity payments for each live bird that is culled during an outbreak, the costs to the industry of mitigation and control programs extend beyond the loss of the bird stock to also include lost production and increased cost of adjusting management to adapt to control measures, even for farms that are not infected.

A mathematical programming model was developed and utilized to estimate individual producer net returns above transportation costs for each week of the outbreak period as well as total industry profit. While this thesis only captures the laying hen population results here provide a path for inference to other poultry populations.

Highly Pathogenic Avian influenza is a highly contagious diverse group of virus's much like the "flu" found in humans. The risk of human infection of HPAI is small, but from 2003-2015 there have been 449 human deaths worldwide from HPAI. In poultry, HPAI has approximately ninety to one hundred percent mortality rate and spreads quickly from bird to bird. This is, in part, because of the intensive production practices used today. Preventing the spread of the disease and implementing eradication measures are important not only to prevent the economic loss to the industry but also for public safety.

From December 2014 through June 2015 there was 219 confirmed detections of HPAI and over 48 million birds were affected in the United States. Minnesota alone had 101 detections and 7.7 million birds affected from HPAI from March to June 2015. In Minnesota, poultry is a billion-dollar industry and when a disease such as HPAI is not contained the impact can be significant.

When there is a detection of HPAI, there is a protocol that is enacted to help prevent the spread of the disease. One of the protocols is to implement control areas around the infected premises. These control areas are a method of containment and implementation may include culling of poultry and restricting travel inside the control area. A three kilometer and a ten kilometer “control area” perimeter are standard practice and guidelines from the OIE and USDA APHIS. These control areas can have an impact to producers that are not directly affected with HPAI. For the purpose of this research the three and ten kilometer control areas area restricted travel and all laying hens in a control area are culled.

Using a linear programming model, total industry profit, individual producer profit, and the cost to producers for rerouting around the control areas can be estimated. By parameterizing and solving the model iteratively to represent adaptation to on outbreak across time, results for each time period can be compared to a base model that represents an uninfected circumstance. The change in net revenue as compared to the base equilibrium scenario quantify the lost benefits that comprise the economic impacts from HPAI.

This research evaluated two alternative control area sizes, a three kilometer and a ten kilometer radius control area. For each of the control area sizes three different models were developed to serve as proxies for different producer-processor relationships. In the OPEN model, trade from producer to processor is not restricted. All producers are allowed to ship to all processors. In the CONTRACT model, producers are restricted to shipping eggs to the base model processor. In the DEMAND model, demand for each processor is restricted to the level that was obtained in the base model. Implementing the OPEN, CONTRACT, and DEMAND models allows for comparisons of separate industry structures.

Overall total industry cost ranged from $7 million in the three kilometer model to $10 million in the ten kilometer models. In an industry that employs more than 26,000 people, the loss of revenue of this magnitude can be a significant impact to the people of Minnesota. The cost of the loss of eggs can be significant to everyone in the country. In the face of the outbreak weekly price increases were observed here in Colorado during the summer of 2015.

The loss of revenue for the industry, when increasing the size of the control area from three to ten kilometer, was on average $3 million dollars for the three models. Using this value can help state and federal agencies determine the optimal size of the control areas. As the majority of the cost comes from the initial control area. Should the risk of the disease spread and loss of revenue to the industry and society be larger than the three million dollars the larger control areas are a reasonable measure to prevent disease spread. As in this case seems likely.

Among individual producers who had losses of over $1 million, the average loss was $2.4 million for the three kilometer control area models and $2 million for the ten kilometer models. For producers with revenue loss between $500k and $1 million, the average loss was $698k for the three kilometer models and $613k for the ten kilometer models. When the revenue loss was between $10k and $500k the average loss was $275K for the three kilometer models and $86K for the ten kilometer models.

Surprisingly there were producers with an increase in revenue during the outbreak period, though those producers increased revenue on average of $2 dollars. Another interesting finding was that while total industry revenue decreased when the size of the control area increased, average revenue loss for individual producers decreased. This is the result more producers being affected in the larger control areas but the average size of the producers decreased. This result has more to do with producer size than control area size as one large producer or several smaller producers can skew the average results. This result would certainly be specific to the particular study area and not generalizable beyond this setting.

The transportation costs for rerouting around the control areas for the three kilometer control area was $25.98 total for the 14-week period. The ten kilometer control area transportation costs for the industry was approximately $11k. On average, the increased transportation costs for an individual producer was $156.12 when a ten kilometer control area was enacted.

One advantage to this model is that the framework for employed here to evaluate impacts that are governed by the relative locations for the producer and for the processor can be adapted to not only other disease outbreaks but a broader set of natural disasters as well. In September 2013, Colorado experienced a significant flood event. During this time, I was a heavy equipment hauler. When transporting heavy equipment, I was rerouted around flooded and damaged roads. The costs to my employer were similar to the cost of the transportation of eggs when rerouted around control areas.

The type of industry structure and the size of the control areas had a significant impact on the average loss of revenue for each producer. The more restricting the industry structure the less able the producer was to adapt to the changing conditions. In both the three kilometer and ten kilometer areas the OPEN models had the ability to adapt and capture more revenue. The

CONTRACT model was the most restricting. Individual producers can use this to determine the costs and benefits of vertical integration or other marketing decisions.

When Processor 5 was located in a control area it was forced to shut down and not accept any eggs. As a result, there was a loss to the industry of eggs that could have been shipped. If the processor was identified as a “Dirty” processor and eggs from “Dirty” farms were shipped to this processor. Revenue that was once lost may be able to be captured. The costs associated with sanitization and the risk of human transfer would have to be considered.

Limitations to this research revolve largely around the lack of data to accurately describe the producers and processors. Systematic methods were utilized to derive proxies to create a reasonable representation of the true distribution of producer and processor types and locations. More detailed information would not only provide for more accuracy but would also allow further refinement to reflect important costs such as increased biosecurity measures, washing and sanitizing of buildings and vehicles, lost or increased wages to employees, permitting, and surveillance costs were not captured in this effort. The use of a targeted survey, while costly, would offer the best opportunity to obtain the individual producer information that could document relevant opportunities and costs that would refine the overall impact estimates. This is an opportunity for further research.

In conclusion, preventing the spread of HPAI is important to society. The costs to the Minnesota laying hen industry are significant, reaching into the millions of dollars for the 14-week period. Measures to prevent disease spread are important and need to be enforced. As the United States government provides indemnity payments for the culled bird, the costs to the industry are much greater than the per bird price. These costs need to be considered when determining the best implementation of control measures in the face of a disease outbreak.

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APPENDIX

Table A.1. GAMS Code for Baseline Optimization Model

```
Sets
     i Producers     / 1 * 79 /

     j Processors          / 1 * 7 / ;

  Parameters
    a(i) capacity of producer i in truckloads per week
       / 1       20.5733
         2       19.0004
         3       13.7388
         4       13.9897
         5       0.0660
         6       0.0489
         7       2.9648
         8       0.6758
         9       3.2419
         10       13.6824
         11       8.9468
         12       0.5197
         13       0.5203
         14       0.5233
         15       7.0925
         16       0.524
         17       0.4581
         18       0.5207
         19       0.534
         20       13.747
         21       0.5238
         22       0.5555
         23       0.4346
         24       0.5931
         25       0.5228
         26       0.5219
         27       0.7938
         28       0.499
         29       0.5244
         30       0.7643
         31       7.4102
         32       0.5253
         33       0.6701
         34       0.5264
         35       1.3159
         36       20.7521
```

37	25.6829
38	11.0013
39	0.0978
40	0.0695
41	0.097
42	25.4746
43	60.1024
44	0.0776
45	29.008
46	13.1022
47	1.1159
48	10.9944
49	6.8171
50	0.6334
51	2.8747
52	0.4397
53	0.4455
54	1.1118
55	0.4377
56	0.5621
57	5.7572
58	7.7263
59	2.1532
60	0.66756
61	0.908
62	1.4667
63	0.4386
64	0.4404
65	0.4395
66	0.4605
67	0.6185
68	0.6967
69	0.3268
70	0.3287
71	0.2932
72	0.0468
73	0.2193
74	0.3251
75	0.3278
76	0.0512
77	36.3582
78	0.06
79	87.4188 /;

Table d(i,j) distance in thousands of miles

	1	2	3	4	5	6	7
1	180.307	143.794	38.266	187.143	179.594	266.962	312.167
2	199.173	162.66	57.132	202.717	195.168	285.829	331.033
3	184.969	154.094	64.065	182.554	175.005	268.938	314.199
4	179.901	143.388	81.135	240.058	198.053	266.557	311.761
5	63.978	108.351	205.606	122.076	91.952	34.46	65.851
6	159.984	204.357	301.612	217.759	187.958	88.834	46.54
7	161.507	153.931	204.386	65.073	113.218	156.26	172.484
8	43.215	48.563	145.91	67.851	12.596	102.197	148.914
9	36.836	53.036	150.383	67.97	14.412	95.536	142.253
10	56.849	61.868	163.107	48.186	7.544	114.864	161.581
11	68.532	64.162	113.959	147.511	105.506	138.833	182.046
12	80.556	44.044	67.076	122.689	97.455	167.212	212.416
13	74.075	37.498	83.057	127.959	90.191	160.731	205.935
14	79.075	53.16	99.504	144.004	101.999	149.377	192.589
15	75.314	38.738	86.581	129.199	91.43	161.97	207.174
16	75.914	47.673	103.827	138.517	96.512	146.744	189.957
17	71.402	30.737	75.004	108.867	79.903	158.058	203.262
18	61.654	36.441	99.563	127.285	85.279	153.754	197.508
19	59.707	34.172	91.44	125.338	83.333	151.808	195.604
20	64.956	28.48	85.748	119.725	81.956	151.647	196.852
21	58.591	33.056	90.324	124.221	82.216	150.691	194.487
22	59.004	33.791	98.778	124.635	82.629	151.105	194.9
23	66.132	22.349	84.145	110.88	72.589	151.416	196.62
24	71.984	28.788	77.7	101.539	69.402	157.268	202.472
25	70.193	27.392	80.85	103.719	69.084	155.477	200.681
26	55.265	30.053	97.445	120.896	78.89	147.365	191.161
27	48.971	39.761	109.254	126.784	84.779	132.864	176.076
28	47.137	37.965	111.165	124.951	82.945	129.072	172.284
29	44.472	35.391	112.272	121.899	79.893	130.454	173.666
30	48.593	21.204	100.585	114.025	72.02	140.495	184.49
31	42.135	25.647	106.725	115.413	73.408	134.821	178.033
32	46.469	15.603	97.36	109.478	67.473	136.306	181.511
33	54.896	10.852	95.428	105.104	63.901	140.893	186.098
34	47.67	7.695	100.284	105.124	63.119	133.588	178.792
35	137.763	182.137	279.391	184.265	163.277	53.959	20.819
36	103.176	147.549	244.787	78.46	67.289	44.946	86.539
37	109.495	153.868	251.123	91.583	78.961	45.372	74.828
38	68.658	69.876	156.647	152.003	109.998	116.532	155.147
39	87.23	131.603	228.858	142.694	115.203	20.09	42.481
40	93.141	137.515	234.769	145.918	118.655	9.514	41.416
41	97.612	141.986	239.241	136.309	123.126	13.985	47.243
42	20.946	30.919	126.356	106.623	64.617	114.473	157.811

43	85.235	129.609	226.863	67.827	55.205	52.52	103.238
44	80.171	105.312	209.657	57.023	44.401	63.859	107.232
45	83.176	101.706	206.051	44.277	45.804	79.384	120.06
46	84.24	109.382	213.468	48.592	48.106	75.089	117.329
47	56.676	11.715	101.747	94.503	58.255	140.762	185.966
48	66.711	35.828	80.251	75.272	56.51	150.819	196.024
49	56.777	18.211	105.211	85.752	49.836	140.863	186.068
50	74.848	43.974	81.353	73.982	64.884	158.818	204.079
51	57.612	23.045	117.412	81.948	49.652	141.792	186.996
52	61.833	30.95	84.459	77.341	53.818	145.942	191.146
53	55.324	21.196	115.556	83.28	47.364	139.506	184.71
54	39.029	6.002	105.334	93.071	51.066	124.664	169.868
55	37.32	8.98	115.628	87.066	45.061	122.16	167.365
56	32.031	16.415	114.899	88.523	46.518	118.677	163.882
57	34.454	11.276	117.275	84.452	42.446	119.546	164.75
58	73.141	50.642	124.292	62.905	53.687	158.887	204.149
59	71.055	47.86	122.412	62.04	51.542	156.802	202.063
60	36.091	14.626	120.511	85.033	43.027	120.177	165.381
61	60.3	37.976	122.267	62.604	42.205	146.047	191.308
62	40.826	20.965	126.969	74.071	32.065	127.059	172.306
63	47.046	30.723	132.391	65.842	30.427	132.839	178.1
64	37.637	24.844	129.181	74.74	32.735	123.443	168.704
65	72.185	51.911	130.586	53.786	46.561	152.473	199.19
66	41.047	28.246	132.591	73.82	25.788	127.177	172.439
67	30.666	28.822	126.17	87.525	32.165	114.223	160.94
68	19.501	35.567	132.821	95.328	35.358	104.176	149.38
69	158.124	202.497	299.752	216.895	186.354	107.349	66.454
70	154.878	199.251	296.505	212.682	182.851	92.481	54.091
71	148.75	193.123	290.378	206.554	176.723	86.352	47.947
72	155.004	199.377	296.632	212.808	182.977	92.607	54.217
73	157.439	201.813	299.067	215.244	185.413	95.042	56.653
74	147.785	192.159	289.413	205.59	175.759	85.388	44.595
75	153.583	197.956	295.211	211.357	181.557	90.976	49.275
76	154.836	199.21	296.464	212.641	182.81	92.328	50
77	8.44	54.819	152.074	114.857	59.908	78.852	124.104
78	24.82	71.074	168.421	79.194	32.109	82.281	128.998
79	93.607	99.244	180.894	16.018	46.845	109.244	147.136

```
;

  Scalar f freight in dollars per mile /2.67/ ;

  Parameter c(i,j) transport cost in dollars per mile;
    c(i,j) = f * d(i,j) ;
```

```
Variables
   x(i,j) shipment quantities
   z Total Profit ;

scalar p revenue per truck    /10777.91/;

Positive Variable x ;

Equations
   profit define objective function
   supply(i) observe supply limit at producer i;
   supply(i) .. sum(j, x(i,j)) =l= a(i) ;
   profit .. z =e=sum((i,j), x(i,j)*(p-c(i,j))) ;

Model transport /all/ ;

Solve transport using lp maximizing z ;

Display x.l, x.m , z.l;
 execute_unload "Gamsoptimum.gdx" x.L x.M;
 execute 'gdxxrw.exe Gamsoptimum.gdx var=x.m rng=sheet1!';
 execute 'gdxxrw.exe Gamsoptimum.gdx var=x.l rng=NewSheet!';
```

Table A.2. Location and Population of Laying Hen Operations as Generated from FLAPS.

Identifier	Latitude	Longitude	Bird Population	County
1	46.9029	-96.1622	481,415	Becker
2	47.1093	-96.24	444,610	Clay
3	46.7948	-96.6043	321,488	Clay
4	47.2531	-95.2133	327,359	Bagley
5	44.7066	-93.0246	1,545	Dakota
6	43.5458	-92.3653	1,145	Fillmore
7	44.2224	-95.8844	69,377	Lyon
8	45.1357	-94.3399	15,813	Meeker
9	45.0795	-94.274	75,860	Meeker
10	45.0114	-94.5561	320,168	Meeker
11	46.0879	-93.565	209,355	Milaca
12	46.1679	-94.5464	12,162	Morrison
13	46.156	-94.3475	12,175	Morrison
14	46.1355	-93.8828	12,252	Morrison
15	46.1312	-94.2481	165,964	Morrison
16	46.0868	-93.913	12,261	Morrison
17	46.0198	-94.5399	10,720	Morrison
18	45.9939	-94.0006	12,184	Morrison
19	45.9842	-94.1638	12,261	Morrison
20	45.969	-94.2546	321,679	Morrison
21	45.969	-94.1594	12,256	Morrison
22	45.9582	-93.9995	12,999	Morrison
23	45.9496	-94.4578	10,170	Morrison
24	45.9442	-94.595	13,878	Morrison
25	45.9442	-94.5594	12,234	Morrison
26	45.9377	-94.0514	12,213	Morrison
27	45.9355	-93.8493	18,575	Morrison
28	45.8945	-93.8276	11,677	Morrison
29	45.862	-93.8849	12,272	Morrison
30	45.8534	-94.1151	17,885	Morrison
31	45.8393	-94.0027	173,398	Morrison
32	45.8339	-94.1962	12,292	Morrison
33	45.8285	-94.3983	15,684	Morrison
34	45.7853	-94.3097	12,317	Morrison
35	43.695	-92.937	30,791	Mower
36	44.3445	-94.1195	485,599	Nicolett
37	44.2051	-94.0449	600,981	Nicolett
38	45.8793	-93.1056	257,430	Pine

Identifier	Latitude	Longitude	Bird Population	County
39	44.4062	-93.0559	2,288	Rice
40	44.2127	-93.3099	1,626	Rice
41	44.1986	-93.4504	2,270	Rice
42	45.5551	-93.8806	596,106	Sherburne
43	44.5812	-94.0535	1,406,397	Sibley
44	44.5748	-94.2837	1,815	Sibley
45	44.564	-94.5604	678,787	Sibley
46	44.538	-94.5086	306,592	Sibley
47	45.768	-94.4891	26,111	Sterns
48	45.715	-94.9268	257,268	Sterns
49	45.7129	-94.6523	159,521	Sterns
50	45.7031	-95.0879	14,822	Sterns
51	45.6977	-94.7355	67,267	Sterns
52	45.688	-94.8555	10,288	Sterns
53	45.6869	-94.675	10,424	Sterns
54	45.6707	-94.2632	26,015	Sterns
55	45.6048	-94.3378	10,243	Sterns
56	45.5745	-94.2546	13,153	Sterns
57	45.5724	-94.3237	134,719	Sterns
58	45.5572	-95.0976	180,796	Sterns
59	45.5518	-95.049	50,384	Sterns
60	45.5367	-94.3291	15,621	Sterns
61	45.5226	-94.8479	21,248	Sterns
62	45.4924	-94.474	34,321	Sterns
63	45.4546	-94.6166	10,264	Sterns
64	45.4394	-94.4351	10,306	Sterns
65	45.4221	-95.063	10,284	Sterns
66	45.4102	-94.4826	10,776	Sterns
67	45.3897	-94.2481	14,473	Sterns
68	45.3313	-94.1238	16,303	Sterns
69	44.0214	-91.6822	7,647	Winona
70	44.0008	-91.8659	7,692	Winona
71	43.976	-91.9675	6,860	Winona
72	43.9663	-91.8497	1,094	Winona
73	43.9479	-91.8432	5,131	Winona
74	43.9306	-92.0216	7,607	Winona
75	43.8787	-91.9751	7,670	Winona
76	43.8625	-91.9827	1,199	Winona
77	45.2697	-93.6742	850,781	Wright

Identifier	Latitude	Longitude	Bird Population	County
78	45.0201	-93.9779	1,405	Wright
79	44.7252	-94.9442	2,045,600	Renville

Table A.3. Location and Population of Turkey Operations as Generated from FLAPS.

Latitude	Longitude	Population	Production Type
46.626173	-93.625519	9	backyard
46.574294	-93.771431	6	backyard
46.532141	-93.736845	6	backyard
46.494312	-93.24723	6	backyard
46.493232	-93.428809	7	backyard
46.456483	-93.641732	6	backyard
45.400516	-93.412597	12398	turkeys
45.36701	-93.489335	10551	turkeys
45.303241	-93.452587	2769	turkeys
45.297837	-93.499063	7055	turkeys
45.292433	-93.489335	31116	turkeys
45.269736	-93.454749	4071	turkeys
45.230826	-93.450426	1165	turkeys
47.147132	-96.108178	74460	turkeys
47.007705	-96.070349	13667	turkeys
47.003382	-96.016308	22805	turkeys
46.994735	-95.781769	156710	turkeys
46.950421	-95.862831	26795	turkeys
46.908269	-96.070349	52833	turkeys
46.899622	-95.983883	5544	turkeys
46.821803	-95.213254	32286	turkeys
46.785055	-95.230547	40072	turkeys
46.762357	-95.921195	11239	turkeys
46.743983	-95.225143	17738	turkeys
46.728852	-95.230547	22520	turkeys
46.722367	-95.735293	6921	turkeys
48.337122	-95.537502	6	backyard
48.280919	-95.513724	6	backyard
48.280919	-95.497511	6	backyard
47.885336	-94.652305	6	backyard
47.790224	-94.917107	6	backyard
47.775092	-94.874955	6	backyard
47.627019	-95.013301	6	backyard
47.608645	-95.184072	6	backyard
47.583786	-94.897652	6	backyard
47.558927	-95.134353	14	backyard
47.503804	-94.886844	6	backyard

Latitude	Longitude	Population	Production Type
45.791775	-93.814664	2	backyard
45.756108	-93.94004	2	backyard
45.715036	-93.856816	1	backyard
45.692339	-93.909777	2	backyard
45.686935	-94.042719	1	backyard
45.646944	-93.80926	2	backyard
45.623166	-93.855736	1	backyard
45.58858	-93.936798	9	backyard
45.44483	-96.674531	76301	turkeys
45.411324	-96.180594	40873	turkeys
44.139191	-94.117296	8036	turkeys
44.13811	-94.043799	5123	turkeys
44.073261	-94.172418	7041	turkeys
44.07218	-94.037314	7466	turkeys
44.006249	-93.795209	1063	turkeys
43.986795	-94.158367	1623	turkeys
43.984633	-94.124861	6411	turkeys
43.961936	-94.223217	8901	turkeys
43.942481	-94.221055	34762	turkeys
43.918703	-93.830877	8802	turkeys
43.91546	-93.869786	16960	turkeys
43.906813	-94.335623	3617	turkeys
43.904652	-94.157286	3190	turkeys
43.880874	-94.255641	5304	turkeys
43.880874	-93.963818	2786	turkeys
44.382377	-94.849015	20556	turkeys
44.313204	-94.521525	9374	turkeys
44.280779	-94.991684	237144	turkeys
44.247274	-95.084635	27802	turkeys
44.219172	-95.043564	47823	turkeys
44.143514	-94.941966	4824	turkeys
44.140272	-94.718235	30802	turkeys
46.763438	-92.874345	2	backyard
46.557	-92.9727	2	backyard
46.53106	-92.537127	2	backyard
46.486747	-92.758697	1	backyard
46.419735	-92.804091	1	backyard
44.906578	-93.898969	6	backyard

Latitude	Longitude	Population	Production Type
44.864426	-93.849251	12	backyard
44.855779	-93.968142	20	backyard
44.837405	-93.932474	17	backyard
44.812546	-93.911939	7	backyard
44.782283	-93.891403	8	backyard
44.730403	-93.751976	9	backyard
44.729322	-93.873029	10	backyard
44.727161	-93.661187	6	backyard
44.680685	-93.88708	11	backyard
44.676362	-93.732521	6	backyard
44.672039	-93.71739	7	backyard
46.888814	-94.295632	8139	turkeys
46.815318	-94.452352	34178	turkeys
46.801267	-94.683649	6914	turkeys
46.774246	-94.510717	39453	turkeys
46.698589	-94.385341	23911	turkeys
46.695346	-94.494504	6465	turkeys
46.594829	-94.65879	1909	turkeys
46.441352	-94.699861	9312	turkeys
46.440271	-94.651224	836	backyard
45.10545	-95.32566	3723	turkeys
45.061136	-95.601271	9961	turkeys
45.035196	-95.440227	2006	turkeys
45.02655	-95.550472	8441	turkeys
44.959539	-95.390509	2163	turkeys
45.71936	-93.017014	1750	turkeys
45.508598	-92.787879	2427	turkeys
45.472931	-92.953245	3205	turkeys
45.40592	-92.668988	19088	turkeys
45.377818	-92.718706	12493	turkeys
45.321615	-92.938114	5235	turkeys
46.774246	-96.383789	12506	turkeys
46.706154	-96.650753	23310	turkeys
47.715646	-95.562361	3	backyard
47.675656	-95.412126	3	backyard
47.672413	-95.386186	2	backyard
47.48543	-95.304043	1	backyard
47.442197	-95.442389	1	backyard

Latitude	Longitude	Population	Production Type
47.422742	-95.506158	3	backyard
47.357893	-95.267295	2	backyard
44.080827	-95.246759	10212	turkeys
43.945723	-95.361327	56102	turkeys
43.926268	-95.162455	148628	turkeys
43.905733	-95.202446	5207	turkeys
43.852772	-94.874955	4060	turkeys
46.669406	-94.301036	16	backyard
46.574294	-93.853574	10	backyard
46.348401	-93.892484	19	backyard
46.323542	-93.968142	15	backyard
46.309491	-93.986516	9	backyard
46.258692	-93.92707	11	backyard
44.691494	-93.031065	32009	turkeys
44.690413	-93.233179	30010	turkeys
44.628806	-92.921901	97454	turkeys
44.147838	-92.782475	12496	turkeys
44.113251	-92.980266	46746	turkeys
44.067857	-93.035388	78459	turkeys
44.030028	-92.723029	64984	turkeys
43.971663	-92.686281	16216	turkeys
43.964097	-92.86786	2470	turkeys
43.933834	-92.988913	25005	turkeys
43.917622	-92.843001	15675	turkeys
45.87608	-95.323498	1	backyard
45.83717	-95.248921	3	backyard
45.820957	-95.629372	4	backyard
43.847368	-92.417155	4499	turkeys
43.804135	-92.329608	3108	turkeys
43.777114	-92.18802	3448	turkeys
43.761983	-92.184778	3274	turkeys
43.631203	-91.904843	60030	turkeys
43.623637	-92.087503	1626	turkeys
43.597697	-92.144787	3170	turkeys
43.57608	-92.421479	2672	turkeys
43.567434	-92.27881	2857	turkeys
43.556626	-92.024815	6344	turkeys
43.532847	-92.262597	3636	turkeys

Latitude	Longitude	Population	Production Type
43.528524	-92.224768	10602	turkeys
43.517716	-91.942672	9094	turkeys
43.516635	-91.738396	4015	turkeys
43.752255	-93.614711	23620	turkeys
43.654981	-93.470961	4033	turkeys
43.64093	-93.080783	5872	turkeys
43.502584	-93.226694	8716	turkeys
43.501503	-93.292625	7062	turkeys
44.461277	-92.935952	9469	turkeys
44.424529	-92.747888	4840	turkeys
44.405075	-93.034307	13534	turkeys
44.38562	-92.598734	5485	turkeys
44.370488	-92.590088	63925	turkeys
44.351033	-92.718706	16510	turkeys
44.328336	-92.674392	27107	turkeys
44.277537	-92.875426	9782	turkeys
44.25592	-92.916497	11271	turkeys
44.211607	-92.692766	100593	turkeys
44.208364	-93.025661	30621	turkeys
44.199717	-92.907851	9629	turkeys
47.286558	-94.708508	2	backyard
47.192526	-94.738771	1	backyard
47.021756	-94.667436	3	backyard
46.938532	-95.106252	3	backyard
45.678288	-93.344505	44765	turkeys
45.652348	-93.477446	44530	turkeys
45.595065	-93.464476	3662	turkeys
45.58858	-93.162926	8228	turkeys
45.452396	-93.03755	21232	turkeys
45.451315	-93.452587	38498	turkeys
45.44483	-93.428809	11919	turkeys
45.441587	-93.476365	8251	turkeys
45.426456	-93.279655	6391	turkeys
47.201173	-93.556347	19821	turkeys
47.187122	-93.509871	178268	turkeys
43.742528	-95.016543	6	backyard
43.734962	-94.927916	6	backyard
43.656062	-95.407803	6	backyard

Latitude	Longitude	Population	Production Type
43.57608	-95.136515	6	backyard
43.559868	-95.27378	6	backyard
46.012264	-93.174815	164	backyard
45.836089	-93.346666	89	backyard
45.822038	-93.426647	52	backyard
45.784209	-93.226694	165	backyard
45.365929	-95.212173	46734	turkeys
45.35404	-94.965745	19552	turkeys
45.351879	-95.046807	47835	turkeys
45.350798	-94.940886	106314	turkeys
45.344313	-95.135434	57890	turkeys
45.330262	-95.195961	425273	turkeys
45.31405	-95.222981	232741	turkeys
45.30108	-94.809025	37253	turkeys
45.291352	-95.205688	346103	turkeys
45.214614	-94.930077	292681	turkeys
45.180027	-95.05113	26700	turkeys
45.068702	-95.175425	284129	turkeys
45.003852	-95.197041	29076	turkeys
44.999529	-94.985199	4694	turkeys
44.984398	-95.184072	165045	turkeys
44.968185	-94.764711	91282	turkeys
44.929275	-95.191637	34446	turkeys
44.923871	-95.048968	17221	turkeys
44.910901	-94.882521	6816	turkeys
44.90874	-95.13003	163224	turkeys
44.906578	-95.182991	56536	turkeys
44.899012	-95.020867	65887	turkeys
48.672178	-94.42317	32845	turkeys
47.956671	-93.126178	9045	turkeys
44.949811	-96.067107	68123	turkeys
47.056342	-91.669223	29043	turkeys
47.020675	-91.708133	12070	turkeys
48.940223	-95.0641	6	backyard
48.856999	-94.910622	4	backyard
48.806201	-94.764711	4	backyard
48.658127	-94.65879	3	backyard
44.528289	-93.649298	155	backyard

Latitude	Longitude	Population	Production Type
44.506672	-93.830877	939	backyard
44.496945	-93.703339	1343	turkeys
44.483975	-93.736845	359	backyard
44.466682	-93.771431	4212	turkeys
44.345629	-93.751976	363	backyard
44.344548	-93.88816	1354	turkeys
44.289426	-93.839523	688	backyard
44.225657	-93.6266	1677	turkeys
44.204041	-93.634166	59956	turkeys
44.491541	-96.183836	38140	turkeys
44.560714	-96.056299	115529	turkeys
44.489379	-95.762314	353374	turkeys
44.303477	-95.995772	117862	turkeys
44.209445	-95.722323	56568	turkeys
44.914144	-94.116215	6	backyard
44.839567	-94.092437	2	backyard
44.833082	-94.494504	3	backyard
44.832001	-94.118376	6	backyard
44.819031	-94.252399	3	backyard
44.79093	-94.045961	3	backyard
44.699059	-94.341027	2	backyard
44.640695	-94.42317	3	backyard
47.323306	-95.794739	68331	turkeys
47.283316	-96.026035	30357	turkeys
48.279838	-95.739616	83421	turkeys
48.247413	-96.606439	82177	turkeys
43.846287	-94.647981	13728	turkeys
43.833317	-94.777681	3438	turkeys
43.800892	-94.518282	882	backyard
43.730639	-94.7766	13298	turkeys
43.690648	-94.626365	32697	turkeys
43.654981	-94.798216	2081	turkeys
43.647415	-94.790651	3281	turkeys
45.306484	-94.459918	2855	turkeys
45.264332	-94.404795	10403	turkeys
45.260008	-94.579889	25602	turkeys
45.226503	-94.569081	17932	turkeys
45.213533	-94.627446	9171	turkeys

Latitude	Longitude	Population	Production Type
45.19732	-94.709589	10512	turkeys
45.054651	-94.464241	3981	turkeys
45.016822	-94.350754	17082	turkeys
44.993044	-94.530171	5939	turkeys
44.928195	-94.538818	31261	turkeys
44.902255	-94.660951	12124	turkeys
45.897696	-93.680642	6	backyard
45.66748	-93.588771	3	backyard
45.664238	-93.714147	6	backyard
45.642621	-93.73036	6	backyard
45.627489	-93.714147	3	backyard
45.625328	-93.735764	2	backyard
45.616681	-93.638489	6	backyard
46.297602	-94.576647	28657	turkeys
46.110619	-94.368047	39489	turkeys
46.107376	-94.500989	144359	turkeys
46.095487	-94.337784	12880	turkeys
46.083598	-94.399391	13178	turkeys
46.079275	-94.427493	62213	turkeys
46.078194	-94.167014	12340	turkeys
46.063063	-94.056769	28758	turkeys
46.026314	-94.154044	40393	turkeys
46.015506	-94.060012	26716	turkeys
45.999294	-94.51504	7666	turkeys
45.998213	-94.597183	12853	turkeys
45.996051	-94.421008	59971	turkeys
45.989566	-94.426412	7314	turkeys
45.979839	-94.470726	39525	turkeys
45.966869	-94.432897	4145	turkeys
45.94201	-94.061093	25136	turkeys
45.939848	-94.110811	15234	turkeys
45.934444	-94.469645	7897	turkeys
45.921474	-93.824392	43765	turkeys
45.896615	-93.879514	72444	turkeys
45.880403	-93.921666	57243	turkeys
45.873918	-94.560435	30094	turkeys
45.869595	-94.040557	44846	turkeys
45.866352	-94.627446	17340	turkeys

Latitude	Longitude	Population	Production Type
45.856625	-94.302117	67711	turkeys
45.854463	-93.846008	10955	turkeys
45.85014	-93.885999	22221	turkeys
45.844736	-94.381017	17068	turkeys
45.843655	-94.202681	3860	turkeys
45.835008	-94.421008	25937	turkeys
45.792856	-94.517201	20833	turkeys
45.78529	-94.51504	35032	turkeys
45.782048	-94.546384	23725	turkeys
45.776644	-94.452352	35502	turkeys
43.835479	-93.012691	4123	turkeys
43.773872	-92.525238	14538	turkeys
43.769548	-92.52848	13918	turkeys
43.613909	-92.677635	19364	turkeys
44.082988	-95.663959	137707	turkeys
43.792246	-95.538583	68222	turkeys
43.777114	-95.746101	16406	turkeys
43.730639	-95.997934	23180	turkeys
47.443278	-96.460528	112055	turkeys
43.95437	-92.382569	18709	turkeys
43.854934	-92.589007	90634	turkeys
46.708316	-95.549391	85832	turkeys
46.600233	-96.124391	17368	turkeys
46.596991	-95.328902	71182	turkeys
46.589425	-96.046571	10418	turkeys
46.585102	-95.612079	120962	turkeys
46.540788	-95.308367	31830	turkeys
46.539707	-96.261656	33320	turkeys
46.533222	-96.095208	49791	turkeys
46.533222	-95.531017	32058	turkeys
46.487827	-95.453197	36057	turkeys
46.468373	-96.181674	10469	turkeys
46.446756	-95.216496	29540	turkeys
46.403523	-95.340791	44226	turkeys
46.359209	-96.11034	33923	turkeys
46.346239	-95.745021	11438	turkeys
46.346239	-95.22082	86624	turkeys
46.314895	-96.201129	50673	turkeys

Latitude	Longitude	Population	Production Type
46.312734	-95.15597	74707	turkeys
46.280309	-95.154889	10868	turkeys
46.237076	-96.095208	64661	turkeys
46.212217	-95.478056	93329	turkeys
46.194923	-95.981722	29128	turkeys
46.187358	-95.308367	300028	turkeys
46.170064	-96.082238	15467	turkeys
46.119266	-96.249767	59999	turkeys
46.109538	-96.232473	101922	turkeys
48.166351	-95.921195	46599	turkeys
47.993419	-95.649908	141656	turkeys
46.264096	-92.950003	6	backyard
46.226267	-92.90677	3	backyard
46.219782	-93.006206	4	backyard
46.213297	-92.861375	3	backyard
46.197085	-92.77599	5	backyard
46.157094	-92.786798	4	backyard
46.149529	-92.892719	6	backyard
46.089002	-92.951084	2	backyard
46.037123	-92.993236	3	backyard
46.009021	-92.955407	3	backyard
45.905262	-93.057005	3	backyard
45.858786	-92.911093	5	backyard
45.858786	-92.859213	4	backyard
45.776644	-93.057005	4	backyard
45.752865	-92.99864	6	backyard
43.9414	-96.086562	54221	turkeys
48.003146	-96.749108	20778	turkeys
47.834537	-96.649672	50740	turkeys
45.729087	-95.565603	37779	turkeys
45.698824	-95.742859	25861	turkeys
45.696662	-95.424015	24186	turkeys
45.491305	-95.35268	24654	turkeys
45.414567	-95.568846	18001	turkeys
45.114097	-93.104561	111118	turkeys
47.893983	-96.375142	8471	turkeys
47.856154	-96.072511	124589	turkeys
44.626644	-95.318094	5431	turkeys

Latitude	Longitude	Population	Production Type
44.479652	-95.375378	23287	turkeys
44.447227	-95.24784	10179	turkeys
44.440742	-95.327821	29732	turkeys
44.3867	-95.113818	14414	turkeys
44.373731	-95.092201	26008	turkeys
44.367246	-94.950613	11113	turkeys
44.362922	-95.492107	24214	turkeys
44.308881	-95.253244	11590	turkeys
44.288345	-95.555876	119771	turkeys
44.235385	-95.184072	22539	turkeys
44.206202	-95.427257	38228	turkeys
44.838486	-95.000331	2638	turkeys
44.784445	-94.806863	21468	turkeys
44.746616	-94.561515	43361	turkeys
44.745535	-94.620961	11695	turkeys
44.540178	-93.445021	13021	turkeys
44.494783	-93.470961	63310	turkeys
44.465601	-93.421243	40489	turkeys
44.429934	-93.214805	26494	turkeys
44.420206	-93.180219	8753	turkeys
44.403994	-93.479608	26536	turkeys
44.34671	-93.158602	65873	turkeys
44.311043	-93.06457	40177	turkeys
44.303477	-93.164007	12610	turkeys
44.271052	-93.445021	14477	turkeys
44.261325	-93.419082	64672	turkeys
44.220253	-93.37801	53429	turkeys
44.211607	-93.496901	76267	turkeys
43.69281	-96.128714	10	backyard
43.570676	-96.147088	38	backyard
43.546898	-96.098451	25	backyard
43.519877	-96.389193	29	backyard
48.917526	-96.033601	31719	turkeys
48.811605	-95.523451	3415	turkeys
48.802958	-95.497511	3571	turkeys
48.746755	-95.556957	82898	turkeys
48.742432	-96.187079	69930	turkeys
48.734866	-96.094128	25442	turkeys

Latitude	Longitude	Population	Production Type
48.693795	-96.0844	21693	turkeys
47.55028	-92.924063	6	backyard
47.534068	-92.336093	59	backyard
47.489754	-92.686281	17	backyard
47.357893	-92.935952	47	backyard
47.075797	-92.840839	35	backyard
47.059585	-92.729514	53	backyard
46.859632	-92.01833	83	backyard
46.855308	-92.920821	6	backyard
46.798025	-92.712221	36	backyard
44.723918	-93.502305	11	backyard
44.690413	-93.531488	18	backyard
44.68717	-93.557427	21	backyard
44.655826	-93.673076	66	backyard
44.655826	-93.333696	15	backyard
44.606108	-93.732521	42	backyard
44.563956	-93.567155	6	backyard
44.544501	-93.552023	26	backyard
44.544501	-93.499063	21	backyard
45.546427	-93.833038	11	backyard
45.543185	-94.072982	9	backyard
45.489144	-93.915181	41	backyard
45.4578	-93.898969	13	backyard
44.670958	-94.048123	10	backyard
44.598542	-94.377775	7	backyard
44.554229	-94.55395	8	backyard
44.53045	-94.155125	36	backyard
44.499106	-94.066497	8	backyard
45.767997	-94.282662	24176	turkeys
45.764754	-94.590698	69394	turkeys
45.730168	-94.92035	18691	turkeys
45.721521	-94.425331	23220	turkeys
45.717198	-95.002493	25502	turkeys
45.630732	-95.124626	60292	turkeys
45.62857	-94.401553	35836	turkeys
45.61452	-94.284824	11739	turkeys
45.612358	-94.510717	20723	turkeys
45.603711	-94.25348	40359	turkeys

Latitude	Longitude	Population	Production Type
45.60155	-95.060857	6183	turkeys
45.596145	-95.010058	28612	turkeys
45.591822	-94.547465	38387	turkeys
45.585337	-94.622042	77046	turkeys
45.559397	-94.387502	43594	turkeys
45.555074	-95.002493	36417	turkeys
45.506437	-94.325895	17268	turkeys
45.502114	-94.94629	72796	turkeys
45.494548	-94.827399	80300	turkeys
45.490224	-95.110575	62503	turkeys
45.472931	-94.699861	52515	turkeys
45.468608	-94.82848	16962	turkeys
45.468608	-94.469645	11802	turkeys
45.45888	-94.209166	7578	turkeys
45.45888	-94.130266	139925	turkeys
45.439426	-94.866308	13788	turkeys
45.432941	-94.673921	27382	turkeys
45.397273	-94.259965	12886	turkeys
45.390788	-94.457756	138329	turkeys
45.390788	-94.254561	47585	turkeys
45.386465	-94.212408	86268	turkeys
45.371334	-94.14864	16014	turkeys
45.370253	-94.663113	306472	turkeys
45.368091	-94.124861	442489	turkeys
45.329181	-94.223217	6811	turkeys
45.324858	-94.186469	235941	turkeys
45.315131	-94.232944	32633	turkeys
45.292433	-94.325895	48757	turkeys
44.144595	-93.330454	6254	turkeys
44.131625	-93.162926	35668	turkeys
44.064614	-93.320726	40229	turkeys
44.063533	-93.269928	62836	turkeys
44.057048	-93.174815	24569	turkeys
44.041917	-93.145632	15798	turkeys
44.038674	-93.222371	94995	turkeys
43.933834	-93.265604	63264	turkeys
43.921945	-93.154279	63383	turkeys
43.907894	-93.402869	9492	turkeys

Latitude	Longitude	Population	Production Type
45.399435	-95.982802	209347	turkeys
45.365929	-95.440227	168500	turkeys
45.274059	-96.011985	136930	turkeys
45.240553	-95.852022	291221	turkeys
45.22326	-95.625049	409991	turkeys
45.222179	-95.913629	150469	turkeys
45.222179	-95.57425	377372	turkeys
45.19624	-95.609917	60391	turkeys
45.172461	-95.986045	138700	turkeys
46.345158	-94.751741	26017	turkeys
46.342997	-94.805782	66728	turkeys
46.251126	-94.67176	76877	turkeys
46.212217	-94.925754	43614	turkeys
46.152771	-94.931158	311489	turkeys
46.120346	-94.926835	380716	turkeys
46.068467	-94.928996	96296	turkeys
46.02091	-94.956017	178741	turkeys
46.012264	-95.134353	40866	turkeys
45.99497	-95.146243	107388	turkeys
45.945252	-94.974391	56571	turkeys
45.914989	-95.066261	58015	turkeys
45.871756	-95.081393	444466	turkeys
45.783128	-94.659871	103510	turkeys
44.345629	-92.17505	7	backyard
44.338063	-92.424721	8	backyard
44.178101	-92.131817	8	backyard
46.646709	-94.844692	6038	turkeys
46.591587	-95.152728	12555	turkeys
46.505121	-94.98628	10229	turkeys
46.497555	-95.023028	13261	turkeys
46.446756	-94.867389	1860	turkeys
46.415412	-95.032756	1434	turkeys
46.401361	-94.905218	1769	turkeys
46.384068	-94.928996	5658	turkeys
44.13811	-93.705501	2492	turkeys
44.12406	-93.561751	12572	turkeys
44.087311	-93.71739	15923	turkeys
44.081907	-93.693612	1359	turkeys

Latitude	Longitude	Population	Production Type
44.03327	-93.701177	11182	turkeys
43.945723	-93.610388	75354	turkeys
43.938157	-93.539053	3195	turkeys
43.890601	-93.695773	1780	turkeys
43.99436	-94.803621	137765	turkeys
43.86358	-94.821995	64456	turkeys
44.053806	-91.927541	43303	turkeys
43.99328	-91.879984	10889	turkeys
43.96734	-92.0313	4090	turkeys
43.946804	-91.894035	28884	turkeys
45.271897	-94.052446	80134	turkeys
45.270817	-93.880595	6112	turkeys
45.263251	-94.110811	571	backyard
45.254604	-93.821149	12900	turkeys
45.247038	-93.53473	1020	turkeys
45.186512	-93.700097	7020	turkeys
45.150845	-94.22754	24156	turkeys
45.121663	-93.755219	4596	turkeys
45.11842	-93.722794	1797	turkeys
45.117339	-94.252399	6938	turkeys
45.101127	-93.904373	4762	turkeys
44.801738	-95.650989	10221	turkeys
44.793091	-96.171947	48802	turkeys
44.776879	-96.154654	64392	turkeys
44.677443	-95.618564	31057	turkeys
44.637452	-96.251928	17860	turkeys
44.635291	-95.73097	8033	turkeys
44.576926	-95.582897	22662	turkeys

Table A.4. Minnesota HPAI Cases Reported

County	Flyway	Type	Breed	Date	Size
Pope	Mississippi	Commercial	Turkeys	3/4/15	44000
Lac Qui Parle	Mississippi	Commercial	Turkeys	3/27/15	66000
Stearns	Mississippi	Commercial	Turkeys	4/2/15	65700
Nobles	Mississippi	Commercial	Turkeys	4/2/15	21000
Stearns	Mississippi	Commercial	Turkeys	4/4/15	78000
Kandiyohi	Mississippi	Commercial	Turkeys	4/4/15	26500
Meeker	Mississippi	Commercial	Turkeys	4/7/15	310000
Kandiyohi	Mississippi	Commercial	Turkeys	4/7/15	30000
Watonwan	Mississippi	Commercial	Turkeys	4/9/15	30000
Stearns	Mississippi	Commercial	Turkeys	4/9/15	45000
Lyon	Mississippi	Commercial	Turkeys	4/9/15	66000
Cottonwood	Mississippi	Commercial	Turkeys	4/9/15	48000
Le Sueur	Mississippi	Commercial	Turkeys	4/11/15	21500
Kandiyohi	Mississippi	Commercial	Turkeys	4/11/15	38400
Swift	Mississippi	Commercial	Turkeys	4/13/15	153500
Stearns	Mississippi	Commercial	Turkeys	4/13/15	68500
Swift	Mississippi	Commercial	Turkeys	4/14/15	154000
Redwood	Mississippi	Commercial	Turkeys	4/14/15	84800
Meeker	Mississippi	Commercial	Turkeys	4/14/15	26100
Meeker	Mississippi	Commercial	Turkeys	4/14/15	18400
Kandiyohi	Mississippi	Commercial	Turkeys	4/14/15	30700
Stearns	Mississippi	Commercial	Turkeys	4/15/15	67000
Otter Tail	Mississippi	Commercial	Turkeys	4/15/15	19400
Kandiyohi	Mississippi	Commercial	Turkeys	4/15/15	152000
Roseau	Mississippi	Commercial	Turkeys	4/16/15	26900
Kandiyohi	Mississippi	Commercial	Turkeys	4/17/15	23000
Redwood	Mississippi	Commercial	Turkey	4/20/15	35500
Wadena	Mississippi	Commercial	Turkeys	4/20/15	301000
Redwood	Mississippi	Commercial	Turkeys	4/20/15	24300
Kandiyohi	Mississippi	Commercial	Turkeys	4/20/15	62200
Kandiyohi	Mississippi	Commercial	Turkeys	4/20/15	5000
Cottonwood	Mississippi	Commercial	Turkeys	4/20/15	7500
Stearns	Mississippi	Commercial	turkeys	4/21/15	53900
Meeker	Mississippi	Commercial	Turkeys	4/21/15	10700
Meeker	Mississippi	Commercial	Turkeys	4/21/15	34100
Kandiyohi	Mississippi	Commercial	turkeys	4/21/15	130400
Kandiyohi	Mississippi	Commercial	Turkeys	4/21/15	43600

County	Flyway	Type	Breed	Date	Size
Pipestone	Mississippi	Backyard	Mixed Poultry	4/22/15	150
Stearns	Mississippi	Commercial	turkeys	4/22/15	72500
Stearns	Mississippi	Commercial	turkeys	4/22/15	28600
Otter Tail	Mississippi	Commercial	turkeys	4/22/15	34500
Meeker	Mississippi	Commercial	turkeys	4/22/15	58900
Kandiyohi	Mississippi	Commercial	turkeys	4/22/15	34500
Kandiyohi	Mississippi	Commercial	turkeys	4/22/15	19100
Kandiyohi	Mississippi	Commercial	turkeys	4/22/15	62600
Clay	Mississippi	Commercial	Layer Chickens	4/23/15	408500
Kandiyohi	Mississippi	Commercial	turkeys	4/23/15	54300
Kandiyohi	Mississippi	Commercial	turkeys	4/23/15	36900
Meeker	Mississippi	Commercial	Turkeys	4/24/15	40200
Kandiyohi	Mississippi	Commercial	turkeys	4/24/15	67000
Kandiyohi	Mississippi	Commercial	turkeys	4/24/15	42900
Chippewa	Mississippi	Commercial	turkeys	4/24/15	64900
Stearns	Mississippi	Commercial	turkeys	4/27/15	26900
Swift	Mississippi	Commercial	turkeys	4/28/15	18000
Steele	Mississippi	Commercial	turkeys	4/28/15	82900
Stearns	Mississippi	Commercial	Turkeys	4/28/15	19100
Stearns	Mississippi	Commercial	turkeys	4/28/15	45100
Kandiyohi	Mississippi	Commercial	turkeys	4/28/15	8400
Kandiyohi	Mississippi	Commercial	turkeys	4/28/15	50900
Kandiyohi	Mississippi	Commercial	turkeys	4/28/15	4200
Kandiyohi	Mississippi	Commercial	turkeys	4/28/15	32100
Stearns	Mississippi	Commercial	Layer Chickens	4/29/15	202500
Kandiyohi	Mississippi	Commercial	Turkeys	4/29/15	13200
Kandiyohi	Mississippi	Commercial	turkeys	4/30/15	11200
Stearns	Mississippi	Commercial	Turkeys	5/1/15	20500
Stearns	Mississippi	Commercial	Turkeys	5/1/15	14800
Otter Tail	Mississippi	Commercial	Turkeys	5/1/15	36400
Swift	Mississippi	Commercial	Turkeys	5/4/15	46200
Renville	Mississippi	Commercial	Turkeys	5/4/15	12900
Meeker	Mississippi	Commercial	Turkeys	5/4/15	30400
Kandiyohi	Mississippi	Commercial	Turkeys	5/4/15	0
Kandiyohi	Mississippi	Commercial	Turkeys	5/4/15	7400

County	Flyway	Type	Breed	Date	Size
Nicollet	Mississippi	Commercial	Layer Chickens	5/5/15	1102900
Swift	Mississippi	Commercial	Turkeys	5/5/15	151300
Pipestone	Mississippi	Commercial	Turkeys	5/5/15	72200
Kandiyohi	Mississippi	Commercial	Turkeys	5/5/15	89100
Kandiyohi	Mississippi	Commercial	Turkeys	5/5/15	40600
Kandiyohi	Mississippi	Commercial	Turkeys	5/5/15	37300
Kandiyohi	Mississippi	Commercial	Turkeys	5/6/15	65000
Swift	Mississippi	Commercial	Turkeys	5/11/15	65600
Kandiyohi	Mississippi	Commercial	Turkeys	5/11/15	22400
Swift	Mississippi	Commercial	Turkeys	5/12/15	37900
Meeker	Mississippi	Commercial	Turkeys	5/18/15	138800
Renville	Mississippi	Commercial	Layer Chickens	5/19/15	2045600
Kandiyohi	Mississippi	Commercial	Turkeys	5/19/15	42600
Renville	Mississippi	Commercial	Turkeys	5/27/15	95300
Brown	Mississippi	Commercial	Turkeys	5/27/15	46800
Renville	Mississippi	Commercial	Turkeys	5/28/15	48900
Kandiyohi	Mississippi	Commercial	Turkeys	5/28/15	50800
Renville	Mississippi	Commercial	Turkey	5/29/15	29300
Meeker	Mississippi	Commercial	Turkey	5/29/15	4900
Brown	Mississippi	Commercial	Turkey	5/29/15	7300
Renville	Mississippi	Commercial	Turkeys	6/1/15	47800
Brown	Mississippi	Commercial	Turkeys	6/1/15	18300
Blue Earth	Mississippi	Commercial	Turkeys	6/2/15	19400
Kandiyohi	Mississippi	Commercial	Turkeys	6/3/15	37000
Brown	Mississippi	Commercial	Turkeys	6/3/15	15900
Renville	Mississippi	Commercial	Pullet Chickens	6/4/15	415000
Renville	Mississippi	Commercial	Turkeys	6/4/15	24800
Kandiyohi	Mississippi	Commercial	Turkeys	6/5/15	44000
Brown	Mississippi	Commercial	Turkeys	6/5/15	39000