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Cost Parameters of an Outbreak of Foot and Mouth Disease

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Introduction

Foot and mouth disease, commonly referred to as FMD, is a devastating and highly contagious viral disease that can affect animals with cloven hooves such as cattle, small ruminants, and pigs. The etiological agent is foot and mouth disease virus (FMDV). The disease is generally characterized by fever, lameness, and vesicular lesions on the tongue, feet, snout, and teats (Grubman & Baxt, 2004). Vesicular lesions caused by FMDV pop and turn into red areas called erosions which cause immense pain and discomfort; this, in turn, leads to other symptoms such as depression, anorexia, excessive salvation, lameness, and reluctance to move or stand (APHIS, 2013). The virus does not usually cause death, but it does cause weight loss, decreases in milk production, and losses in draught power (Grubman and Baxt, 2004). Animals with these symptoms quickly become weak and unproductive. FMDV spreads through a variety of methods, making the disease even more alarming. The contagious nature of the virus and the fact that it is not always easily noticed—because lesions are typically found in the mouth—allows it to spread rapidly. FMD is currently listed as an OIE List A disease, meaning that it has the potential to spread extensively and rapidly within and between countries, causing a severe economic impact (Alexandersen et al., 2003). Currently, FMD is enzootic in all continents except North America and Australia, causing concern for potential spread to these continents.

In the instance of an outbreak, there would be a variety of devastating consequences for animals, the general public, and the economy. A major consequence would be the impact an outbreak would have on trade. Trade would be disrupted between countries, leading to trade embargos as a result from attempts to protect agriculture industries and food supplies (Boisvert et al., 2012). The OIE Animal Health Code regulates when a country can resume exports, and a country can be granted FMD free status 3 months after the last outbreak if the control method is slaughter and 12 months after the last outbreak if the control method is vaccination (Davies, 2002). Another consequence would be the effect on the supply chain. A large reduction in animal numbers due to depopulation would cause a reduction in the availability of animals for food products (Boisvert et al., 2012). With depopulation would come a great deal of social effects on the rural population. Producers would have to face losing the herds they may have spent years establishing. In addition to these consequences, there is the potential for widespread consumer concerns regarding the safety of meat and dairy products. This was noticed in the 1997 Taiwan outbreak where there was a temporary rejection of pork products due to the amount of publicity that the epidemic received. Their concerns revolved around the idea that FMD might be zoonotic as well as ethical concerns about the method of destroying healthy pigs (Yang et al. 1997). These consequences would each come with their own set of issues that would need to be dealt with in the instance of an outbreak.

FMD has been a known disease for hundreds of years. The first description of the disease was in 1546 by an Italian monk Girolamo Fracastoro (Sutmoller et al., 2002). In 1897, Loeffler and Frosch found that FMD was caused by a filterable agent, and determined that it was likely a viral disease. There have even been large-scale epidemics in recent years throughout the world. These epidemics include those occurring in Taiwan in 1997, South Korea in 2000, the United Kingdom in 2001, and Japan in 2010. The 1997 Taiwan outbreak occurred after the country had been disease free for over 68 years. It was identified in March and had spread throughout the entire island within four months (Yang et al., 1999). This outbreak was unique in that the virus infected only pigs even on farms also inhabited by both cattle and goats. Throughout the span of the four month outbreak, 4.03 million pigs were destroyed, and the outbreak was estimated to cost a total of approximately $6 billion. The Korean outbreak began in March of 2002. It was controlled by depopulation and vaccination of all potentially infected animals, resulting in the slaughter of over 500,000 animals (Grubman and Baxt, 2004). The outbreak in the United Kingdom started in February 2001 and all countries were declared disease free by January 2002. For this outbreak, all infected and in-contact susceptible animals were depopulated, resulting in the slaughter of 4 million animals with 2.5 million more animals being slaughtered for welfare reasons. The total estimated economic losses were between $12.3 and 13.8 billion (Grubman and Baxt, 2004). The principal costs associated with this outbreak were from the slaughter and disposal of livestock, the cleaning and disinfection of premises where slaughter occurred, and administration costs (Thompson et al. 2002). The epidemic occurring in Japan was confirmed on April 20, 2010. It occurred in an area that was heavily populated with cattle and pigs and lasted for three months. This particular outbreak was contained by emergency vaccination (Hayama et al., 2013). The initial control measures once the disease was first detected were restrictions on movement, culling animals on detected farms, and increasing biosecurity measures. Even though these control measures were utilized, it still led to a large-scale epidemic. This outbreak affected 292 farms and 290,000 animals were culled (Hayama et al. 2013). These outbreaks set an example for how disastrous an outbreak could be in an unaffected area.

The clinical signs associated with foot and mouth disease are fairly consistent across species; however, there are some unique characteristics for different animals. The signs are generally characterized by an acute febrile reaction accompanied by vesicles in and around the mouth and on the feet. Infection by FMDV results in fever, general depression and dullness, a reduction in feed intake, an inability to maintain body temperature, and sometimes death (Alexandersen et al., 2003). Pigs and cattle express much more severe signs than sheep, which rarely show vesicles in the mouth. Pigs, sheep, and cattle all present with vesicles in the interdigital space, on the heel bulb, and along the coronary band. Cattle can present with excessive salivation, a drop in milk production, and sometimes abortion. Pigs, specifically, are susceptible to separation of the horn of the hoof and sometimes even complete shedding of the horn of the hoof caused by inflammation of the feet. One complication that accompanies vesicles is that once an animal has ruptured vesicles, that area may be predisposed to secondary infection (Alexandersen et al., 2003). Although the mortality in adult animals is low, one major concern associated with FMD is the high potential for mortality in young animals. Young animals with FMD often die of acute myocarditis, or inflammation of the heart muscle. FMD may also cause abortion in pregnant animals (Alexandersen et al., 2003). FMD is a somewhat unique disease in that some animals can be persistently infected and become known as carrier animals. A carrier animal is one that the virus can be recovered from 28 or more days following infection (Davies, 2002). For domestic species, cattle have the longest reported carrier state at 3.5 years. Sheep have a much shorter carrier state at nine months, and goats are even shorter at four months. Uniquely, pigs have no reported carrier state (Alexandersen et al., 2003).

Foot and mouth disease virus is the causative agent for foot and mouth disease. FMDV belongs to the *Apthovirus* genus and the *Picornaviridae* family (Grubman and Baxt, 2004). It is a single stranded, non-enveloped, plus-sense RNA virus (Alexandersen et al., 2003). One of the major reasons that FMD is so difficult to develop an effective vaccine and establish an effective diagnostic tool is that there are seven serotypes, each with multiple subtypes (Grubman and Baxt, 2004). The virus can survive in the environment, but there are a variety of factors that determine the length of time it can survive. These factors include the initial viral concentration in the contaminated material, the strain of the virus, the humidity, the pH, and the temperature. The

FMDV is a moderately stable virus; however, it can be inactivated by heat and the proper disinfectants (Alexandersen et al., 2003).

The foot and mouth disease virus is transmitted very readily between animals and farms through both direct and indirect contact. FMDV spreads between farms by direct contact between animals, or by indirect contact with contaminated animal products, by mechanical transfer on people or fomites (e.g., vehicles carrying contaminated dirt on their tires), in addition to local and airborne transmission (Gloster et. al., 2010). Pigs release the greatest amount of airborne virus, whereas cattle excrete less virus in their breath but are more susceptible to infection via the respiratory route. This combination makes airborne transmission from pig farms to cattle farms the most likely route between farms (Alexandersen et al., 2003). Infected animals secrete virus in all bodily secretion, including milk, semen, urine, saliva, and feces (Grubman and Baxt, 2004). Alexandersen et al. (2003) stated that feeding virus-contaminated material to animals has caused many of the recent outbreaks. The incubation period, which is the interval of time between exposure to an infective dose of virus to the appearance of clinical signs, ranges from 4 to 14 days between farms for airborne spread and from 2 to 14 days as a result of direct contact. The incubation period is so variable due to the different factors such as the strain and dose of the virus, the route of transmission, the animal species, and the husbandry conditions (Alexandersen et al., 2003). The combination of these factors makes the potential for rapid spread of the disease high, which is a major cause for concern.

Due to the potential for rapid spread of FMD, it is necessary that a hasty investigation be performed if an infection is suspected. The more rapid the diagnosis, the more quickly control measures may be enacted. FMD is challenging to clinically diagnose simply due to the fact that there are several other viral vesicular diseases that present with lesions very similar to those found in FMD infected animals. These diseases include swine vesicular disease, vesicular stomatitis, and vesivirus infection (Alexandersen et al., 2003). If a case of FMD were suspected, there would be an initial investigation performed by USDA APHIS at Plum Island, New York. Once an outbreak is confirmed, National Animal Health Laboratory Network (NAHLN) labs would then be authorized to test swab samples for FMDV (USDA, 2015). Currently there is a major need for an effective on-site diagnostic tool in order to establish a more rapid diagnosis.

Foot and mouth disease is most well known for its potential to cause severe economic upset. The disease can be very painful for the animal, but is especially devastating to the economy (Pendell et al., 2007). Ultimately, the economic outcome of an outbreak depends on the control strategy and farm density in an outbreak area (Bergevoet and Asseldonk, 2014). This makes predicting the overall costs involved with an outbreak rather challenging. The total costs of an epidemic are the sum of the direct and indirect costs. Direct costs would include surveillance, depopulation, cleaning and disinfection, empty stable, compensation, and the costs associated with having a national standstill. The indirect costs would involve restrictions on exports, losses in tourism revenue, and all of the costs that agricultural producers would incur (Halasa et al., 2013). The costs that agricultural producers would incur include losses in production (Knight-Jones and Rushton, 2013), price changes, and the costs associated with withholding animals (Thompson et al., 2002). The losses do not stop with producers, but they also impact the industries that supply goods and services to the directly affected sectors (Thompson et al., 2002). So many areas of the national economy would be impacted by a large epidemic, even those that are not directly connected to the livestock industry.

The most recent outbreak in the United States was in 1929; however, there is a constantly growing concern about a major biosecurity event, which would affect the agriculture industry in the United States as well as its marketing channels and international trade. Terrorist organizations or rogue states could easily target the $100 billion per year United States livestock industry by employing the etiologic agent of FMD (Grubman and Baxt, 2004). An outbreak would be devastating for the supply chain as well as United States exports of livestock, meat, and dairy products (Boisvert et al., 2012). Paarlberg et al. (2002) found that a large FMD outbreak could lead to a $14 billion loss in farm income for the United States. These facts are why there are such extensive measures put in place to protect the United States from the threats of an outbreak.

Although the United States has been free of FMD since 1929 (Grubman & Baxt, 2004), the potential for an outbreak is always present. Foot-and-mouth disease would be acted upon quickly by the United States Department of Agriculture's Animal and Plant Health Inspection Service (USDA APHIS) to prevent spread of the disease as much as possible. Alexandersen et al. (2003) mentioned that extreme measures would be necessary in order to eradicate FMD, and if rapid and effective application is not applied, the probability of an outbreak reaching epidemic status greatly increases. If an outbreak were to happen, numerous decisions would need to be made to best fit the situation. Sutmoller et al. (2002) listed the different options for control strategies as stamping-out infected farms and direct potential contagious contacts, stamping-out infected farms and ring culling, stamping-out infected farms plus ring vaccination, stamping-out infected farms plus ring vaccination with subsequent slaughter of vaccinated animals, ring vaccination only and slaughter of vaccinated animal, or strategic vaccination. Each step involved with controlling an outbreak would involve decisions. One of the more costly steps is disposal. Yang et al. (1999) compared the cost of various disposal methods and determined that the easiest and most cost effective method of disposal was burial. Typical USDA protocol would include quarantining the facility where infected livestock are present and restricting the movement of people and livestock into and out of the area, destroying the herd and nearby herds if necessary, declaring a state of agricultural emergency which would free up money to help control the disease and compensate farmers for production losses, determining whether vaccinating animals would help to slow the spread (as vaccines are not always guaranteed to be effective), and closing all livestock and meat export markets for up to ninety days following successful control of the disease (Mathur, 2001). Depopulation would be met with a great deal of social pressure, so other methods such as protective emergency vaccination in order to avoid the negative public perception would also be explored (Halasa et al., 2013). Although euthanasia is accompanied by social pressure, Hayama et al. (2013) found that the prompt culling strategy of detected farms was the ideal method to control the spread of disease. They did agree, however, that this method would require the greatest amount of resources. When facing an outbreak, it would be important for officials to evaluate the situation and establish the best method for control.

In the case of an outbreak, the first step in response efforts, following determination of infected animals, would be euthanizing the affected herds. This would involve rendering each animal unconscious using either a captive bolt gun or a tranquilizer prior to administering a euthanasia solution. The methods of restraint used during euthanasia would depend on the availability of animal handling equipment and general setup of the operation.

Following euthanasia, disposal of the carcasses would be required. When planning for this stage of response, certain environmental and safety factors would need to be kept in mind. First, to prevent spread of the disease, proper covering of the carcasses is necessary. Additionally, ground water needs to be protected by the use of plastic liners, particularly in the case of burial. The disposal method would depend highly on available space and resources. Social acceptance should also be kept in mind. Burning of animal carcasses, for example – as was done during the UK outbreak in 2001 – might not be as acceptable in today's more animal-welfare conscious society.

Upon disposal of infected carcasses, proper cleaning and disinfection of potentially contaminated areas would be required. Two methods would be used: dry cleaning methods and wet cleaning. Dry cleaning involves the removal of solid waste and any potentially infected soil, feed, and objects not easily cleaned (e.g., worn wooden feed troughs). Wet cleaning involves disinfection of any remaining cleanable surfaces (e.g., metal feed troughs, metal fence panels, concrete floors). If the infected herd is in a pasture setting, the pasture would be rested for several months, until the virus is no longer contagious.

The final step involved in the response would be to consider vaccinating vulnerable, yet uninfected, herds. Such vaccination would occur within a carefully selected perimeter surrounding the infected herds. The size of this perimeter would depend on the potential for infected herds to spread the disease to nearby farms. This, in turn, depends on factors such as distance between farms, number of shared fence-lines, prior movement of animals/people/vehicles between farms, movement of any flowing water between farms, and wind speed and direction.

While the general steps of an FMD response seem straightforward, the details of carrying out such a response are intricate and vary widely depending on the circumstances encountered on each unique farm. The type of animals affected (e.g., beef cows, dairy cows, sheep, pigs), the size of the operation, the animals' location at the time of infection (e.g., pasture, corral, barn, feedlot), and type of animal-handling facilities available on-site all influence the methods of response used. In turn, the methods used influence the cost of the response efforts. The purpose of the study detailed below is to analyze the cost parameters of foot and mouth disease in the United States for cattle, sheep, and swine in varying operating situations.

Data Collection Methods

There were three main methods used to gather information. The primary method was secondary data collection, using Internet sources and posted information. Personal communication via phone conversations was also a highly utilized method. Finally, email correspondence was a valuable tool in gathering data.

Partial Budget Analysis

Results

As the methods for calculating a response strategy depend so greatly on a specific scenario, examples detailing the response method for a small cow-calf operation, a small farm flock sheep operation, and a farrow-to-finish swine operation will be used. The example of a small cow-calf operation has 94 head of cattle and is made up of large pastures where cattle handling equipment is not readily available. The example used for sheep will be a farm flock setting with 54 sheep, consisting of numerous pens and the availability of handling equipment as well as access to tractors on site. For the farrow-to-finish swine operation with 766 pigs, the set up would include large barns as well as outdoor facilities where large numbers of animals are fed together. This example will consist of minimal equipment and handling facilities.

Euthanasia – Cattle

For the cow-calf example, the most practical euthanasia method for euthanizing animals in a pasture setting would be using a tranquilizer gun to sedate the animal prior to administering the euthanasia solution. By utilizing this method, it would eliminate the need for cattle handling equipment, which would need to be transported to the location of the animals in this set up.

To estimate the costs associated with euthanasia, previously estimated hourly rates based upon a 94 head operation were used for personnel hours. The personnel involved in the euthanasia process would include one euthanasia operator for six hours, one safety officer for six hours, two euthanasia crew members for six hours, and four animal handlers for six hours. The required number of hours by each class of crew member needed to complete a 94 head operation was adopted from previous APHIS assumptions. Using these assumptions, the total personnel cost per 94 head cattle operation would be $1,656.00

The supplies needed to complete a 94 head operation include Level C PPE (personal protective equipment), a tranquilizer gun with associated accessories, a tranquilizer solution, euthanasia solution, and syringes and needles required to administer the euthanasia solution. The Level C PPE requirements involve skin protection up to chemical/biological resistant clothing (such as Tyvek suits) and air purifying respirator protection. The mandatory dust masks used would fall under Level C (APHIS, 2011). To calculate the overall cost of one PPE unit, the costs of one set of Tyvek coveralls with boots, one dust mask, and one pair of nitrile gloves were added together, and a cost of $8.63 per unit was generated. To estimate the number of PPE units needed for the 94 head operation a don and doff rate of every two hours in the winter and every three hours in the summer was indicated by APHIS. The incidence of disease is estimated to be higher in the winter, and it is the more conservative value, so it was estimated that an eight man team working for six hours would use a total of 24 units of PPE, resulting in a total cost of $207.12 for PPE. The tranquilizer gun was estimated to have a useful life of 5,000 uses, so one 94 head cattle herd will use up 1.9% of the useful life of the gun costing $8.01 per 94 head operation. To administer the tranquilizer solution, 20cc reusable aluminum syringes would be used. The cost incurred per syringe is calculated based on a useful life of 200 uses, costing $0.11 each time, and thus $11.78 for the entire operation. A charge is also required to expel the liquid from the syringe, resulting in a total farm cost of $99.16 for charges. A rubber plunger that is present within the syringe is recommended to be replaced every 3-4 uses, which would cost a total of $84.01. The needles will also need replacing periodically. Assuming they are thoroughly disinfected between each use, one needle should be useful up to 50 times. The total farm cost for needles is $17.35. The final, and most expensive, accessory included with the tranquilizer gun is a propellant, which involves a total farm cost of $127.46. In total, the use of a tranquilizer gun would cost $347.77 per 94 head cattle operation. The calculations associated with the tranquilizer gun and all of the associated accessories are estimated assuming one in every ten animals require a second shot. The tranquilizer solution used for calculations in this study was Xylazine, and the required dose was calculated using an average bovine weight of 1,350 pounds. The recommended dose is 1 milliliter per 220 pounds of body weight, so each animal will be administered an average of 6.12 milliliters of Xylazine, costing $322.34. Following tranquilization of the animal, an intravenous euthanasia solution will be administered using one 60-milliliter syringe, one 30-milliliter syringe, and a 2-inch x 14-gauge needle. In order to provide for the chance of loss or breakage of syringes, six additional needles and syringes were used to calculate the total number needed. The standard recommended dose for euthanasia solution is 1 milliliter per 10 pounds of body weight. In the case of cattle, the recommended dose is slightly excessive, and 70 milliliters is estimated to be an adequate amount for euthanasia of a 1,350-pound animal (Fox, J.D., personal communication, June, 2015). The total cost of the euthanasia solution and the associated supplies comes to $2,848.79 per farm.

The equipment necessary for this method will not require handling equipment; however, it will require the use of a ½ ton pickup in order to transport supplies and a crew. In this case, the pickup would only be needed for half of the day, resulting in a rental cost of $37.50.

Although this method is the most practical for this setting, it may not be the most cost effective, resulting in a total farm cost of $5,420.52 or $57.67 per head. The additional cost of using the tranquilizer gun and solution may not be enough to offset the cost and time input required with using portable cattle handling equipment.

Euthanasia – Sheep

For the farm flock sheep operation, the most practical euthanasia method would be the combination of captive bolt and euthanasia solution. The euthanasia solution would be given after the animal is rendered unconscious by the captive bolt gun. This method would be an option due to the availability of handling and restraint equipment that would be present at a farm flock facility.

In order to estimate the costs associated with euthanasia for a farm flock operation, previously determined APHIS values were used for the required personnel, hourly rates, and required hours. The personnel involved in euthanasia includes a euthanasia operator for three and a half hours, a safety officer for three and a half hours, two euthanasia crew members each for three and a half hours, and four animal handlers for three and a half hours each. With the APHIS assumptions, the total cost of personnel for euthanizing a 54 head sheep flock comes to a total of $966.00.

Euthanasia would also require a number of supplies. The supplies needed would include Level C PPE, a .25 caliber captive bolt gun, charges for the captive bolt gun, euthanasia solution, 30 milliliter disposable syringes, 1 ½-inch x 18-gauge disposable needles, and a sharps container. For an eight man team changing PPE every two hours, the total number of PPE units would be 16 for the entire operation, resulting in a cost of $138.08. The captive bolt gun was estimated to have a useful life of 10,000 uses; so one 54 head flock of sheep would use 0.7% of the overall life of the gun. The total farm cost for the gun would come to $12.46. This value is rather conservative as it was calculated by estimating that three out of every ten head would require a second charge. In order to fire, the captive bolt gun would require charges, which were also calculated based on the estimation that 3 out of every 10 animals will require a second charge, resulting in a total farm cost of $9.13. The euthanasia solution is the most expensive supply at $301.51 for the entire flock. The total amount of euthanasia solution needed was established using a standard dose of 1 milliliter per 10 pounds of body weight. The average ovine weight is 135 pounds, so each animal would require 13.5 milliliters or 729 milliliters for the entire farm. In order to administer the euthanasia solution, 30 milliliter disposable syringes would be necessary. The price of 60 syringes was calculated in case syringes either became contaminated or were broken. The cost of syringes totaled $26.40. In addition to these supplies would be 1 ½-inch x 18-gauge needles. The cost for 60 of these needles would be $8.97. The final supply required for euthanasia is a sharps container for used needles. With bulk pricing, one container would cost only $1.40. The total costs for supplies associated with euthanizing a 54 head flock of sheep comes to $496.55.

The necessary equipment would be quite simple due to the availability of handling equipment on-site. Still, a ½ ton pickup would be needed for transporting supplies and crew members. The pickup would be needed for a third of the day, resulting in a rental cost of only $22.50.

This method is both the easiest method to carry out and the most cost effective. The total costs of euthanasia for the entire farm with this simple strategy comes to a total of $1,485.05 or $27.50 for each sheep.

Euthanasia – Swine

For this example of a 766 head farrow-to-finish operation there is a limited availability of handling equipment, adding a challenge to completing euthanasia measures. For this example, the combination of a tranquilizer or sedative with euthanasia solution will be used. This combination would be practical as well as being one of the more cost effective methods.

In order to estimate the personnel costs associated with euthanasia, the required personnel, hourly rates, and required hours were obtained from previous estimations. The personnel involved in the euthanasia process for swine include a euthanasia operator for six hours, a safety officer for six hours, two euthanasia crew members for six hours each, and four animal handlers for six hours each. By using these values a total farm cost for personnel of $1656.00 for a 766 head swine operation was generated.

The necessary supplies for euthanasia using this method would be Level C PPE, Xylazine as a sedative, euthanasia solution, 12 milliliter disposable syringes, 30 milliliter disposable syringes, 2-inch x 14-gauge disposable needles, 3 ½-inch x 16-gauge disposable needles, and a sharps container. The total number of PPE units for an 8 man team changing every 2 hours came to a total of 24 and costing $207.12. The next cost that would be incurred is the sedative needed to make the animal unconscious prior to euthanasia. For these calculations, the Rompun brand of Xylazine was used. The recommended dose for this drug is 1 milliliter per 220.5 pounds of body weight. This dosage for an average weight pig at 250 pounds is 1.13 milliliters per animal and 868.63 milliliters for the whole farm. The total farm cost for the tranquilizer solution is $486.43. The euthanasia solution is responsible for the largest fraction of the cost of euthanizing an operation at $7,920.44. This value was calculated by first finding the total amount of euthanasia solution needed. Vet One Euthanasia Solution was used to determine the cost of euthanasia. The standard dose is 1 milliliter per 10 pounds of body weight, so the average weight pig would need 25 milliliters. The whole herd would require a total of 19,150 milliliters. To administer the tranquilizer solution, 12 milliliter disposable syringes and 2-inch x 14-gauge disposable needles would be needed. The total cost for the syringe and needle set comes to $276.82. For administration of the euthanasia solution, a 30 milliliter syringe and a 3 ½-inch x 16-gauge disposable needle will be needed for each animal. These needles are also a major portion of the cost at $2,079.00 for the whole farm, and the syringes are only $338.80, totaling $2,417.80 for the entire set. The final cost is the sharps container at only $1.40. The combined cost for all of the supplies needed for euthanasia comes to $11,308.61 per farm.

The final cost category in the euthanasia process is equipment. There will be additional equipment required for this example operation due to the limited availability of handling equipment. The equipment needed will include a 7 feet x 16 feet bumper pull flatbed trailer with tandem 5,000 pound axles, a crew cab ¾ ton pickup with a towing package, a crew cab ½ ton pickup, pig snares, and 8 feet x 50 inch wire panels. The trailer and the two pickups will only be used for half of the day, reaching a total rental cost of $121.75. Five pig snares will be needed for initial restraint of the pigs, and it was estimated that each snare would be able to be used at 100 pig operations before needing replacement. With these estimations, the total farm cost for the snares is only $1.55. The final cost incurred in the equipment category is the wire panels. Previous APHIS assumptions expressed a need for 12 panels, which are also assumed to be useful over 100 operations, costing $1.56 for the entire farm. With all of these calculations, the total farm cost for equipment is $124.86.

The total farm cost for euthanasia achieved by adding the three cost categories comes to a total of $13,089.46 and $17.09 per head. The cost of the euthanasia solution is where a majority of the cost arises from; however, there is a large number of animals being euthanized in this scenario.

Disposal - Cattle

In the case of a small cow-calf operation, on-site burial would likely be the most feasible and cost effective option. By using this method, it would be assumed that an adequate amount of space is available for burial of animals and that the water table is not unusually high and likely to become contaminated.

In order to estimate the costs associated with disposal, previously estimated personnel hourly rates were utilized. The personnel involved in disposal activities include a crew representative for six hours, two crew members for six hours, and a safety officer representative for six hours. The previously estimated time requirement to properly dispose of carcasses from a 94 head operation was also used. Based on these assumptions, a total personnel cost of $888.00 was established.

The supplies needed for on-site burial would include Class C PPE, lime to cover the carcasses, and a thick plastic liner. Using the don and doff rates mentioned earlier, it was estimated that the four man team plus the two contracted equipment operators would require a total of 18 units of PPE. This would involve a cost of $155.34 per operation. One of the more costly aspects of on-site burial is the use of lime to cover the carcasses at $886.06 per operation. This value was reached using a previous APHIS estimate of seven tons per 94 head cattle operation. The final supply for this method is the thick plastic liner for the burial pit to prevent contamination of ground water. One 20 feet x 100 feet x 6 millimeter liner is assumed to be adequate for one operation at a cost of $72.98. The total of these three supplies for the entire operation is $1,114.38.

The most costly aspect of the on-site burial method is the use of equipment. The equipment used will include a track hoe with an operator, a backhoe with an operator, 14-foot chains with hooks on both ends, 5-foot chains with a hook and a ring, and a crew cab ½ ton pickup with a tow package. The operated track hoe and backhoe will each need to be used for the six hours required to finish the operation, and the total cost of this equipment is $1,159.98. The chains will be able to be used extensively across operations, so the total cost incurred per operation due to chain use would be $4.54. The final cost associated with equipment is the use of a ½ ton crew cab pickup, which would only be used for half of one day, resulting in a rental cost of $37.50. The total operation cost of equipment for on-site burial was $1,202.02.

On-site burial, when feasible, would very likely be the most widely used method simply because of the low cost associated with it due to the minimal supplies required compared to other disposal methods. The overall farm cost for on-site burial of a 94 head cattle operation is calculated to be $3,204.40 or $34.09 per head.

Disposal – Sheep

For a small farm flock setting one of the more feasible options would be rendering. For most farms, on-site burial is the least-cost option, but there is not always enough available space. Additionally, for this setting with the low number of animals being disposed of, the costs involved with rendering are actually lower than burial. With rendering, it is assumed that the animals have been euthanized on the farm prior to being transported to a rendering facility, eliminating the added risks involved with transporting live animals.

One advantage of the rendering option is the reduced need for personnel hours compared to the other disposal options. APHIS's previously determined required personnel and hourly rates were used to develop these calculations. The personnel involved in disposal would include one crew representative for three hours, two crew members for three hours each, and one safety officer representative for three hours. Using these assumptions, the total cost of personnel for this example is $444.00.

The second cost category for rendering is the supplies. Since most of the rendering process will take place at a rendering facility, the on-farm supplies are limited. One cost would be the PPE for all of the crew members. 10 units of PPE would be needed for a four man team in addition to the contracted equipment operator changing every two hours in a six hour period, costing $86.30. Rendering costs are considered more of a service cost, but it is included in the supplies section. By averaging costs from different rendering companies, a cost of $3.50 for each 100 pounds of body weight was developed. The average ovine weight is 135 pounds, so a 54 head sheep operation would cost $255.15 for rendering. The total of these supplies comes to $341.45 for the whole operation.

The final cost category for disposal is equipment. The necessary equipment would be a back hoe with an operator, 14-foot chains with hooks on each end, 5-foot chains with a hook and a ring, and a crew cab ½ ton pickup with a towing package. For a three hour time period, an operated backhoe would result in a cost of $279.99. Each of the chains is assumed to be useful for 100 operations. The six 14-foot chains would have a total farm cost of $3.60, and the two 5-foot chains would cost $0.94. The final charge is the ½ ton pickup, which would be needed for a quarter of a day, costing $18.75. The overall equipment cost comes to a total of $303.28 for the entire farm.

The overall farm cost for rendering is $1,088.73 or $20.16 per head. Rendering is a somewhat low cost option, especially for farms with lower numbers of animals.

Disposal – Swine

For this example of a farrow-to-finish swine operation, one of the more feasible options for disposal would be composting. Composting would be useful in situations where there is ample space for on-site burial, but there may be other issues such as a high water table.

The first cost category would be personnel. Previously estimated values for personnel, required number of hours, and hourly rates were utilized. The personnel needed for disposal of a swine herd would be one crew representative for nine hours, two crew members for nine hours each, and one safety officer representative for nine hours. The total personnel cost for a 766 head swine operation was calculated to be $1,332.00.

The second cost category for disposal would be supplies. For composting, the necessary supplies would include Level C PPE, thick plastic liners, wood chips, large square straw bales, and sawdust. For the 4 man team plus the 2 equipment operators for nine hours, 27 units of PPE would be used, costing $233.01. The next cost would be the plastic liners that would line the bottom of the composting bins to prevent seepage into the ground. Two plastic liners would come to a total cost of $145.96. The bottom layer of the composting bin would be 18 inches of wood chips, which the carcasses would be placed on top of. The wood chips are the major cost associated with composting at $4,596.00. The sides of the composting bin would be composed of large square straw bales. It was calculated that 38 tons of straw would be needed, costing $2,432.00. The final supply involved in composting is the sawdust that becomes the top layer of the composting bin. The total cost of sawdust was calculated to be $1,011.12. Overall, disposing of 766 pig carcasses by the method of composting has a supply cost of $8,418.09.

The final cost category of disposal is equipment. The needed equipment includes a track hoe with an operator, a backhoe with an operator, 14-foot chains with hooks on each end, 5-foot chains with a hook and a ring, and a ½ ton crew cab pickup with a towing package. The costs of renting the track hoe and backhoe make up the majority of the cost of equipment. For the nine hours, the cost of renting an operated track hoe is $900.00, and the cost of renting a backhoe for nine hours is $839.97. Each of the chains is assumed to be useful for 100 operations. The six

14-foot chains would have a total farm cost of $3.60, and the two 5-foot chains would cost $0.94. The final cost is renting the ½ ton pickup, which would cost $56.25 for the three quarters of a day it is needed for. The added cost of these values comes to a total of $1,800.76 for equipment.

Composting is one of the more complex options due to the fact that everything must be done correctly in order to ensure that the virus is killed. This is a unique alternative to burial that would allow the infected animals to stay on the farm without potentially harming the ground water. The total farm cost for disposal of a 766 head pig farm using composting is $11,550.85 or $15.08 per head.

Cleaning and Disinfection – Cattle

The process of cleaning and disinfection is fairly straightforward; however, it would be highly variable depending on the set-up of each operation. For this example of a small cow-calf operation, it will be assumed that a small barn area would require disinfection.

As with other processes involved with responding to an FMD outbreak, previous APHIS assumptions for hourly personnel rates were utilized. Additionally, the number of crew members needed is based on previous assumptions. For cleaning and disinfection, one crew representative and four crew members would be available for six hours, resulting in an overall operation cost of $1,020.00 for personnel.

The supplies needed for cleaning and disinfection would be class C PPE, shovels, rakes, brooms, buckets, brushes, the disinfection agent Vircon, and a hand pump sprayer. A five man team would require 15 units of PPE, costing $166.50. Before any true disinfection is done, dry cleaning is necessary which involved the removal of any manure, and potentially infected hay or dirt. Dry cleaning involves the use of shovels and other similar equipment, which could be used multiple times. The total cost of this type of equipment would be only $4.94. The use of Vircon would be the major variable cost and would be adjusted per 500 square feet. This example will use only a 500 square foot area, resulting in a cost of only $2.45 for Vircon use. In order to apply the Vircon, hand pump sprayers would be used; however, their ability to be used multiple times results in a cost of $0.84 per farm. The total supply cost for this operation would be $173.88.

Equipment required for cleaning and disinfection of a small cow-calf operation would be a ¾ ton crew cab pickup with a towing package, a 2 ton flatbed truck with a Class 1 DOT hitch, a 500 gallon water tank mounted on the 2 ton truck, a water truck, an enclosed box trailer, a compact skid steer for removing large amounts of debris, a spray pump, a 300 ft. hose and nozzle to accompany the spray pump, 100 ft. sections of garden hose, and a pressure washer with both hot and cold settings and a 100 ft. hose. The trucks, trailer, skid steer, and pressure washer were estimated to be used for half of the day, resulting in a total rental cost of $287.27. The miscellaneous equipment was estimated to be usable for approximately 100 farms and came to a total of $18.37. The overall cost of equipment for cleaning and disinfection was $305.64.

When cleaning and disinfecting a small cow-calf operation, it can be assumed that approximately $1,499.52 will be spent in total. This number could vary drastically from farm to farm, necessitating adjustments in required time and amounts of certain products.

Cleaning and Disinfection – Sheep

For the example of a small farm flock sheep operation, the cleaning process would be very similar to the process for cattle, with minor adjustments. The major difference is required personnel hours. Each of the crew members would only be needed for three hours, making the whole farm personnel costs $510.00.

The supplies would also be impacted by the change in personnel hours. The difference between the cattle supplies and supplies for the sheep flock is that only 10 units of PPE will be used, costing $86.30. This change makes the cost of supplies for cleaning and disinfecting the facility for a sheep flock $93.68.

The final cost category for cleaning and disinfection is equipment. The main difference between the costs for cattle and sheep operations is that this farm flock would only require three hours of cleaning as opposed to six, cutting equipment rental costs in half. With these changes, the total cost of equipment is $162.00.

The least costly portion of responding to an outbreak is most frequently cleaning and disinfection. The overall farm costs for cleaning and disinfection for a 54 head farm flock is $765.68 or $14.18 per head.

Cleaning and Disinfection – Swine

The cleaning and disinfection process for swine is also extremely similar to that for cattle. Although there would be differences in size, the required number of hours for personnel is identical for the two operations, making all of the cost values identical.

Vaccination – Cattle

Vaccination methods would likely be very similar on each operation; however, the required equipment would vary based on availability. For this cow-calf operation example, it is estimated that cattle handling equipment is not readily available, so portable equipment will need to be provided.

Previous APHIS assumptions were once again used for required personnel and hourly rates and number of crew members needed. The personnel required to vaccinate a 94 head cow-calf herd included one vaccination operator for three hours, one safety officer for three hours, two vaccination crew members for three hours, and two animal handlers for three hours. The total personnel costs for this example operation would result in a total of $636.00.

The supplies required for vaccination would include class C PPE, a car refrigerator, the FMD vaccine, a disposable 5 milliliter fixed variable plastic applicator with feed tube, a repeat 50 milliliter plastic applicator, 1 ½-inch X 18-gauge needles, a sharps container, USDA radio-frequency identification (RFID) ear tags, an ear tag applicator, and a RFID ear tag reader. The six man team required to vaccinate a small cow-calf operation would utilize nine units of PPE throughout the three hours on the site. The PPE used would cost a total of $77.67. In order to refrigerate the vaccine, a portable car refrigerator would need to be available. The refrigerator chosen for this study is used by veterinarians and has a variety of settings. Although the number is conservative, it was estimated that the refrigerator would be useful for approximately 100 different operations, resulting in a total cost of $5.96 per operation for the use of the portable refrigerator. Vaccine costs vary and are updated frequently, so establishing a specific cost per dose is impossible. For the purpose of the current study, a previously used dose cost of $0.85 was used, which translates into a farm cost of $79.90. There are many accessories needed to administer the vaccine, including syringes. Two different syringe types were utilized for calculating the total cost. The disposable, 5 milliliter fixed variable plastic applicator with a feed tube could be used over 10 operations, assuming it is thoroughly disinfected between uses. Two of this type of syringe would be utilized, costing $2.60 per operation. The other type of syringe used would be a repeat 50 milliliter syringe that is more durable than the plastic syringe. This syringe could be used over 50 operations with thorough disinfection between each operation and would cost $2.83 for the example operation. Cattle would require 1 ½-inch X 18-gauge disposable needles for administration of the vaccine. For this operation 100 needles were calculated into the final cost, allowing for one needle per animal as well as 6 extra needles in the case of breakage or any type of contamination. This number of needles would cost a total of $14.95. With the use of needles, a sharps container would be necessary. It would be best if these are disposed of between operations, so one sharps container would be needed, costing $1.40. Ear tags to identify vaccinated animals would also be required. These would account for one of the major operational costs at a total of $202.10. To insert the ear tags, an applicator would be needed. This applicator would be useful over approximately 100 operations, costing a total of $0.22. The final cost for supplies would be an ear tag reader to ensure that the tags are functioning properly. This reader was estimated to be useful over 400 operations, costing only $2.74 for use at the example operation. The total supplies required for vaccinating an entire operation would be $390.36.

Finally, the equipment required for vaccinating a small cow-calf herd would be a portable squeeze chute, 10 feet x 5 feet portable cattle panels, a 7 feet x 16 feet bumper pull flatbed trailer with tandem 5000 pound axles, a crew cab ¾ ton pickup with a towing package, and a ½ ton crew cab pickup. The portable handling equipment is necessary due to the limited availability of nearby equipment. Minimizing movement of animals would be critical, and portable equipment would provide that opportunity. Although the calculated value is conservative, it is assumed that one squeeze chute would be useful over 100 operations. Using this assumption, a farm cost of $60.14 is generated for the chute. To accompany the squeeze chute, 30 portable cattle panels would be necessary. With the 100 farm useful life, the panels would cost $45.00. The rented vehicles and trailer would only be needed for a quarter of the day, costing a total of $60.88. Using these values an overall equipment cost comes to $166.01.

Vaccination is another costly method of prevention and control of the disease; however, it may be determined to be necessary. The overall cost of vaccinating a 94 head herd of cattle would cost $1,192.38 or $12.68 per animal.

Vaccination – Sheep

For vaccination of a farm flock sheep operation with handling equipment available, there would be many similarities with the outlined cattle operation. This farm has available handling equipment, reducing the final equipment costs.

For personnel, previous assumptions were used for required personnel, hourly rates, and the number of hours the personnel would be needed. The personnel on-site would include a vaccination operator for two hours, a safety officer for two hours, two vaccination crew members for two hours each, and two animal handlers, each for two hours. The overall personnel costs totals $424.00.

The second cost category for vaccination is supplies. The necessary supplies would be very similar to those for cattle, with only minor adjustments. The number of PPE units is only six as opposed to nine due to the fact that a sheep operation would require only two hours instead of three to complete. The PPE costs for this operation is $51.78. A major difference in cost would be found in the actual vaccine cost. Previous assumptions have each unit of vaccine costing $0.85, which would make the cost of vaccine $45.90 for the operation. Sheep would require a different size needle, costing only $14.27. The simple difference in number of RFID tags needed makes a drastic difference in cost, as the sheep operation would only incur a cost of $116.10 for tags. These changes make the overall farm cost for supplies $243.79.

The final cost category is equipment. This section is unique in costs because of the availability of handling equipment. Only a ½ ton crew cab pickup would be necessary for transporting supplies and a crew, costing only $12.50 in rental costs for the two hours it is used on the farm.

Although there are not major differences between the cattle and sheep operation, there is a rather large difference in cost, likely due to the difference in numbers of animals. The overall farm cost for vaccination of a 54 head flock of sheep is $680.29 or $12.60 per head.

Vaccination – Swine

Vaccination for swine is also quite similar to that for cattle. The required personnel and hours needed for personnel are identical between the cattle and swine operations.

The major difference in costs is found in the supply section. Since there are 766 head of pigs in this example, there will be difference for amount of vaccine needed, the number of needles needed, and the number of RFID tags needed. The vaccine will cost a total of $651.10 using the previously assumed vaccine cost. For the 800 needles needed, a cost of $119.60 was generated. Finally the 766 RFID tags would generate a cost of $1,646.90. With these differences, a total supply cost for vaccination of this example swine operation is $2,511.01.

The final cost category would be equipment. Pig handling equipment would be needed due to the lack of equipment on-site. The necessary equipment would include a 7-foot x 16-foot bumper pull flatbed trailer with tandem 5,000 pound axles, a ¾ ton crew cab pickup with a towing package, a ½ ton crew cab pickup, pig snares, and 8 feet x 50 inch wire panels. The trailer and the two pickups would be used for only a quarter of the day and cost a total of $60.88. The pig snares and panels are estimated to be useful for 100 operations. The 5 snares would cost a total of $1.55, and the 12 panels would cost a total of $1.56. The overall cost for equipment is calculated to be $63.98.

Compared to some of the other costs, vaccination is rather inexpensive, especially for operations with high animal numbers. The 766 head swine herd would cost a total of $3,211.00 to vaccinate or $4.19 per head.

Discussion

The purpose of the study was to analyze the cost parameters of foot and mouth disease in the United States for cattle, sheep, and swine in varying operating situations. This study provided a detailed break-down of all of the expected costs that would be incurred in the instance of a foot and mouth disease outbreak. Having access to these costs will be beneficial in making a variety of economic and management decisions. It enables response officials to identify the most cost-effective or feasible combinations of response strategies to best fit the situation in a timely manner. This study could be used as a tool to develop the least-cost scenario for each operation type.

Limitations

Although these results will allow for outbreak response officials to determine the most effective scenario, it is accompanied by a variety of limitations. The first major limitation is the differences in operation sizes. It is nearly impossible to predict the size of a specific operation because each operation is so drastically different. In this case, a typical size of operation was used; however, the operations that could potentially be impacted by an outbreak may be either much larger or much smaller than the sizes used. The generated values could be variable simply due to the fact that a larger operation might have a lower per head cost as some of the overall costs could be spread out over more animals. Another limitation that relates to the first is the specificity of each operation. Not only is the exact herd size specific, but also the materials present and sizes or availability of facilities are specific. For example, cleaning and disinfection for a corral composed of wood would look entirely different than one made of a type of metal. This could result in highly variable costs even across operations with similar herd sizes. Sizes of facilities needing disinfecting could also present issues. A smaller barn or corral area would take less time and fewer supplies to complete than a large area when considering cleaning and disinfection. The availability of handling equipment is also a major factor when calculating costs for both euthanasia and vaccination. Finally, machinery availability could also vary across farms, leading to either increases or decreases in costs. The final limitation is that the price information is constantly changing. This is true for all supplies and equipment, but it is especially true for the cost of vaccines. With the vaccine constantly changing, the price cannot be predicted until it is actually being put into use.

Conclusion

Foot and mouth disease is an ever-present threat to many countries, specifically the United States. It has the potential to create severe economic upset along with a multitude of other consequences. It is important to implement as many protection methods as possible, but it is equally important to be able to rapidly respond to an outbreak in order to effectively prevent spread as much as possible. This disease would impact so many levels of society, and it would be essential to effectively manage it as quickly as possible.

These results highlight the specific costs associated with an outbreak along with options for different scenarios to fit specific situations. These results will help with planning and preparedness for an outbreak in addition to budgeting. Being able to anticipate the different costs and potential methods of responding will greatly impact the response speed and thus slow the spread of the disease.

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