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# Modeling the impact of vaccination control strategies on a foot and mouth disease outbreak in the Central United States

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ABSTRACT

The central United States (U.S.) has a large livestock population including cattle, swine, sheep and goats. Simulation models were developed to assess the impact of livestock herd types and vaccination on foot and mouth disease (FMD) outbreaks using the North American Animal Disease Spread Model. In this study, potential FMD virus outbreaks in the central region of the U.S. were simulated to compare different vaccination strategies to a depopulation only scenario. Based on data from the U.S. Department of Agriculture National Agricultural Statistics Service, a simulated population of 151,620 livestock operations characterized by latitude and longitude, production type, and herd size was generated. For the simulations, a single 17,000 head feedlot was selected as the initial latently infected herd in an otherwise susceptible population. Direct and indirect contact rates between herds were based on survey data of livestock producers in Kansas and Colorado. Control methods included ring vaccination around infected herds. Feedlots ≥3000 head were either the only production type that was vaccinated or were assigned the highest vaccination priority. Simulated vaccination scenarios included low and high vaccine capacity, vaccination zones of 10 km or 50 km around detected infected premises, and vaccination trigger of 10 or 100 detected infected herds. Probability of transmission following indirect contact, movement controls and contact rate parameters were considered uncertain and so were the subjects of sensitivity analysis. All vaccination scenarios decreased number of herds depopulated but not all decreased outbreak duration. Increased size of the vaccination zone during an outbreak decreased the length of the outbreak and number of herds destroyed. Increased size of the vaccination zone primarily resulted in vaccinating feedlots ≥3000 head across a larger area. Increasing the vaccination capacity had a smaller impact on the outbreak and may not be feasible if vaccine production and delivery is limited. The ability to vaccinate all the production types surrounding an infected herd did not appear as beneficial as priority vaccination of feedlot production types that have high numbers of indirect contacts. Outbreak duration, number of herds depopulated and the effectiveness of vaccination were sensitive to indirect contact transmission probability and movement restrictions. The results of this study will provide information about the impacts of disease control protocols which may be useful in choosing the optimal control methods to meet the goals of rapid effective control and eradication.

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## 1. Introduction

Foot and mouth disease (FMD) is a highly contagious disease that affects all cloven-hooved animals and is endemic in parts of Asia, Africa and South America. The FMD virus can spread rapidly through susceptible livestock populations prior to the recognition of clinical signs (Burrows, 1968; Burrows et al., 1981); consequently, early detection prior to the spread of the disease is difficult. FMD is a major constraint to international trade because countries currently free of FMD, like the United States (U.S.), take every precaution to prevent the entry of the disease. The U.S. livestock population is naïve to FMD with the last outbreak occurring in 1929 (Graves, 1979).

The potential impact of an outbreak in the U.S. would likely be devastating. A secure food supply is vital to the economy with U.S. farms selling $297 billion in agriculture products through market outlets in 2007 (USDA-NASS 2007). In the U.S. the concern for FMD virus re-introduction and the potential economic impacts have risen with the increase of international travel and trade of animals and animal products. At the same time agriculture has become more concentrated with larger capital investments (Hueston, 1993) resulting in increased risk to agricultural production and business continuity.

Because FMD is a foreign animal disease in the U.S., there are few avenues available for the study of potential impacts of and effective control strategies for the disease in the event of an introduction. Epidemiological disease modeling is one such avenue. In such models, various control measures, such as movement restrictions, increased biosecurity, depopulation, pre-emptive culling, and vaccination have been implemented in various combinations to evaluate the spread of simulated outbreaks (Ferguson et al., 2001; Gibbens et al., 2001; Bouma et al., 2003; Sutmoller et al., 2003; Perez et al., 2004; Pluimers, 2004; Yoon et al., 2006; Volkova et al., 2011). Depending on the size of the outbreak, timeliness of control implementation, the workforce capacity, and the available resources, the optimal control strategy may vary. The efficacies of different control measures under different conditions can be readily compared using epidemiological modeling.

In the U.S., epidemiological disease models have been used to estimate the potential economic impacts of an outbreak. Pendell et al. (2007) estimated economic losses of an outbreak confined to Kansas ranged from $43 to $706 million depending on the type of livestock herd that was initially infected. In an economic model of the impact to the entire U.S., Paarlberg et al. (2002) estimated that a FMD outbreak could decrease U.S. farm income by approximately $14 billion and in 2012 it was estimated that an outbreak originating from the proposed National Bio- and Agri-Defense Facility in Kansas could exceed $100 billion in costs (NBAF, 2012).

Epidemiological disease models are dependent on accurate estimates of the frequency and distance distribution of contacts between livestock operations to estimate disease spread and impact, and to guide control measures (Gibbens et al., 2001; Woolhouse and Donaldson, 2001; Dickey et al., 2008; Premashthira et al., 2011). Previous studies that have modeled FMD outbreaks in the central U.S. have relied on expert opinion or contact rates adapted from other regions (Pendell et al., 2007; Greathouse, 2010; Premashthira, 2012). In order to improve the validity of models of this region of the U.S., we used the results of a recent survey of livestock producers (McReynolds et al., 2014a) to inform model parameters used in the current study.

The primary objective of this study was to model FMD outbreaks in the Central U.S., using the best available information to establish rates of contact among herds in this region, to identify optimal vaccination control strategies based on their effectiveness in minimizing simulated outbreak durations and numbers of herds depopulated. A secondary objective was to analyze the sensitivity of the model to specific input parameters, including movement controls, direct contact rate, indirect contact rate, and probability of indirect transmission.

## 2. Materials and methods

### 2.1. Study population

The number of herds, type of herds and herd sizes at the county level were generated from the U.S. agricultural census 2007 NASS data (NASS, 2007) and adjusted according to criteria by Melius et al. (2006). The study area included Wyoming, South Dakota, Colorado, Nebraska, Kansas, the northern region of New Mexico and Oklahoma, and the Texas Panhandle (Fig. 1). There were 151,620 livestock herds in the study area in 2007 (USDA, 2007) including 86,655 cow/calf, 3232 dairy, 979 large feedlots (≥3000 head), 25,096 small feedlots (<3000 head), 1071 large swine (≥1000 head), 6463 small swine (<1000 head), 5159 beef and swine, and 22,965 small ruminant herds (Table 1). NASS data do not account for mixed production types such as beef-swine yet data suggest approximately 7% of Kansas and Colorado herds report having both beef cattle and swine (McReynolds et al., 2014a) To account for this production type seven percent of beef and swine operations were randomly re-designated in the NASS data set from the population of cow/calf operations and small swine in Kansas, Nebraska, Eastern Colorado, and Oklahoma (McReynolds et al., 2014a). The total population was 39,413,228 animals in all production types (Table 1). Heterogeneous random locations within counties were generated for herds using a weighting scheme based on altitude, flatness, and human population developed by Lawrence

**Table 1**
Simulation population of the 8-state region in the central U.S. that was used in NAADSM with the number of animals and herds by production type.

| Production type | Animals | Herds |
|---|---|---|
| Cow-calf | 9,698,630 | 86,655 |
| Feedlot-large (≥3000 head) | 9,147,279 | 979 |
| Feedlot-small (<3000 head) | 7,377,698 | 25,096 |
| Dairy | 1,062,276 | 3232 |
| Swine-large (≥1000 head) | 9,227,569 | 1071 |
| Swine-small (<1000 head) | 663,465 | 6463 |
| Beef-swine mix | 520,283 | 5159 |
| Sheep | 1,716,028 | 22,965 |
| Total | 39,413,228 | 151,620 |

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