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Research Paper

Web-based forecasting system for the airborne spread of livestock infectious disease using computational fluid dynamics

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Livestock infectious diseases, such as foot-and-mouth disease (FMD), cause substantial economic damage to livestock farms and their related industries. Among various causes of disease spread, airborne dispersion has previously been considered to be an important factor that could not be controlled by preventive measures to stop the spread of disease that focus on direct and indirect contact. Forecasting and predicting airborne virus spread are important to make time for developing strategies and to minimise the damage of the disease. To predict the airborne spread of the disease a modelling approach is important since field experiments using sensors are ineffective because of the rarefied concentrations of virus in the air. The simulation of airborne spread during past outbreaks required improvement both for farmers and for policy decision makers. In this study a free license computational fluid dynamics (CFD) code was used to simulate airborne virus spread. Forecasting data from the Korea Meteorological Administration (KMA) was directly connected in the developed model for real-time forecasting for 48 h in three-hourly intervals. To reduce computation time, scalar transport for airborne virus spread was simulated based on a database for the CFD computed airflow in the investigated area using representative wind conditions. The simulation results, and the weather data were then used to make a database for a web-based forecasting system that could be accessible to users.

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Nomenclature

A_{animal}	recommended rearing area (m^3 $head^{-1}$)
$C_{aerosol}$	livestock aerosol concentration by animal species, ages, and floor type (mg m^{-3})
C_μ	empirical constant of the turbulence model (approximately 0.09)
N_{animal}	number of animals in a livestock house (head)
$P_{infection}$	infection ratio in an infected livestock house (%)
p	constant pressure (Pa)
Q_{point}	livestock aerosol emission rate for attaching a virus (mg s^{-1}).
S_ϕ	source term
s	time interval for CFD simulation (s)
t	time (s)
U	velocity (m s^{-1})
u^*	fiction velocity (m s^{-1})
z_0	height of the surface roughness (m)
Γ	diffusion coefficient
δ	bound layer depth (m)
ε	turbulent dissipation rate (m^2 s^{-3})
κ	von Karman constant (0.4)
ρ	density (kg m^{-3})

Abbreviations

AWS	automatic weather station
CDMA	code division multiple access
CFD	computational fluid dynamics
DEM	digital elevation model
FMD	foot-and-mouth disease
GIS	geographical information system
PM10	particle matter under 10 μm
SAS	severe acute respiratory syndrome
SEM-EDX	scanning election microscopy energy dispersive X-ray spectroscopy
$TCID_{50}$	50% tissue culture infective dose
TIN	triangular irregular network
WDAS	weather data acquisition server
WebFoS	web-based forecasting system

1. Introduction

To increase productivity, the livestock industry is moving to mass operation systems, therefore large economic damage can occur during outbreaks of livestock infectious diseases. Since 2000, in Korea there have been four foot-and-mouth disease (FMD) outbreaks. During the 2010/11 FMD outbreak, 3.35 million pigs were slaughtered to prevent virus spread, which resulted in a decrease in animals of 32%, while the direct damages, including the costs for farm compensation and preventive measures, reached 3 billion USD and related damages, including costs to feed companies, the decrease in exports, and reduced consumer demand, reached 4 billion USD, as estimated by KREI (2011). Therefore, there is an urgent need to minimise the damage from livestock infectious diseases at the early stages of any outbreak by means of preventive measures. The outbreak of livestock infectious diseases has not be blocked because of the various transmission routes, and tracking of the spread has failed due to the difficulties in field monitoring. There are three routes by which FMD can be transmitted by livestock aerosols and surface contact to respiratory organs (Weber & Stilianakis, 2008); 1) direct contact from infected animal to healthy animals, 2) indirect contact by infected objects such as the human body, vehicles, equipment, feed, refrigerators, and 3) airborne spread through airflow. The airborne spread of livestock disease has not be considered in terms of taking preventive measures due to a lack of information. However, a comprehensive counterplan should consider not only direct and indirect contact transmissions but also airborne transmission via considering the continuously changing airflow patterns from weather conditions.

A current preventive measure that has been used to reduce FMD spread has been the use of preventive vaccinations within 3 km of infected farms or eradication of neighbouring animals within 1 km (Martínez-López, Perez & Sánchez-Vizcaíno, 2010). Geering and Lubroth (2002) suggested a disease management strategy based on; 1) denying access of the virus to susceptible host animals, 2) avoiding contact between infected and susceptible animals, 3) reducing the number of infected or potentially infected animals in livestock populations, and 4) reducing the number of susceptible animals. Most of the preventive measures used to date have focused on a blockade of direct and indirect transmission of virus regardless of the airborne transmission. Multiple factors should be considered in making preventions and forecasting, but there are a substantial number of difficulties basing this on field experiments, including a lack of basic information on virus spread, the presence of an incubation period, and having a detection problem or a delay in disease declaration.

It is difficult to measure airborne spread under ever-changing weather conditions, thus rare quantitative data are available from simulation models. Viruses that are suspended in the air exist as fine particles; there are limitations to capturing these viruses when using an air sampler and also to detect a quantitative dose of the virus under field or laboratory conditions. Modelling approaches of airborne virus spread have been developed to get over these limitations. Martínez-López et al. (2010) suggested an FMD spread model that used seven variables; (1) movement of animals, (2) local spread, (3) infectivity, (4) zones, (5) resources for depopulation, (6) movement restriction, and (7) surveillance. Stevenson et al. (2013) suggested a spatial and stochastic simulation model was developed for epidemiological investigation and considered airborne spread, animal movement, farm operating methods, incubation period, indirect contact, susceptibility, and other factors. Their model calculated the probability of infection by the distance from the infected farms via airborne spread of virus using weather information and look-up tables. However, considerable numbers of quantitative variables relied on expert opinions and required more research.