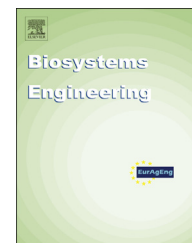


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## Research Paper

# Prediction of the spread of highly pathogenic avian influenza using a multifactor network: Part 1 – Development and application of computational fluid dynamics simulations of airborne dispersion



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Highly pathogenic avian influenza (HPAI) virus can be spread rapidly, resulting in high mortality and severe economic damage to the poultry industry. A prediction of HPAI dispersion is challenging considering various spread factors, such as indirect transmission by airborne spread as well as direct transmission through contact by humans, vehicles, wild animals, and migratory birds. Because of the complexity of the spread of HPAI, it is difficult to provide prompt treatments against epidemics. Moreover, there is little information on the airborne spread of the HPAI virus because of the limitations of field experiments for determining the mechanism of the spread of the disease due to the difficulty of making accurate measurements in the presence of unstable and uncontrollable weather conditions. In this study, CFD (computational fluid dynamics) was used to estimate the dispersion of the virus attached to aerosols produced by livestock using a GIS (geographical information system) to model a three-dimensional specific topography that includes the farm location, road network, and related facilities. The CFD simulation was conducted to predict the dispersion of virus from source farms according to various wind conditions. The weather conditions during the period of interest were analysed using CFD simulations to complete a frequency matrix form. The results were used as background data, to be used to take preventive measures against HPAI occurrences and spread based on the multifactor network process introduced in Part II.

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Nomenclature	
$C_{1\epsilon}, C_{2\epsilon}$	constants with values of 1.44 and 1.92
$C_{3\epsilon}$	constant for the ratio of the horizontal and perpendicular velocity components to the gradient direction
$C_\mu$	empirical constant of the turbulence model (approximately 0.09)
$F_{\text{wind}}$	weighting factor for the frequency of wind conditions during the research period (%)
$G_k$	turbulent kinetic energy generated by mean velocity gradients ( $\text{kg m}^{-1} \text{s}^{-2}$ )
$G_b$	turbulent kinetic energy generated by buoyancy ( $\text{kg m}^{-1} \text{s}^{-2}$ )
$k$	turbulent kinetic energy ( $\text{m}^2 \text{s}^{-2}$ )
$M_{\text{CFD}}$	pathogen-laden aerosol concentration from infected farms and affecting nearby farms arranged in a 39 by 39 matrix form during the research period ( $\mu\text{g m}^{-3}$ )
$M_{\text{wind}}$	distribution of aerosol concentrations generated from the infected farm at a steady-state condition without a change in the wind speed and direction ( $\mu\text{g m}^{-3}$ )
$M_{\text{Road}}$	distribution of aerosol concentrations generated from the road through livestock-related vehicles ( $\mu\text{g m}^{-3}$ )
$P_t$	possibility of airborne HPAI spread on the time period $t$ (%)
$P_{t-1}$	HPAI infection possibility in the poultry house on the $(t - 1)$ th day (%)
$t$	time (s)
$u$	velocity at a height of $z$ m ( $\text{m s}^{-1}$ )
$u^*$	friction velocity ( $\text{m s}^{-1}$ )
$Y_M$	fluctuating dilation of the compressible turbulence in the overall dissipation rate ( $\text{kg m}^{-1} \text{s}^{-2}$ )
$z_0$	height of the surface roughness (m)
$\delta$	boundary layer depth (m).
$\epsilon$	turbulent dissipation rate ( $\text{m}^2 \text{s}^{-3}$ )
$\kappa$	von Karman constant
$\mu$	viscosity ( $\text{kg m}^{-1} \text{s}^{-1}$ )
$\rho$	density ( $\text{kg m}^{-3}$ )
$\theta_e$	characteristic angle ( $60^\circ$ for triangular and $90^\circ$ for tetragonal angles)
$\theta_{\text{max}}, \theta_{\text{min}}$	maximum and minimum side angle of each mesh ( $^\circ$ )
<b>Abbreviations</b>	
APQA	Animal and Plant Quarantine Agency in Korea
CFD	computational fluid dynamics
FMD	foot-and-mouth disease
GIS	geographical information system
HPAI	highly pathogenic avian influenza
PCR	polymerase chain reaction
PM10	particulate matter less than $10 \mu\text{m}$ in aerodynamic diameter
TCID <sub>50</sub>	tissue culture median infective dose for influenza infection
TIN	triangular irregular network
TSP	total suspended particle
UDF	user-defined function

## 1. Introduction

Highly pathogenic avian influenza (HPAI) is a highly contagious virus that affects mortality and egg production in the poultry industry. There is a high risk of HPAI outbreaks in Korea because of frequent human and supply exchanges with neighbouring South-East-Asian countries where HPAI has often occurred. Furthermore, the habitats of migratory birds in the infected regions of Korea are located near the poultry industry. There have been four major HPAI outbreaks in Korea since 2000. They have resulted in much economic damage, including the costs of disease control, compensation for farmers, and decline in the related industries. During the 2008 HPAI epidemic, 8.46 million birds within 950 poultry farms were culled, with an economic loss of at least 575 million US\$, including direct costs (compensation for farmers) and indirect damages (the poultry industry, including feed, circulation, and processed food) from April to May (Woo, Lee, Hwang, Lee, & Kim, 2008). It was recently reported that long-term exposure and close contact with HPAI-infected poultry has produced a mutation in the virus strain that can be transmitted among humans (Hayden & Croisier, 2005; Koopmans et al., 2004; Ungchusak et al., 2005; Yang, Halloran, Sugimoto, & Longini, 2007). Dozens of victims of avian influenza were reported in

China and Taiwan in 2013, and airborne dispersion was strongly presumed to be the main mechanism for the spread of the avian influenza virus.

HPAI can be spread very quickly through livestock farms and cannot be controlled only by vaccine protection because of genetic diversity and mutation of the virus. Therefore, early preventive measures against epidemics are the most important method of reducing the damage of an outbreak. Migratory birds are major candidates for the long-distance dispersal of zoonotic pathogens (Gaidet et al., 2010), and HPAI viruses have been frequently detected in wild birds (Kim et al., 2012). When HPAI initially occurs, it can be spread farm-to-farm for short distances by means of direct and indirect transmissions. Direct transmission of HPAI involves mechanical movements of viruses between farms through humans, vehicles, and wild and domestic animals, while indirect transmission involves the airborne transmission of HPAI virus. Airborne transmission has been verified by field experiments (Spekreijse, Bouma, Koch, & Stegeman, 2011; Tsukamoto et al., 2007).

During an HPAI outbreak, general disease control in Korea has been conducted by preventing direct transmission using the slaughter of animals, access control, and disinfection for 0.5 km, 3 km, and 10 km from the infected farm. However, the criteria for these disinfection ranges are unclear, and this

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