

# Mitigation Strategies for Foot and Mouth Disease: A Learning-Based Approach

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## ABSTRACT

*Prediction of epidemics such as Foot and Mouth Disease (FMD) is a global necessity in addressing economic, political and ethical issues faced by the affected countries. In the absence of precise and accurate spatial information regarding disease dynamics, learning-based predictive models can be used to mimic latent spatial parameters so as to predict the spread of epidemics in time. This paper analyzes temporal predictions from four such learning-based models, namely: neural network, autoregressive, Bayesian network, and Monte-Carlo simulation models. The prediction qualities of these models have been validated using FMD incidence reports in Turkey. Additionally, the authors perform simulations of mitigation strategies based on the predictive models to curb the impact of the epidemic. This paper also analyzes the cost-effectiveness of these mitigation strategies to conclude that vaccinations and movement ban strategies are more cost-effective than premise culls before the onset of an epidemic outbreak; however, in the event of existing epidemic outbreaks, premise culling is more effective at controlling FMD.*

*Keywords: Autoregressive, Bayesian Network, Culls, Neural Networks, Spatio-Temporal Models*

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## 1. INTRODUCTION

Predictive epidemiology refers to the analytical study of disease dynamics to predict future outbreaks in space and time so that effective mitigation strategies can be implemented to curb the recurrence of epidemics. Since epizootic diseases like the Foot and Mouth Disease (FMD) raise several political, administrative, economic and welfare issues, it is imperative

to analyze the disease dynamics to facilitate adequate preventive measures, especially in countries that report recurring epidemic outbreaks instances. Since the FMD outbreak in the United Kingdom in 2001, several analytical spatio-temporal models have been developed to spatially locate such epidemic outbreaks in time (Morris et al., 2001 ; Bates et al., 2003a, 2003b; Carpenter et al., 2004; Ferguson et al., 2001; Keeling et al., 2001). However, it is important to address that spatio-temporal models have parameters of a possibly global

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structure. Such structures allow region-independence and adaptability of the models by taking information regarding the environment and neighborhood of geographical locations expressed in terms of model parameters. But, in the absence of the sensitive spatial parameters, we attempt to train a learning-based model on a certain regional data with latent parameters to mimic the predictive performance of spatial predictive models. The novel contribution of this paper is that we study local information regarding the temporal evolution of infection that is hard-coded in geographical regions, by using different learning-based models. Additionally, we simulate instances of mitigations strategies to study the cost-effectiveness of culling, vaccination and movement strategies to reduce the total number of infected livestock at the end of a period under study. Also, the utility function to assess the cost-effectiveness of mitigation strategies is defined in terms of the percentage reduction in the total number of infected livestock to the total cost incurred in million US dollars.

Numerous learning-based models have been developed so far to achieve temporal epidemic predictions. For example, neural network models have been argued to effectively model the dynamics of temporal data (Abidi & Goh, 2006), while time series models have been applied for forecasting the incidences of influenza-like illnesses (ILI) in France (Hawthornth et al., 2003). Also, Bayesian networks are useful for reasoning under uncertainty in artificial intelligence which not only detects an outbreak, but also estimates how acute the epidemic is (Lagazio et al., 2001; Jiang & Wallstrom, 2006). Regressive models have also been implemented to fit and predict outbreak related data (Kobayashi et al., 2007a, 2007b). Additionally, learning-based prediction models have found their importance in predicting wheat leaf wetness (Francl & Panigrahi, 1997; Chtioui et al., 1999), soy-rust in plants (Alexandersen et al., 1997) and critical diseases like influenza (Viboud et al., 2003), malaria (Krishnamurti et al., 2007; Brit et al., 2008) and SARS (Lai, 2005) in humans. However,

such models have not found any application in prediction of global epizootic epidemics like FMD so far. Our study aims at analyzing the temporal prediction capability of various temporal prediction models and applying them for spatial predictions of FMD epidemic outbreaks in time.

Learning-based predictors are proactive methods for the classification of epidemic severity and for the development of preemptive disease mitigation strategies. They are good tools to analyze infection spread patterns without relying on background spatial information which is generally unknown or estimated. However, it is noteworthy that learning-based models suffer from higher prediction errors than spatio-temporal predictive models in the absence of a high volume of well correlated data (Chowdhury et al., 2009). This is because learning-based models require a considerable training, validation and testing data in order to predict well. Evidently, while an under-trained model produces higher prediction errors, an over-trained model will generate a high variance in its predictions. Thus, due to the generally sparse nature of sensitive data regarding epidemic outbreaks, learning-based models can be trained to estimate logical bounds to the rate of spread of disease infection with time (Viboud et al., 2003; Abeku et al., 2004). Such bounds can eventually be used for development of mitigation strategies to curb the impacts of the epidemic thus predicted.

In this paper, we propose a few learning-based prediction models that can be used to study the temporal evolution of FMD infection and susceptibility at different administrative districts in Turkey. The predictive models when trained for each administrative district separately can be used to predict the probability of infection and the probability of susceptibility to the FMD Virus (FMDV) in future time instants. The different temporal prediction models are neural networks, autoregressive models and Bayesian networks backed up with Monte-Carlo simulation models. Neural networks are non-linear models to detect sudden fluctuations in infection incidence

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