Fuzzy Logic and Dempster-Shafer Theory to Predict
the Risk of Highly Pathogenic Avian Influenza H5n1 Spreading

Andino Maseleno, Md. Mahmud Hasan, Norjaidi Tuah and Charles Rangga Tabbu

Abstract: This research aims to combine Fuzzy Logic and Dempster-Shafer theory by calculating the similarity between Fuzzy membership function in the context to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading and finally to develop a realistic and useful Web mapping for displaying maps on a screen to locate the risk of Highly Pathogenic Avian Influenza H5N1 spreading. The novelty aspect of this work is that basic probability assignment is proposed based on the similarity between membership function. This research has considered population changes in an area to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading. Population density in the area include very low, low, medium, high and very high. This work is recommended to human experts and physicians who specializes in diagnosing and treatment of Highly Pathogenic Avian Influenza H5N1. The human experts will find it useful as an aid in the decision making process and confirmation of suspected cases. The risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction obtained degree of belief 20% of very low, 34.7% of low, 18.3% of medium, 22.4% of high and 19% of very high. In this research it is Fuzzy Logic and Dempster-Shafer theory, which resulted in a 0% rejection. Fuzzy Logic and Dempster-Shafer theory have shown good results to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading. The risk of Highly Pathogenic Avian Influenza H5N1 spreading in areas which include Batang, Kendal, Kota Magelang, Kota Salatiga, Kota Semarang, Magelang, Semarang, Temanggung, Wonosobo.

Key words: Fuzzy logic • Dempster-Shafer theory • The risk of disease spreading • Highly pathogenic avian influenza H5N1

INTRODUCTION

Based on Cumulative Number of Confirmed Human Cases of Avian Influenza (H5N1) Reported to World Health Organization (WHO) in the 2013 from 15 countries, Indonesia has the largest number of death because of Avian Influenza which are 160 deaths [1]. Avian Influenza results from infection by viruses in the influenza virus A genus and influenza A species of the family Orthomyxoviridae. These viruses are also called type A influenza viruses [2]. The idea to study the risk of Highly Pathogenic Avian Influenza H5N1 spreading was motivated by research published about mapping the risk of spread of Highly Pathogenic Avian Influenza H5N1 in Indonesia [3]. Glanville et al. using map layer of Indonesian major cities represents those cities in Indonesia that have a population greater than 50,000. It is expected that such cities are likely to have at least one poultry market. The density of cities was calculated over an area of 100 km and the risk of spread classified according to this population density (higher density = higher risk). In this research, the risk of Highly Pathogenic Avian Influenza H5N1 spreading is not classified according to higher population density which is equal to higher risk of Highly Pathogenic Avian Influenza H5N1 spreading. This research has considered population changes in an area to find the risk of Highly Pathogenic Avian Influenza H5N1 spreading. Population density is
usually shown as the number of people per square kilometre [4]. Disease spreading and population density are highly correlated [5, 6, 7].

Fuzzy Logic can handle problems with imprecise data and give more accurate results. Professor L. A. Zadeh introduced the concept of Fuzzy Logic [8]. The formalisation of Fuzzy sets started in the 1960s with the works of Zadeh in Fuzzy sets and Dempster [9] in belief functions, set functions which generalise additive probability measure. Belief functions offer a non Bayesian method for quantifying subjective evaluations by using probability. In the 1970s, it was further developed by Shafer, whose book Mathematical Theory of Evidence [10] remains a mathematical framework in which assessments of evidence can be represented by belief functions, or the so-called Theory of Evidence. This research presents Fuzzy Logic and Dempster-Shafer theory implement to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading. Dempster-Shafer theory is a powerful tool for combining accumulative evidence and changing prior knowledge in the presence of new evidence. It also allows for the direct representation of uncertainty of system responses where an imprecise input can be characterized by a set or an interval and the resulting output is a set or an interval. Fuzzy Logic is a logic operations method based on many-valued logic rather than binary logic or two-valued logic. Two-valued logic often considers 0 to be false and 1 to be true. Fuzzy Logic deals with truth values between 0 and 1 and these values are considered as intensity or degrees of truth. Dempster-Shafer theory, a probabilistic reasoning technique, is designed to deal with uncertainty and incompleteness of available information. Dempster-Shafer mathematical theory of evidence allows one to combine evidence from different sources and arrive at a degree of belief which is represented by a belief function that takes into account all the available evidence. The Degree of belief is expecting a truth value which is the relation between Fuzzy Logic and Dempster-Shafer mathematical theory of evidence.

Risk Factor Identification: Population density and urbanization are two major factors affecting disease spreading. People who live in close proximity to one another spread diseases more quickly and easily [11]. Also affecting the spread of encountering new diseases is migration: this increases as humans move into previously uninhabited lands because of population growth, or as humans migrate into areas where they do not have resistance to certain diseases. Disease in a population increases with the density of that population. High densities makes it easier for parasites to find hosts and spread the disease. Population density is a measurement of the number of people in an area. It is an average number. Population density is calculated by

$$
(m_1 \oplus m_2)(A) = \begin{cases} 0, & A = \emptyset \\ \sum_{B_i \cap B_j \neq \emptyset} w_i(B_i) m_2(B_j) - \sum_{B_i \cap B_j = \emptyset} m_i(B_i) m_2(B_j), & A \neq \emptyset 
\end{cases}
$$

Where $A \in 2^S$, $B_i \in 2^S$ and $B_j \in 2^S$.

To use Dempster-Shafer mathematical theory of evidence, there must be the feasible measures to determine basic probability assignment. The Fuzzy theory also requires basic probability assignment. Basic probability assignment which is called the primitive function is the fundamental and important object of the mathematical theory of evidence. The membership function of a Fuzzy set is a generalization of the indicator function in classical sets. In Fuzzy Logic, it represents the degree of truth as an extension of valuation. Fuzzy Logic is a logic operation method based on many-valued logic rather than binary logic or two-valued logic. Two-valued logic often considers 0 to be false and 1 to be true. Fuzzy Logic deals with truth values between 0 and 1 and these values are considered as the intensity or degrees of truth. Dempster-Shafer mathematical theory of evidence, a probabilistic reasoning technique, is designed to deal with uncertainty and incompleteness of available information. Dempster-Shafer mathematical theory of evidence allows one to combine evidence from different sources and arrive at a degree of belief which is represented by a belief function that takes into account all the available evidence. The Degree of belief is expecting a truth value which is the relation between Fuzzy Logic and Dempster-Shafer mathematical theory of evidence.
dividing the number of people by an area. In this research, population density is a parameter in the algorithm. Population density of an area may change over time. In recent decades, some cities have seen their urban centers lose population density, as residents spread farther out to suburbs and exurbs [12].

Population density affect the disease spreading within a population and other populations because a population that is very dense will generally see a faster disease spreading due to the larger amount of contact between individuals. In a population that is not very dense, close contact is much less likely to occur, thus halting the disease spreading. Population density is measured by the average of the number of contacts with susceptible individuals by each individual in the population during a fixed length time period [13]. Population density and growth are significant drivers for the emergence of different categories of infectious diseases [11]. Most diseases require that their host organisms come into close contact with another compatible organism in order to spread, meaning that denser populations of suitable hosts promote faster spread of a disease and that less-dense populations inhibit disease communication. Because disease prevention relies so heavily on contact between potential carriers, lower population densities have an increased chance of controlling disease spreading. In this study, a novel combination of Fuzzy Logic and Dempster-Shafer mathematical theory of evidence are applied to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading. The risk of Highly Pathogenic Avian Influenza H5N1 spreading is not classified according to higher population density which is equal to higher risk of Highly Pathogenic Avian Influenza H5N1. This research has considered population changes in an area to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading. Population density in an area can be very low, low, medium, high and very high.

**Fuzzy Logic and Dempster-Shafer Theory to The Risk of Highly Pathogenic Avian Influenza H5N1:** Implementation of the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction in Central Java. Central Java is a province of Indonesia. It forms the middle portion of the island of Java. The administrative capital is Semarang. The province is 32,800.69 km² in area, approximately a quarter of the total land area of Java. The province's population is 32,779,832 million in 2014 [14]. Assume that the population density of five different conditions in which already known is available as shown in Table 1. Table 1 shows population density for inputs to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading. Area1 is a population density in Kendal and Area 2 is a population density in Temangun.

Figuring out the system processes for the risk of Highly Pathogenic Avian Influenza H5N1 spreading system can be complicated. Figure 1 shows system architecture of risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction using Fuzzy Logic and Dempster-Shafer theory. Knowledge base has been obtained from Fuzzy Logic and Dempster-Shafer theory. Spatial database has been obtained from map database to complete the mapping.

The set of linguistic variables and their meanings is compatible and consistent with the set of conditional rules used, the overall outcome of the qualitative process is translated into objective and quantifiable results. In this research work, Fuzzy Logic and Dempster-Shafer theory implement to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading. Fuzzy inference systems use Fuzzy sets and if-then rules relevant to Fuzzy sets to make decisions about incomplete or vague information. In this work, Tsukamoto Fuzzy reasoning algorithm [15] is used to determine the membership function. This Fuzzy system has taken two parameters as linguistic variables that affect the risk of Highly Pathogenic Avian Influenza H5N1 spreading. A linguistic variable is a variable whose values can be expressed by means of natural language terms [16, 17, 18].

Fuzzy mathematical tools and the calculus of Fuzzy IF-THEN rules provide a most useful paradigm for the automation and implementation of an extensive body of human knowledge heretofore not embodied in the quantitative modelling process. These mathematical tools provide a means of sharing, communicating and transferring this human subjective knowledge of systems.

![Table 1: Population density for inputs to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading.](image-url)
and processes. On the basis of the description of input and output variables, this research has constructed 25 rules for the risk of Highly Pathogenic Avian Influenza H5N1 spreading. The Fuzzy rules are nearly a series of if-then statements. These statements are derived by an expert to achieve optimum results. Following is the description of the rules of the risk of Highly Pathogenic Avian Influenza H5N1 spreading:

IF Area1 Density is [Very Low] AND Area2 Density is [Very High] THEN The Risk of Highly Pathogenic Avian Influenza H5N1 Spreading should be [Medium]

IF Area1 Density is [Low] AND Area2 Density is [Very High] THEN The Risk of Highly Pathogenic Avian Influenza H5N1 Spreading should be [Low]

IF Area1 Density is [Medium] AND Area2 Density is [Very High] THEN The Risk of Highly Pathogenic Avian Influenza H5N1 Spreading should be [Very Low]

IF Area1 Density is [High] AND Area2 Density is [Very High] THEN The Risk of Highly Pathogenic Avian Influenza H5N1 Spreading should be [Very Low]

IF Area1 Density is [Very High] AND Area2 Density is [Very High] THEN The Risk of Highly Pathogenic Avian Influenza H5N1 Spreading should be [Very Low]

Overall rule matrix suggest how the risk of Highly Pathogenic Avian Influenza H5N1 spreading should be changed is shown in Figure 2.

There are two input variables which include Area1 and Area2 taken in this Fuzzy system. These variables use different membership functions. Area1 functions which include Area1_{very\ low}, Area1_{low}, Area1_{medium}, Area1_{high}, Area1_{very\ high}. Area2 functions which include Area2_{very\ low}, Area2_{low}, Area2_{medium}, Area2_{high}, Area2_{very\ high}. Area1 is a Fuzzy range of population density in Kendal and Area2 is a Fuzzy range of population density in Temanggung. Fuzzy ranges of population density of two areas in Central Java to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading can be defined as follows:

Area1_{very\ low} = 8,000; Area1_{low} = 11,000; Area1_{medium} = 14,000; Area1_{high} = 17,000; Area1_{very\ high} = 20,000

Area2_{very\ low} = 6,000; Area2_{low} = 8,000; Area2_{medium} = 10,000; Area2_{high} = 12,000; Area2_{very\ high} = 14,000
For this implementation, condition 1 of population density for inputs to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading is used to describe the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction using Fuzzy Logic and Dempster-Shafer theory which can be defined as follows:

\[
\begin{align*}
\text{Area1}_{\text{very low}} &= 9,500; \text{Area1}_{\text{low}} = 12,500; \text{Area1}_{\text{medium}} = 15,500; \\
\text{Area1}_{\text{high}} &= 16,000; \text{Area1}_{\text{very high}} = 19,000 \\
\text{Area2}_{\text{very low}} &= 7,000; \text{Area2}_{\text{low}} = 9,250; \text{Area2}_{\text{medium}} = 10,750; \\
\text{Area2}_{\text{high}} &= 11,500; \text{Area2}_{\text{very high}} = 12,950
\end{align*}
\]

Membership values to predict the risk of Highly Pathogenic Avian Influenza H5N1 spreading are shown as follows:

\[
\begin{align*}
\text{Area1}_{\text{very low}} &= 0.50; \text{Area1}_{\text{low}} = 0.50; \text{Area1}_{\text{medium}} = 0.50; \\
\text{Area1}_{\text{high}} &= 0.666; \text{Area1}_{\text{very high}} = 0.666; \text{Area2}_{\text{very low}} = 0.50; \\
\text{Area2}_{\text{low}} &= 0.375; \text{Area2}_{\text{medium}} = 0.625; \text{Area2}_{\text{high}} = 0.75; \\
\text{Area2}_{\text{very high}} &= 0.475.
\end{align*}
\]

The result of Highly Pathogenic Avian Influenza H5N1 Fuzzy rules between Area1 versus Area2 are shown in Figure 3.

The similarity between Fuzzy membership function to get the basic probability assignment can be calculated by the equation 2.

\[
Bel(\text{variables}) = \frac{\sum n \min\{\max(\mu_A(u) \wedge \mu_B(u),\max_v (\mu_B(v)\wedge (\mu_B(v)))\} \text{variables}}{n(\text{variables})}
\]

\[
(2)
\]
In Kendal and Temanggung, the highest basic probability assignment value is very low which is equal to 0.20. The risk of Highly Pathogenic Avian Influenza H5N1 spreading in areas which include Batang, Kendal, Kota Magelang, Kota Salatiga, Kota Semarang, Magelang, Semarang, Temanggung, Wonosobo. Figure 4 shows the risk of Highly Pathogenic Avian Influenza H5N1 spreading.

RESULTS AND DISCUSSION

Figures 5, 6, 7, 8, 9 are shown graphics of the risk of Highly Pathogenic Avian Influenza H5N1 spreading in areas which are in close proximity to Kendal and Temanggung. Figure 5 shows condition 1 of the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction is very low. It means the risk of Highly Pathogenic Avian Influenza H5N1 spreading is very rare but cannot be excluded. The final ranking of the degree of belief is 0.2 > 0.167 > 0.153 > 0.146 > 0.141. It can be seen from figure 5 that the final ranking of Highly Pathogenic Avian Influenza H5N1 spreading is Very Low > Medium > High > Very High > Low.

Figure 6 shows condition 2 of the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction is low. It means the risk of Highly Pathogenic Avian Influenza H5N1 spreading is rare but does occur. The final ranking of the degree of belief is 0.347 > 0.177 > 0.146 > 0.112 > 0.062. It can be seen from figure 6 that the final ranking of Highly Pathogenic Avian Influenza H5N1 spreading is Low > Very Low > High > Very High > Medium.

Figure 7 shows condition 3 of the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction is medium. It means the risk of Highly Pathogenic Avian Influenza H5N1 spreading occurs regularly. The final ranking of the degree of belief is 0.183 > 0.179 > 0.169 > 0.17 > 0.146. It can be seen from figure 7 that the final ranking of Highly Pathogenic Avian Influenza H5N1 spreading is Medium > High > Very High > Very Low > Low.

Figure 8 shows condition 4 of the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction is high. It means the risk of Highly Pathogenic Avian Influenza H5N1 spreading occurs very often. The final ranking of the degree of belief is 0.224 > 0.206 > 0.139 >
0.132 > 0.091. It can be seen from figure 8 that the final ranking of Highly Pathogenic Avian Influenza H5N1 spreading is High > Very Low > Very High > Low > Medium.

Figure 9 shows condition 5 of the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction is very high. It means the risk of Highly Pathogenic Avian Influenza H5N1 spreading occurs almost certainly. The final ranking of the degree of belief is 0.19 > 0.132 > 0.107 > 0 = 0. It can be seen from figure 9 that the final ranking of Highly Pathogenic Avian Influenza H5N1 spreading is Very High > High > Medium > Low = Very Low.

Using the population density of five different conditions, the degree of belief of each condition are different in the risk of Highly Pathogenic Avian Influenza H5N1 spreading prediction. Figure 10 shows the risk of
Highly Pathogenic Avian Influenza H5N1 spreading for each condition. The risk of Highly Pathogenic Avian Influenza H5N1 spreading of condition 1 is very low obtained degree of belief 0.2, the risk of Highly Pathogenic Avian Influenza H5N1 spreading of condition 2 is low obtained degree of belief 0.347, the risk of Highly Pathogenic Avian Influenza H5N1 spreading of condition 3 is medium obtained degree of belief 0.183, the risk of Highly Pathogenic Avian Influenza H5N1 spreading of condition 4 is high obtained degree of belief 0.224, the risk of Highly Pathogenic Avian Influenza H5N1 spreading of condition 5 is very high obtained degree of belief 0.19.

CONCLUSIONS

In the absence of empirical data, experts in related fields provide necessary information. The fundamental objects of this theory of evidence are called focal elements and the primitive function associated with it is called basic probability assignment. Focal elements are usually crisp subsets of some universal set. However, in certain situations focal elements may also be represented by Fuzzy numbers. There are many situations where human often face at the same time Fuzzy and non Fuzzy uncertainties. This suggests to combine mathematical theory of evidence and Fuzzy sets frameworks. Thus, the goal of this work is to estimate basic probability assignments using Fuzzy membership functions which capture vagueness. The advantage of this method is a new method to obtain basic probability assignment proposed based on the similarity measure between membership function. This research proposes combining Fuzzy Logic and Dempster-Shafer theory by calculating the similarity between Fuzzy membership function.

ACKNOWLEDGEMENTS

This work was supported by Graduate Research Scholarship (GRS), reference: UBD/GSR-ADM/01, from Universiti Brunei Darussalam in Brunei Darussalam. We gratefully appreciate this support.

REFERENCES


